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MANAGEMENT SYSTEMS FOR FOOD

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Abstract

The purpose of this paper is to review, synthesize, and evaluate how management systems are transforming sustainable food, while also highlighting the challenges—especially cybersecurity, governance, and cost barriers—that must be addressed. More specifically, the article aims to: Inform readers about the growing pressures on global food systems (population growth, climate change, limited resources); Explain how digital technologies (AI, IoT, blockchain, Big Data, robotics, OT systems, biosensors, Industry 4.0) are being applied across the entire food value chain—from production to waste management; Assess the benefits of these technologies for sustainability, food safety, efficiency, traceability, and waste reduction; Identify risks and challenges, including cybersecurity threats to OT systems, data security issues, infrastructure gaps, high costs, and governance limitations; Argue that technology alone is not sufficient; systemic transformation requires coordinated changes in policy, regulation, infrastructure, expertise, and collaboration; Provide future outlooks and research directions for achieving sustainable, resilient, and secure agri-food systems. As material and methods there wereI used: PRISMA – a research standard applied to explore how digital technologies transform current agri-food business models and support the creation of sustainable value chains. Also, there were used Scopus and Web of Science data bases. Main results of this paper refers to: Operational Technology (OT) is essential but vulnerable in modern agri-food systems. OT enables real-time control of physical processes in farming and food processing (e.g., vertical farming, pathogen detection, energy optimization), but its tight coupling with physical systems exposes it to serious cyber-physical security threats; Digital technologies significantly improve efficiency, sustainability, and food safety across the food value chain.

Key words**:** *cybersecurity challenges, digital technologies, AI, management systems, food*

INTRODUCTION

The purpose of this review is to evaluate the current research on how digital technologies are integrated into sustainable agri-food business models and to offer guidance for future research and managerial strategies [11]. Industrial agri-food waste can be redirected as inputs for other processes by universities, start-ups, and small businesses, promoting a circular economy and sustainable development. About 1 billion tons of food are wasted annually, accounting for one-third of global production. Approximately 38% of this loss occurs during food processing, with major contributions from the beverage industry (26%), ice cream production (21.3%), fruits and vegetables (14.8%), grains and starch products (12.9%), and meat production (8%). Stakeholders such as consumers, investors, employees, suppliers, and regulatory bodies have shown growing ethical interest in production practices and their environmental and social effects. Companies operate more effectively by building internal capacities to advance sustainability, which includes raising awareness, expanding knowledge, and fostering the skills and processes required for sustainable development [8]. The global food system faces a structural crisis, driven by food commodification and market-oriented production, undermining ecological sustainability and social equity. Treating food systems as socio-ecological commons highlights the need for collective management and adaptive governance. However, effective local monitoring systems to assess their development, impacts, and interactions are still insufficient [9]. Modern food systems provide many examples of how closely linked challenges can become concrete barriers to transformation. Integrating policies across domains often requires negotiating difficult trade-offs, as priorities such as biodiversity,

employment, and healthy diets may conflict. Resolving these issues can demand extensive scientific debate and public deliberation, especially on complex topics like GMOs, pesticide use, and labeling. Improvements in the transparency and accessibility of food system data offer opportunities to address these trade-offs, build synergies, and strengthen networks, ultimately supporting transformative change when paired with strong leadership and communication [13]. Circular economy principles are becoming increasingly vital for reducing waste and improving resource efficiency. Strategies like surplus food redistribution, batch preparation, and inventory optimization help minimize losses. At a broader level, standardized carbon tracking, transparency, and cross-sector collaboration are key to scalable carbon mitigation. Digital technologies, including IoT and AI, offer promising solutions for monitoring energy use, predicting waste, and supporting real-time decision-making. Agriculture worldwide has been severely impacted by climate change. Rising temperatures, fluctuating day-night cycles, and unpredictable rainfall patterns have intensified extreme weather events such as droughts and flash floods and increased disease occurrences. These challenges have affected production efficiency and driven the adoption of climate-smart adaptation strategies to sustain year-round productivity. Adaptation measures span all areas of crop production, including soil–water management, nutrient and fertilizer optimization, crop improvement, use of beneficial elements, organic soil amendments, as well as fisheries, livestock, poultry, and mechanization [3].

In this context, the purpose of this paper is: The purpose of this paper is to review and evaluate how digital technologies support sustainable and circular agri-food systems, with a particular focus on reducing food waste, improving nutrient circularity, and enabling sustainable agri-food business models under environmental and climate pressures. More specifically, the paper aims to: Assess current research on the integration of digital technologies (e.g., AI, IoT, data analytics) into sustainable agri-food business models and examine how digital tools contribute to nutrient circularity, food waste reduction, and the reuse of organic waste streams within a circular bioeconomy. Analyze the scale and impacts of food loss and waste, highlighting their environmental, economic, and social consequences across the agri-food supply chain. [6]. Explore governance, policy, and socio-ecological challenges that hinder transformation toward sustainable food systems, including trade-offs among biodiversity, employment, and healthy diets. Identify opportunities for improved transparency, data accessibility, and monitoring systems, supported by digital technologies, to enable informed decision-making and systemic change. Provide guidance for future research and managerial strategies to help stakeholders adopt digital solutions that advance sustainability, resilience, and climate-smart agriculture.

MATERIALS AND METHODS

As material and method for this article, I used: PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), a standard approach for systematically selecting and reporting literature. Its use improves completeness in reporting and addresses a common limitation of literature reviews, where relevant studies may be overlooked. In this review, PRISMA was applied to explore how digital technologies transform current agri-food business models and support the creation of sustainable value chains. Also, I used Scopus and Web of Science due to their extensive and diverse coverage. No publication date restrictions were applied, reflecting the recent nature of research on management systems for food. Only English-language, peer-reviewed articles were included, while conference papers and book chapters were excluded, ensuring the quality and accessibility of the reviewed literature.

RESULTS AND DISCUSSIONS

Transformations should be seen as a dynamic and integrated process, as technology alone cannot drive systemic change [10]. Growing food demand is pushing the agri-food industry

to produce more with limited resources, while also responding to increasing sustainability challenges. Digital technologies like the Internet of Things, artificial intelligence, blockchain, and robotics are changing how food is produced, processed, and delivered. The benefits it can bring are: better efficiency and quality, food safety and ecological sustainability. Real-time control of factors such as: temperature, humidity, pH, digital technologies, aims to minimize food spoilage and food waste. [14]. Opportunities, challenges and perspectives related to the use of these technologies on a large scale in this field are analyzed. Digital technologies include systems, devices, electronic tools and resources that generate, store and process data. In the agri-food sector, in the processing phase, the digital technologies used are AI, the Internet of Things, blockchain, Big Data, robotics and smart sensors. Food systems optimized in this way can have a very good impact on society, the environment, the economy, etc. In the agri-food sector, AI is used in the processing phase to automate the sorting, classification, packaging of food products, to detect food safety risks or to predict the yields of agricultural crops. In fact, AI-based technologies can improve productivity and efficiency throughout the production chain. Such applications are especially relevant in the vegetable supply chain during the agricultural stage, where accurate monitoring is essential for improving crop productivity. IoT systems have been shown to optimize key operational parameters, including pesticide and water usage. Moreover, IoT enables the monitoring of soil composition, environmental conditions, and crop physiology, supporting more precise crop monitoring and management. Advances in digital technologies have allowed machines and robots to perform tasks previously handled by humans. In the present and future, a transition to smart food and agricultural factories may be possible if people will study and apply the new principles of automation and robotization. In agriculture, robotics can help in sowing, planting, weeding, picking, harvesting, handling, cutting, slicing and packaging, achieving high efficiency and low costs involving human labor. Since the development of blockchain in 2009, there are three types: open, private and hybrid blockchains. In the agri-food supply chain, blockchain is increasingly adopted because it helps improve product traceability, transparency, food safety and security [12]. Blockchain technology has emerged as a promising tool in the food industry, primarily for improving transparency and traceability within supply chains. Research highlights both the benefits and challenges of its implementation, emphasizing its role in enhancing traceability, information sharing, and recall effectiveness, particularly when used alongside IoT technologies. Originally adopted to address food safety issues, the integration of blockchain and IoT is increasingly viewed as a key driver in the transition toward a more trustworthy and sustainable agri-food system. [2]. Food fraud, driven by economic motives, compromises food quality and safety. It includes practices such as dilution, substitution, unauthorized additions, unapproved enhancements, and mislabeling. Combating fraud involves risk and vulnerability assessments across the supply chain, with KPIs like detected incidents, high-risk materials, and vulnerable suppliers. [5]. A key challenge for agricultural IoT is data security. High costs remain a barrier, though cheaper wireless sensors are emerging. Predicting yields under different climatic conditions helps optimize irrigation and fertilizer management, improving resource efficiency and productivity. [4]. Precision disease management also supports yield sustainability, with image processing techniques, including genetic algorithms, achieving up to 90% accuracy in managing leaf diseases [3]. AI technologies are increasingly applied in emerging fields like 3D food printing and smart packaging, demonstrating their ability to enhance the consumer experience and reduce environmental impact. However, challenges such as high costs, system integration complexity, and the need for ethical and sustainable policies remain. [7]. Future AI development should focus on accessibility, inclusivity, and collaboration across disciplines to strengthen food security

and sustainability [1]. Industry 4.0 leverages advanced technologies, including big data, AI, IoT, machine and deep learning, cloud computing, system integration, and smart sensors.

CONCLUSIONS

IoT enables real-time monitoring of environmental and product conditions (temperature, humidity, soil composition, traceability), optimizing water, pesticide, and energy use; Industry 4.0 is driving a shift toward Agriculture 4.0 and Food Safety 4.0; Data-driven, predictive approaches replace reactive systems, enabling early detection of pathogens, contaminants, and spoilage through intelligent biosensors integrated with IoT and AI; Blockchain improves transparency and combats food fraud**;** Blockchain adoption enhances traceability, security, and trust in food supply chains, helping address food fraud and accountability challenges; Automation and robotics reduce labor dependence and increase precision. Robotics improves efficiency in seeding, harvesting, processing, and packaging, accelerating the transition to smart agriculture and smart food factories.

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RARE LOCAL FRUIT TREES VARIETIES FROM TRADITIONAL ORCHARDS OF ROȘCANI VILLAGE, HUNEDOARA COUNTY, ROMANIA

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Abstract

Plant genetic resources for food and agriculture (PGRFA) are the main subjects of policies related to ensuring food security at national and international levels. Their full conservation and sustainable use are a must today when we are facing climate change effects, including desertification. The aim of this article is to present the survey results upon the investigation of old apple tree varieties from a traditional orchard in Roșcani village from Hunedoara County, Romania. Based on the history of the place these orchards have been settled after 1750 and before 1768 when they became famous. Based on our analysis the current distribution of the former traditional orchards is still preserved for certain parts of these traditional orchards. In 2018, on a surface of 1 ha of a traditional orchard, with a productivity of 7,800.00 kg/ha, 24 old apple varieties were recorded. At least 7 local old apple varieties and other three local walnut varieties were recorded. The main threat impact for the preservation of these orchards positioned in the border of the forest is the land use change towards agricultural land. There is urgent need for conservation measures to be taken for the preservation of these PGRFA relevant for food security for the future.

Key words**:** *traditional orchards, old varieties, apple varieties, walnut varieties, PGRFA conservation*

INTRODUCTION

Orchards and fruit trees have a huge impact on human civilizations starting from ancient times with evidences from the antiquity orchards [8, 20]. These agricultural ecosystems, expanded and evolved during time all over the globe contributing to the formation of archaic and medieval cultural and impressive landscapes that we are inheriting today [12, 29]. Nowadays, it is well established that traditional orchards (i.e. elder than 100 years) may also be considered hotspots biodiversity [31]. Old orchards, either archaic or traditional, supported during millennia the development of our civilization also based on the systematic observation and better understanding of wildlife [2, 22]. Moreover, orchards facilitated the connectivity and further development of locals' traditional knowledge and local cultural values that connect wildlife, orchards and spiritual life [23, 25].

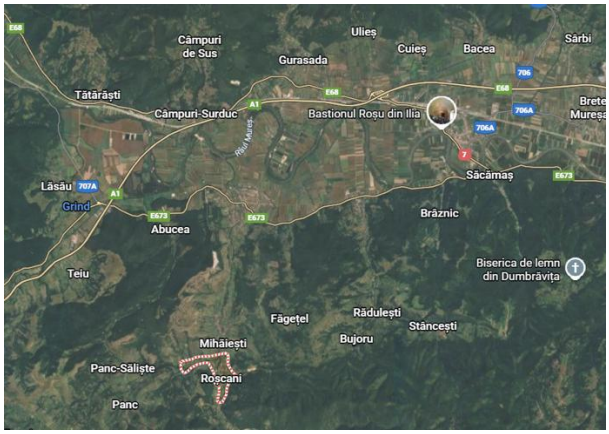
Today, the remains of traditional orchards all over the globe are relevant ecosystems for biodiversity conservation either wild species and habitats as well as for old fruit tree varieties elder than 80-100 years [13, 15]. If agriculture is incriminated today as the main driver for biodiversity loss [11], traditional agro-ecosystems and also traditional orchards may teach us that agriculture can support also biodiversity. Why we need to reconsider agriculture? Because it is impossible to live without agriculture [28] and therefore, we need to reconsider rather agricultural practices of today as well as its evolution for supporting biodiversity conservation [7].

Romania is a country positioned in the South East Europe with the Danube River stretching the South of the country, a shore at the Danube Delta and whish is crossed by the largest range of Carpathian Mountains [9]. This richness in landscapes and ecosystems types contributed also to the cultural life development and covering the entire Carpathians region for more than 7,000 years ago [5]. The hilly-mountain landscape in the peri-Carpathians regions is stretching all the length of the

Carpathians making perfect conditions for fruit tree cultivation during time. The analysis of different archaic settlements proved that apple trees were cultivated for more than 7,000 years ago in the Carpathian region and makes the fruits' trees to become part of the archaic culture [10, 17, 26].
The scope of this article is to survey the apple varieties for one representative traditional orchard of Roscani, a village positioned in Hunedoara County, Romania. The discussions with locals came with different traditional knowledge that connected the orchards with their present and past cultural life.

MATERIALS AND METHODS

Place and time of investigations. These investigations took place in Hunedoara County: Roșcani village (47.455331, 27.382736) (Map 1). They were conducted during 2014 and later during 2018 with the support of locals. Locals provided based on respecting any ethical principles all data related to local names for apple varieties.



Map 1. Traditional orchards of Roscani, Hunedoara County. All this region still capture remains of former traditional orchards that have been developed some more than 250 years ago. These orchards are positioned at the foot of mountains belonging to Carpathians range. Source: https://earth.google.com/, Accessed on 14 January 2026.

Data collection. All fruits varieties taken under study were collected from Roșcani with the support of the locals. They were identified for varieties against the British Pomology published in 1851 [19] and the Romanian Pomology published in 1964 [6]. The fruit collection was done in two different periods: October of 2014 and November 2018 with the support of local people. Local knowledge related to old varieties also was investigated. All maps were created based on the My maps from Google maps [25]. A short characterization of local apple varieties related to the average size of the fruit, skin and flesh color, the size of core is realized.



Map 2. Traditional investigated orchard of Roșcani spotted with the support of Google map. It is around 1 ha cultivated with 121 fruit trees. It can be observed the fruit tree rows, the open connectivity with the forest and the close related agricultural land and Dobra crick. Aerial view created with MyMap Earth Google https://earth.google.com/ (45°51'27"N 22°33'24"E). Accessed on 14 January 2026.

Economic costs assessment. Associated costs to the management of the orchard have been investigated (i.e. pesticides use, pruning and apple fruits harvesting).
Data management. All quantitative data have been collected in EXCEL and statistically analyzed towards standard deviation.

RESULTS AND DISCUSSIONS

Roșcani is a village belonging to Dobra commune in Hunedoara County, located at the foot of the hilly area of the Poiana Ruscii Mountains belonging to the chain range of the Carpathian Mountains, and in close connectivity to the Pădurea Breana and Dobra crick. It is mentioned into the Fiscal Conscription of Transylvania of 1750 that the agricultural land was not fertile (i.e. denominated as a sterile land) and the locals used to work for other landowners in other

villages [16]. The same document emphasizes that the locals used to cultivate spring wheat instead of winter wheat due to very low temperatures recorded during the winter season as well as other cereals. There were no mentions related to orchards existence but only of vineyards cultivation. However, orchards were established late during the XVIII century and after 1750. Thus, in less than 15 years, Roșcani was recorded on the maps of Transylvania Principate's published between 1769 and 1773 as a relevant area for apple orchards [21]. Later, this region became famous for apple production as well as for other services associated with the cultivation of fruit trees.

Today, it is possible to spot, survey and study the former traditional orchards that still exists and that can be observed when searching on Google Earth (Figs. 1-4). The village Roșcani is positioned close to Pădurea Breana - Roșcani (ROSCI0139) [27] in the region of Covurluiu Hills and close to Mureș river basin contributing to the connectivity between wildness and inhabited rural areas.

Identified varieties and local knowledge

A total of 24 apple varieties and 3 walnut varieties have been recorded and they are all presented in Table 1.

There is still a huge diversity among the old apple tree varieties as well as other fruit trees. There were not yet surveyed the plum trees, cherry trees or other fruit-trees. However, the walnuts trees considered as locally relevant and unique have been surveyed.

For very rare local varieties a series of images are presented in Photo 1.

The diversity of varieties and number of specimens is impressive for a small area of orchards and therefore it can be considered as a red hotspot of biodiversity for Hunedoara County. We are underlying again that this type of orchards is similar with those traditional orchards settled during the XVIII century.

Local apple varieties not identified into the orchard but discussed with the locals that should exists in Roșcani are as following: 'Ariuș', 'Struguroase', 'Roșu de Cluj', 'Pădureț din Cerăt', 'Vinești' and 'Roșineț'.

Table. 1 Old apple and walnut varieties recorded in Roșcani, Hunedoara County

Crt. no	**Apple tree varieties** (*Malus domestica* Borch.)	**No of specimens**
1.	Ananas Reinette	2
2.	Batul-Alma (Pătul)	6
3.	Baumann's Reinette	7
4.	Edelborsdorfer (RO Marșanschi)	6
5.	Golden delicious	2
6.	Golden parmen	3
7.	Gustav Dauerapfel (Gustav)	3
8.	Jonathan (Ionatan)	5
9.	Local 'Brăbude'	6
10.	Local 'Frunzos'	6
11.	Local 'Busuioace'	3
12.	Local 'Murgi'	4
13.	Local 'Vânăt' or 'Violet'	5
14.	Local 'Mustos de vie'	8
15.	Local 'Cormoș'	5
16.	Nemes Sovari Alma (Șovari)	5
17.	Ponyik alma (Poinic)	4
18.	Popești	8
19.	Red Astrachan	8
20.	Starking (dublu roșu RO/ double red EN)	7
21.	Starkrimson delicious	2
22.	Szaszpap alma (Popesc RO)	3
23.	Wild apple tree Malus sylvestris	7
24.	Winter Pearmain (Parmen auriu)	6
	Walnut tree varieties (*Juglans regia* L.)	
1.	Local Valea Mare	12
2.	Local De Vie	8
3.	Local Deva	6

Source: original data.



Local 'Murgi'



Local 'Roșcani Alma', 'Vânăt de Roșcani'



‘Ponyik alma’ ‘Poinic de Roșcani’



Local ‘Mustos de vie’



Local ‘Cormoș’



Local ‘Busuioace’ or ‘Roșnițe’



‘Szaszpap alma’ or ‘Popesc’ or Local ‘Popești’



Local ‘Mustosul de vie de Roșcani’



‘Batul-Alma’ or ‘Local ‘Pătul’



Local ‘Brăbude’



Local ‘De Deva’



Local ‘Valea Mare’



Local 'De la vie'

Photo 1. Some relevant old apple and walnut varieties from Roșcani, Hunedoara County.
Source: original data.



Map 2. Other aerial view with the support of Google map of traditional orchards in Roșcani Hunedoara County (45.8612, 22.5470). Source: https://earth.google.com/, Accessed on 14 January, 2026.

Orchard characteristics

Thus, these orchards have the following characteristic: more than 10 m distance between apple tree rows and 6-10 m between trees in a raw, the fruit trees are positioned at the border of forests and are open for wild animals during autumn and winter season.

The taller trees are positioned in the border of the orchard and among these we recorded mainly walnut trees. Wooden enclosers are functioning only during spring time and summer time up to ripping season. The calendar is set towards the Orthodox calendar between 24 April till 8 of September in a similar way like in Fântânele Sibiu County [3].



Map 3. Land use change in Roscani, Hunedoara County. A former traditional orchard of around 5 ha was changed to agricultural land. Source: https://earth.google.com/, Accessed on 14 January 2026

Table 2. Major apple fruit characteristics for local apple varieties recorded in Roșcani, Hunedoara County

Crt. No.	Local variety	Fruit size	Major fruit characteristics
1.	'Brăbude'	6.3 + 0.8	Half green-yellow and light red, strips and spots for the red quarter, medium core and yellowish flesh
2.	'Cormoș'	4.7+0.9	Green with reddish quarter and dark red stripes, medium core and white flesh
3.	'Frunzos'	6 ± 1.2	Light red with dark red stripes very small core and white flesh
4.	'Busuioace'	4.5 ± 1.70	Dark and light red with dark red stripes medium size core and yellowish flesh
5.	'Murgi'	5.7 ±1.3	Redish for more exposed to sun and green, darker red stripes and lighter spots, medium core and white flesh
6.	'Vânăt' (Violet)	5.7 ± 1.5	Dark red with light small spots and dark stripes, medium size core, yellowish flesh
7.	'Mustos de vie'	5.2 ±0.8	Redish for sun exposer and less green, very drak red stripes, medium core and white flesh

Source: original data.

Local identified varieties

In the same way like in case of Fântânele from Sibiu County, the apple-tree varieties from Roșcani Hunedoara County, were cultivated to cover the needs for a whole year. At least 7 local apple varieties have been recorded and described in Table 2. Starting with the summer time apples such is the case of 'Frunzos de vie' to 'Brăbude' all apple cultivars respond the locals' requirements. Local 'Roșnițe' or 'Busuioace' is a red apple variety, medium size to small that were used in the past for Christmas tree decoration. The apple as a

species covers also the cultural life of locals and local gastronomy too.

Among the most appreciated by locals is the local 'Vânătul' (dark red) which is the sweetest among all apple varieties and according to locals it was mentioned starting with the XVII century. It was long time lost the origin of this cultivar according to the locals.

It can be considered that the local 'Murgi' is very rare in this county and it is considered that it is unique by the locals, and not very sweet. Based on these observations some relevant studies should start and it should be more than an obligation to start conservation measures. The fruits can be consumed later up to the spring time.

The walnut trees are also popular due to their use in the cuisine and for ceremonies connected to Orthodox calendar. As an example, during the St Mary on 15 of August it is the custom to holly the walnut branches for the health of the houses.

Major threats

The Roșcani basin of orchards that stretches between Roșcani and Panc villages and the Mureș river basin can be officially recognized as a hotspot reservoir for agri-biodiversity of national and European importance for the conservation and sustainable use of plant genetic resources for food and agriculture in supporting food security for the future (Map 3). We may add herewith the need for recognition of continuing traditional agricultural practices that had not changed too much for more than one century. However, the orchard land use changed mostly during the past 35 years. Such changes can be seen in Maps 3 and 4.

More than 5 ha of traditional orchards were changed towards agricultural land for crop cultivation. The removal of all fruit trees and their replacement with agricultural land for crops will contribute to the decrease of biodiversity and this practice should be stopped.

Based on further discussions with the local more than 33 traditional orchards basins still exist in the region with more than 250 years of existence. Similar studies have been conducted in Europe [30] and it is well established already that they are among the best multifunctional farming systems. Moreover, these farming systems are providing support for wildlife as well and therefore they are very important for biodiversity conservation [4, 22]. In Romania a series of studies [14] have reflected the importance of old apple varieties [1, 18] and a complete survey should further reveal new features that can be used for biodiversity conservation as a whole.

Economic importance of the traditional fruit trees varieties

Traditional orchards are living gene banks for breeders and conservationists relevant for ensuring food security for long term if they are placed in remote rural areas of the main cities where other agricultural activities are not easy to be developed [3].

Traditional orchards are ensuring local needs for fruits either for fresh consumption either for inhouse processing (i.e. jams, compotes, vinegar, apple brandy or for feeding livestock). The fresh fruits from Roșcani are usually sold into local fairies during autumn ensuring some financial incomes. Thus, the local price for apple fruits in the village for 2018 was of 3 lei/ kg (i.e. 0.21 Euros/kg for 2018) and a family was able to sell a maximum amount of around 500 kg/ fair with a maximum amount of 321 Euros. Usually, these families are selling to customers from cities that are aware about the quality of these fruits.

The management costs for these orchards refers mainly to the pruning and harvesting costs that usually are in house. In case a family needs some help the total costs should be around 320 Euros for 100 trees for one person per season for 2018.

The total apple fruit yield in 2018, for 1 ha orchard was 7,800.00 kg and off this for local apple varieties was 2,570.00 kg (Table 3).

A cost-efficient productivity highly depends on the age and the healthy status of the trees, considering that most of the apple trees are over 80 years old. Due to the lack of use of fertilizers and pesticides, as well as due to the lack of professional pruning these orchards are losing between 30 up to 80% of the initial apple varieties specimens starting with more than 80 years ago. Due to the loss of these resources the owners are changing the land use mainly towards crops cultivation. Later, the aging of population, young generation migration to the

cities further contribute to the abandonment of these orchards due to costs associated to traditional pruning and harvesting [3].

Table 3. Apple yield by local varieties/0.3 ha (no. fruits/tree and kg/tree/year in 2018

Variety	No. of apples trees	Average kg fruits /tree	Total (kg)
Local 'Brăbude'	6	5 ± 0.81	360
Local 'Frunzos'	6	5.5 ± 1.24	415
Local 'Busuioace'	3	4.5 ± 0.45	340
Local 'Murgi'	4	7.6 ± 0.57	415
Local 'Vânăt' or 'Violet'	5	5.2 ± 0.95	380
Local 'Mustos de vie'	8	4.5 ± 0.54	300
Local 'Cormoș'	5	5 ± 0.63	360
Total	**37**		**2,570**

Source: original results.

The selling of the fruit as well as the maintenance of these living gene banks are not yet supported at the governmental level based on incentives for apple breeding, biodiversity conservation needs and for ensuring food security for long term. Thus, these landmarks of our history are threatened with erosion even they proved that can support the living of local communities.

CONCLUSIONS

Traditional orchards as multifunctional farming systems in Roșcani, Hunedoara County, are open agro-ecosystems towards the wildlife positioned in the border of forests and, covering a not fertile soil. At least 24 old apple varieties have been recorded and some traditional cultural values related to some of these local apple varieties and walnuts have been identified. The revenues based on the production of this orchard can support self-sufficiency costs at a family level. These orchards are already defining the historical identity of this local community.

The most negative agricultural practice from biodiversity conservation point of view is the land use change by converting the traditional orchards into a not fertile agricultural land for crop cultivation. It should be taken into consideration due to anthropic pressure and climate change the economic value of biodiversity lose. Thus, in case of losing these traditional orchards it should be calculated the economic value of the loss or decrease of ecosystem services, such as: pollinators, clean water and air, soil erosion, carbon sequestration and climate change crisis. We may add the buffering role of these orchards at the landscape scale as they are positioned between wilderness and human settlements and may fight against climate change effects and furthermore, they may ensure food security for the future in remote rural communities.

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DEVELOPMENT OF A SIMPLE POMEGRANATE HARVESTER FOR SUPERIOR FRUIT QUALITY AND ECONOMIC EFFICIENCY

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Abstract

Pomegranate fruit matures through coordinated physiological and structural changes that influence color, flavor, and overall quality, making harvest timing critical to achieve high total soluble solids (TSS), desirable color, and consumer acceptability. This study examined maturity indices during fruit development and developed a simple harvesting machine to collect fruits at optimal quality under both laboratory and field conditions. Laboratory experiments evaluated the relationship between fruit neck moisture content (22, 26, 36, and 46%) and key maturity indicators, including neck shear force, color kinetics, and TSS, revealing that the best quality occurred at 26% neck moisture, corresponding to full ripening, where color and TSS values were maximized. Field experiments assessed the manufactured harvesting machine at cutting disc speeds of 1,100, 1,180, 1,250, and 1,320 rpm (7.49–8.98 m/s) and cutting-edge tilt angles of 0, 12, 21, and 32°, measuring productivity, fruit damage, specific energy, and criterion cost. The optimal machine performance was achieved at 1,250 rpm and a 21° tilt angle, where productivity reached 2,520 fruit/h, fruit damage was limited to 1.71%, energy consumption was 0.020 kWh/Mg, and criterion cost was 418.94 LE/Mg. These findings highlight that harvesting guided by fruit maturity indices ensures superior product quality, while the developed machine provides an efficient, low-damage, sustainable, and cost-effective technological solution for improving pomegranate harvesting operations and supporting modern orchard management practices.

Key words**:** *pomegranate, fruit maturity, neck moisture content, total soluble solids (TSS), harvesting machine, productivity, postharvest quality, economic efficiency*

INTRODUCTION

Pomegranates (*Punicagranatum* L.) are nutrient-rich fruits widely consumed worldwide and represent one of Egypt's most significant fruit crops. They are utilized as food and play roles in the pharmaceutical, cosmetic, and export industries in Europe. Pomegranates possess numerous clinical applications due to key phytochemicals such as ellagic acid, ellagitannins, punic acid, estrogenic flavonoids, anthocyanins, and flavones.

Fateh et al. [6] reported that these constituents contribute to treating ulcers, snakebite, diarrhea, dysentery, hepatic damage, helminthiasis, acidosis, bleeding, and respiratory problems. Karaaslan et al. [15] demonstrated that pomegranate extracts can inhibit the growth of human liver cancer cells. Hussein et al. [10] emphasized the strong antioxidant and phytonutrient potential of pomegranates, highlighting their medical and nutritional benefits.

Regarding fruit quality, Spielmanns et al. [22] noted that attributes such as color, hardness, glossiness, shriveling, and physicochemical properties reflect maturity. Boussa et al. [2] clarified that skin color alone does not ensure edibility, as internal characteristics like total soluble solids (TSS) and acidity must meet market standards. Khodabakhshian et al. [16] found that consumer and processor acceptance depend on several factors, including size, mass, aril yield, skin and aril color, sugar content, acidity, and flavor.

In harvesting research, El-Iraqi et al. [4] developed four tool prototypes (electrical disk cutter, electrical scissors, mechanical disk cutter, and hook) for mango fruit, with electrical scissors giving the lowest fruit injury

(3–4%). Jafari and Bakhshipour [12] observed that pomegranate harvesting remains largely manual, making it labor-intensive, costly, and harmful to workers' health. Mayuoni-Kirshinbaum et al. [20] stressed that fruits must be harvested at optimum maturity for quality and shelf life. Mohammad-Shafie et al. [18] confirmed that pomegranates are prone to bruising from improper harvesting and handling. Masum et al. [19] highlighted that machine harvesting varies in efficiency, with powered machines suited for large-scale orchards while handheld pickers remain popular in smaller farms.

Studies on mechanical harvesting parameters show quality effects. Torregrosa et al. [23] reported that adjusting the catching surface tilt angle reduces impact energy. Zhou et al. [25] found that bruise damage decreased by 70% at a 60° tilt compared with a horizontal surface. Mohamed [21] noted that cutting efficiency increased with saw disc linear speed. Zhao et al. [24] showed that wolfberries remained undamaged at impact angles of 10–30°. El-Termezy et al. [5] tested a toothed-disc machine for pomegranates and found energy use rose with disc speed but dropped with toothed discs. Al-Gezawe [1] built a sensor-equipped harvesting tool for citrus, effective at 17.66 m/s disc speed with 80 teeth. HOU et al. [8] concluded that selecting the correct fruit plate angle significantly lowers damage.

In Egypt, pomegranates are still harvested manually, often causing rind damage and yield loss.

This study, therefore, focuses on identifying the optimal maturity stage for harvesting, designing and fabricating a simple machine from local materials, and optimizing its operating conditions, followed by economic evaluation. The novelty lies in offering a low-cost, locally manufactured solution specifically tailored for pomegranates, aiming to reduce fruit damage, labor dependence, and postharvest losses compared with traditional methods and existing crop-specific machines.

MATERIALS AND METHODS

All of the experiments were conducted at a private farm, El Basatin Association, Abu Shalabi, Faqous, Sharkia Governorate, Egypt, over the years 2022 to 2023, for measuring the gradient of pomegranate fruit maturity signs to identify the stage of high product quality. Then, the harvesting operation of pomegranates was conducted from 1 to 30 October 2023, (90 – 120) days after flowering, using the manufactured pomegranate harvesting machine.

Materials

Pomegranate trees

Experiments were conducted on two pomegranate varieties, Wonderful and Manfaluti, with tree spacing of 3 × 4 m and an average yield of 150–200 fruits per tree. The main physical properties affecting mechanical harvesting performance were measured for 20 fruits, following Jithender et al. [13] and El-Termezy et al. [5], and are summarized in Table 1.

Table 1. The pomegranate's physical properties

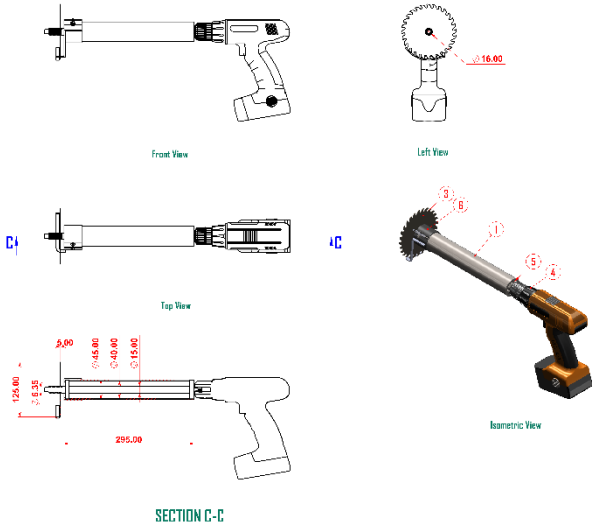
	Pomegranate					
	Wonderful			Manfaluti		
	Average	S.D	C.V(%)	Average	S.D	C.V.(%)
Height, mm	79.2	8.52	10.75	78.26	7.1	9.07
Width, mm	85.82	7.98	9.3	84.09	7.12	8.46
Diameter, mm	86.93	7.98	9.17	85.12	7.04	8.27
Mass, g	380.26	27.6	7.26	367.71	22.92	6.23
Volume, mm^3	1,364,109	411,077.1	30.14	1,284,492	331,595.1	25.82
Surface area, mm^2	104,019.3	19,535.46	18.78	99,785.41	16,571.76	16.61
Diameter, mm	141.54	141.54	100	138.03	138.03	138.03
Sphericity	63,318.36	10,444.7	16.5	60,121.49	8,444.76	14.05

Source: Own experimental results (measured following Jithender et al. [13] and El-Termezy et al. [5]).

The machine for pomegranate harvesting

Using locally available materials, a simple machine was fabricated to harvest

pomegranate fruits and overcome the high-power demand and cost associated with imported equipment. The machine was constructed in a private workshop in El-Sharkia Governorate, Egypt, specifically for this purpose. Its lightweight structure allows telescopic access to fruits located high on the tree. To minimize damage, the design also ensured cutting at the correct stem position. The main components and schematic layout of the manufactured harvesting machine are illustrated in Fig. 1.



Item No.	Part Name
1	Tube
2	Shaft
3	Disc
4	Drill
6	Bush

Dimensions in mm.

Fig. 1. The manufactured pomegranate harvesting machine.
Source: Own experimental results.

The main components of the manufactured pomegranate harvesting machine are as follows:

-The cutting disc

The alloy steel used to make the teethed cutting disc had a diameter of 125 mm and a thickness of 1 mm. A ball bearing was used to secure the cutting disc to the disc base. On the upper end of the telescopic carrier and transmission shaft, the ball bearing was fixed (Fig. 2).

A protective metal cover was fitted over the toothed cutting disc to shield tree leaves and branches from the rotating blades. For cutting, only a 50 mm section of the disc circumference was left uncovered to allow efficient removal of pomegranate fruit twigs.

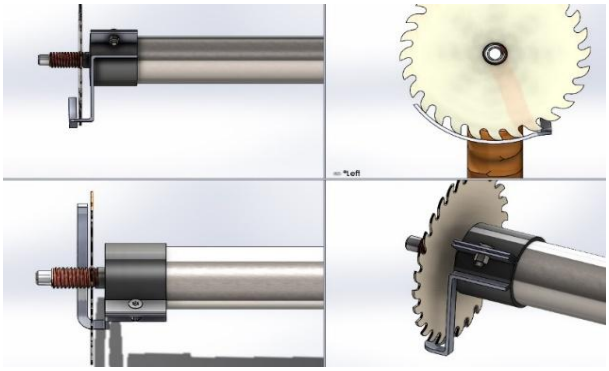


Fig. 2. The cutting disc
Source: Own experimental results.

-Power sources

The machine was powered by a 12 V, 1.5 A dry lithium-ion battery, supported with a fast charger for rapid backup. The battery was suspended in a shoulder bag for operator convenience. Motion was supplied by a DC 12 V motor, with a shaft speed of 1500 rpm reduced to 300 rpm under load. The motor provided an output power of 18 W and a torque of 20 N·m (Figs. 3 and 4).

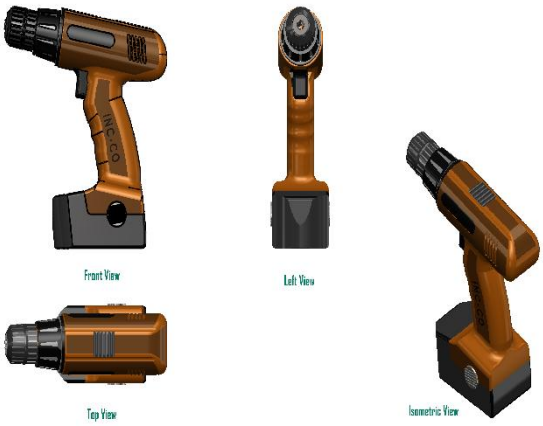


Fig. 3. DC 12 V motor
Source: Own experimental results.

Transmission system and electrical components

The transmission method was chosen to ensure that the electrical motors would always have electricity. An electrical line located inside the telescopic pick-up hand stick carried the current to the motors.



Fig. 4. The battery
Source: Own experimental results.

Methods

Two main experiments (laboratory and field) were carried out:

Laboratory experiments

The laboratory experiments were conducted during 2022–2023 on Wonderful and Manfaluti pomegranate varieties to identify the stage of highest product quality. Ten fruits from each variety were randomly selected, and maturity was assessed by recording skin color changes and total soluble solids (TSS) at different moisture contents.

Experimental conditions of the laboratory experiment

Experiments were conducted on Wonderful and Manfaluti pomegranate varieties to measure the gradient of fruit maturity signs under four neck moisture contents (46, 36, 26, and 22%).

Measurements and determinations of the laboratory experiment

The evaluation was conducted by measuring color kinetics, percentage of total soluble solids (TSS), and fruit neck shear force.

-Measurements of color kinetics

Color of pomegranate juice (PJ) samples was measured using a spectrophotometer (Minolta CM-3600d, Osaka, Japan) and a handheld CR-10 color reader (Konica Minolta, Japan) (Fig. 5a). Measurements were expressed in CIE coordinates (L*, a*, b*), with chroma (C*) and hue angle (H°) calculated from a* and b*. A C illuminant and 10° standard observer were applied.

-Determination of total soluble solids (TSS)

Total soluble solids (TSS) of pomegranate juice were measured using a digital refractometer (PAL-1, Atago, Tokyo, Japan) (Fig. 5b).

-Measurements of fruit neck shear force

Fruit neck shear force was measured for ten pomegranate samples using a Series FGE-XY Digital Force Gauge (Shimpo, Japan), which provides high precision with a compact design. The sensor was connected to the torque gauge via a standard chuck adapter, and the device was supplied with calibration and accessory tools (Fig. 5c).

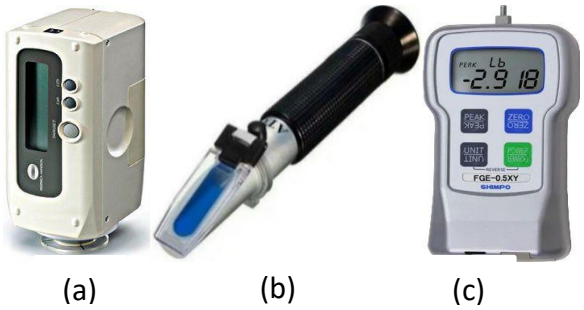


Fig. 5. Measuring device (a) Color reader, (b) Ahandheld refractometer, and (c) Shear force
Source: Own experimental results.

Field experiments

The experimental pomegranate harvesting machine was tested under various operating conditions during the year 2023 as part of the field experiment.

-Experimental conditions of the field experiment

The effectiveness of the manufactured pomegranate harvesting machinery during the harvesting of pomegranates (wonderful variety) was investigated through experiments under four different cutting disc speeds of 1,100, 1,180, 1,250, and 1,320 rpm (corresponding to 7.49, 8.03, 8.51, and 8.98 m/s) and four different cutting-edge tilt angles (0, 12, 21, 32 deg) (Fig. 6).

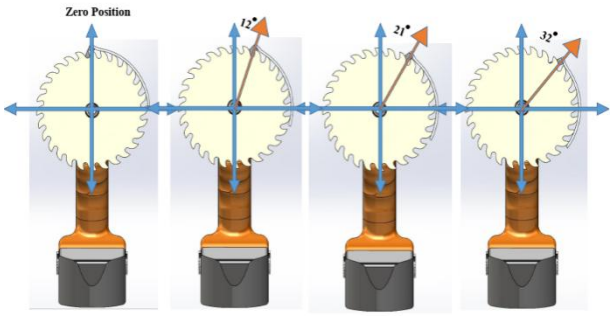


Fig. 6. Cutting-edge tilt angles
Source: Own experimental results.

Measurements and determinations of the field experiment

The following measures were considered when assessing the manufactured pomegranate harvesting machine's performance:

-Machine productivity

Total harvesting time and number of harvested fruits were used to calculate machine performance. Total harvesting time for a full working day was recorded to determine average machine productivity. The total time included selecting and cutting the fruits, and the time required to transport the machine between the trees within the field. Machine performance was determined by the following equations [5]:

$$\text{Machine Productivity, (Fruit/h)} = \frac{\text{No. of fruits}}{\text{Harvesting time}} \quad \text{.....(1)}$$

-Fruit damaged ratio

The percentage of damaged fruits and the percentage of visible damage in the harvested fruits as a result of their falling to the ground or being sliced by the harvesting equipment were used to calculate the fruit-damaged ratio. The following equation was used to calculate the fruit damage ratio

$$\text{Fruits damaged ratio, (\%)} = \frac{\text{No. of damaged fruits}}{\text{No. of total fruits}} \times 100 \quad \text{.....(2)}$$

-Specific energy

This is the calculation of the specific energy needed to run the harvesting machine:

$$\text{Specific energy, (kW.h/Mg)} = \frac{\text{Required power, kW}}{\text{Machine productivity, Mg/h}} \quad \text{.....(3)}$$

Required power for operating the harvesting machine was estimated by using a super-clamp meter (KEW SNAP 2007 A, made in Thailand). Using the following formula, the consumed power was determined based on potential differences and current intensity [1, 3, 11]:

$$P = \frac{I \times V \times \eta \times Cos\theta}{1{,}000} \quad \text{.....(4)}$$

where:

P = The required power, kW;

I = The current intensity, Amperes;

V = The potential difference; Voltage being equal to 220 V;

Cos θ = The power factor (being equal to 0.84);

θ = The phase angle between V and I;

η = The mechanical efficiency (assumed to be 95%).

-Criterion cost

According to Kumar and Goss [17], the criterion cost was calculated as follows:

Criterion costs (LE/Mg) = Operational cost + Total fruit damaged cost

The following calculation was used to determine the operational cost:

$$\text{Operational cost (LE/Mg)} = \frac{\text{Machine hourly cost (LE/h)}}{\text{Machine productivity (Mg/h)}} \quad \text{.....(5)}$$

The total fruit damage cost was estimated using the following formula:

$$Total fruit damaged cost\ (LE/Mg) = Mass of total fruit damaged \times Price of Mg of Pomegranate \quad \text{.....(6)}$$

According to Kepner et al. [14] and Hunt [9], the hourly cost of the harvesting machine is determined using the traditional method of assessing both fixed and variable costs.

$$Machine\ hourly\ cost\ (LE/h) = Fixed\ cost + Variable\ cost \quad \text{.....(7)}$$

RESULTS AND DISCUSSIONS

The following headings were used to present and explain the results:

Results of the laboratory experiment

The laboratory experiment evaluated maturity gradients of *Wonderful* and *Manfaluti*pomegranates using fruit neck shear force, total soluble solids (TSS), and color kinetics to identify the stage of good quality.

Effect of fruit neck moisture content on color kinetics

The effects of pomegranate fruit neck moisture content on the fruit maturity indices regarding color kinetics were studied and evaluated. Table 2 shows the average values of coefficient lightness (L), redness (a), yellowness (b), hue-angle (H), and color-tone (C) at the different fruit neck moisture contents of 46%, 36%, 26%, and 22%.

Table 2. Value of color developing degrees at different fruit neck moisture contents

Fruit neck moisture content,	Color Development Degree									
	L		a		b		H		C	
%	Wonderful	Manfluti	Wonderful	Manfluti	Wonderful	Manfluti	Wonderful	Manfluti	Wonderful	Manfluti
46	65.17	56.47	20.87	20.64	39.16	33.88	70.42	42.05	29.22	27.3
36	49.13	48.13	29.11	27.85	31.16	26.9	66.41	36.47	31.53	29.41
26	39.30	35.60	45.23	38.29	16.67	14.87	37.03	22.67	40.33	38.2
22	29.30	32.85	34.59	31.52	14.01	12.51	21.68	20.48	49.62	40.3

Source: Own experimental results.

A consistent hue representation produced from L, a, and b color spaces is essential for data processing and interpretation. The best values for coefficients L, a, b, H, and C were 39.30, 45.23, 16.67, 37.03, and 40.33, respectively, for the pomegranate Wonderful variety and 35.30, 38.29, 14.87, 22.67, and 38.2 for the pomegranate Manfaluti variety, both at a pomegranate fruit moisture content of 26%. Then, it was found that the best color intensity with the best color consistency was at a fruit neck moisture content of 26%, which might beconsidered the stage of full ripening of the pomegranate fruit.

Effect of fruit neck moisture content on total soluble solids

Table 3 shows the average values of total soluble solids for the two pomegranate varieties (Wonderful and Manfaluti) under different pomegranate fruit neck moisture contents. The obtained results show that the optimum total soluble solids value was achieved at a fruit neck moisture content of 26% under which the total soluble solids were 13.05 for pomegranate (Wonderful variety) and 13.62 for pomegranate (Manfaluti variety). The results of total soluble solids obtained above prove that the fruit neck moisture content of 26% could be considered the moisture content of full ripening of the pomegranate fruits.

Effect of fruit neck moisture content on fruit neck shear force

Table 4 shows the fruit neck shear force values compared to the pomegranate fruit neck moisture content values.

The obtained results show that the high values of fruit neck moisture content decrease the values of fruit neck shear force because the fruits are immature, as the immature fruits have high moisture content are easy to cut. With increasing maturity, the neck of the fruit becomes more solid, requiring a high shear force to be cut. The required shear force for cutting pomegranate fruits is 4.45 and 4.02 N for Wonderful and Manfaluti varieties, respectively, at the fruit neck moisture content of 26%.

Table 3. Effect of moisture content in fruit necks on TSS (total soluble solids)

Fruit neck moisture content, %	TSS, %	
	Wonderful	Manfaluti
46	7.64%	9.4%
36	8.84%	11.18%
26	13.05%	13.63%
22	10.51%	11.32%

Source: Own experimental results.

Table 4. Fruit neck shear force values at different fruit neck moisture contents

Fruit neck moisture content, %	Fruit neck shear force, N	
	Wonderful	Manfaluti
46	1.12	1.07
36	1.99	1.94
26	3.59	3.43
22	4.45	4.02

Source: Own experimental results.

Results of the field experiment

The field experiment was concerned with studying the performance of the manufactured machine during the harvesting of pomegranate fruits (Wonderful variety). The field experiment was carried out based on the recommended value of fruit neck moisture content (26%), which was achieved from the laboratory experiment to guarantee reaching full fruit maturity for preserving fruit quality overall, a high total soluble solids (TSS) content, and good color.

The relationship between cutting disc speed and cutting-edge tilt angle on machine productivity

Machine productivity increased with cutting disc speed up to 1,250 rpm, then declined at 1,320 rpm due to vibration and stem displacement that caused fruit damage, consistent with Al-Gezawe [13]. Productivity also improved with tilt angle up to 21°, but dropped sharply at 32° because of poor cutting geometry. The optimum operating conditions were identified as 1,250 rpm disc speed with a 21° tilt angle, in agreement with Zhou et al. [13].

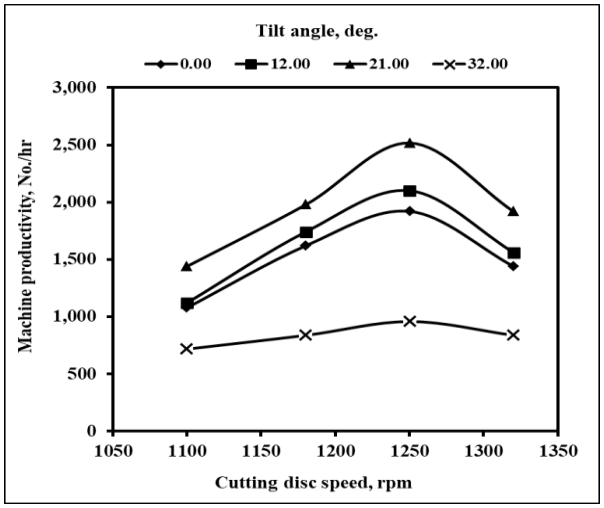


Fig. 7. Cutting disc speed's effect on machine productivity at various cutting-edge tilt angles
Source: Own experimental results.

The relationship between cutting disc speed and cutting-edge tilt angle on the fruit-damaged ratio

The obtained results in Fig. 8 show that the fruit damage ratio is affected by both cutting disc speed and cutting-edge tilt angle.

When cutting disc speed was taken into consideration, the results obtained indicated that, while the fruit damaged ratio decreased up to 1,250 rpm, it increased when disc speed was increased from 1,250 rpm to 1,320 rpm. Fruit damaged ratios decreased from 3.98 to 2.50, from 3.31 to 2.38, from 3.06 to 1.71, and from 4.44 to 2.92%, respectively, when the cutting disc speed was increased from 1,100 to 1,250 rpm, measured at various cutting-edge tilt angles of 0, 12, 21, and 32 degrees. Under the same previous conditions, a further increase in cutting disc speed from 1250 to 1320 rpm resulted in a fruit damage ratio increase of 2.50 to 4.93, 2.38 to 3.59, 1.71 to 3.91, and 2.92 to 6.31%, respectively. Fruit damage ratio increased at high cutting disc speeds because the harvested fruits have lower quality specifications due to the high vibration of the cutting disc that tends to push branches instead of cutting stems, resulting in high fruit damage. These results agreed with the results obtained byEl-Termezy et al. [5].

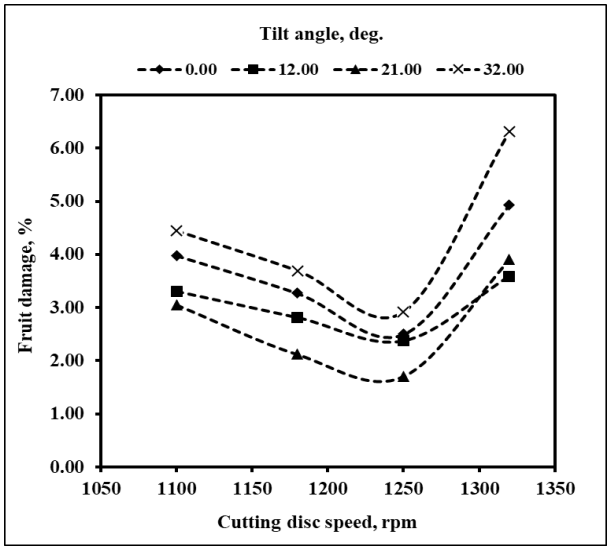


Fig. 8. Change of cutting disc speed to fruit damaged ratio under various cutting-edge tilt angles
Source: Own experimental results.

According to the results obtained, increasing the cutting-edge tilt angle decreased the fruit-damaged ratio by up to 21 degrees, as shown in Fig. 8. The result relates to the effect of cutting-edge tilt angles on the fruit-damaged ratio. The fruit-damaged ratio tends to increase with each additional degree of cutting-edge tilt angle increase, from 21 to 32 degrees. Increasing the cutting-edge's tilt angle from 0 to 21deg, measured at different cutting disc speeds of 1,100, 1,180, 1,250, and 1,320 rpm, decreased the fruit-damaged ratio from 3.98 to 3.06, from 3.27 to 2.12, from 2.50 to 1.71 and from 4.93 to 3.91 %, respectively, and then fruits damaged ratio increased from 3.06 to 4.44, from 2.12 to 3.69, from 1.71 to 2.92 and from 3.91 to 6.31 %, respectively by increasing cutting edge tilt angle from 21 up to 32 deg. This agrees with [24].

Cutting-edge tilt angle and cutting disc speed's effects on specific energy

Table 5 shows that the specific energy is influenced by both cutting disc speed and cutting-edge tilt angle. The specific energy is also affected by the machine's productivity.

The results obtained on the effect of cutting disc speed on specific energy showed that specific energy decreased when the cutting disc speed was increased from 1,100 to 1,250 rpm. Specific energy values will increase when the cutting disc speed increases to between 1,250 and 1,320 rpm. At various cutting-edge tilt angles of 0, 12, 21, and 32 degrees, increasing the cutting disc speed from 1,100 to 1,250 rpm resulted in a decrease in specific energy of 0.048 to 0.027, 0.034 to 0.019, 0.036 to 0.020, and 0.071 to 0.054 kWh/Mg, respectively. Under the same previous conditions, the cutting disc speed increase from 1,250 rpm to 1,320 rpm resulted in an increase in specific energy of 0.027 to 0.036, 0.024 to 0.033, 0.020 to 0.027, and 0.054 to 0.061 kWh/Mg, respectively. When cutting disc speed is increased over 1250 rpm, specific energy increases because machine productivity decreases in accordance. These results agreed with the results obtained byEl-Termezy et al. [5].

Table 5. Cutting disc speed's effect on specific energy at various cutting-edge tilt angles

Cutting-edge tilt angle, deg	**Cutting disc speed, rpm**			
	1,100	1,180	1,250	1,320
0	0.048	0.032	0.027	0.036
12	0.046	0.030	0.024	0.033
21	0.036	0.026	0.020	0.027
32	0.071	0.061	0.054	0.061

Source: Own experimental results.

The data measured regarding the effect of cutting-edge tilt angle on specific energy indicated that a decrease in specific energy of up to 21 degrees was observed when the cutting-edge tilt angle was increased. Any further increase in the cutting-edge tilt angle from 21 up to 32 degrees tends to increase specific energy. At various cutting disc speeds of 1,100, 1,180, 1,250, and 1,320 rpm, increasing the cutting-edge tilt angle from 0 to 21 degrees resulted in a decrease in specific energy of 0.048 to 0.036, 0.032 to 0.026, 0.027 to 0.020, and 0.036 to 0.027 kWh/Mg, respectively. Then, by increasing the cutting-edge tilt angle from 21 to 32 degrees, specific energy increased from 3.06 to 4.44, from 2.12 to 3.69, from 1.71 to 2.92, and from 3.91 to 6.31 kWh/Mg, respectively. The increase in specific energy by decreasing the tilt angles of the cutting-edge and fastening the cutting disc is because of the corresponding decrease in machine productivity. This agrees with [12].

Cutting-edge tilt angle and cutting disc speed's effects on the criterion cost

An economic comparison was carried out between manual harvesting and the manufactured harvesting machine to harvest one Mg of pomegranate.

The manual harvesting of pomegranates was carried out using two laborers. Only one laborer was used for operating the manufactured pomegranate harvesting machine. The daily hire of a skilled worker for manual harvesting was 300 LE, and the daily hire of a normal worker for operating the manufactured harvesting machine was 150 LE. Table 6 shows that the mean value of the hourly cost (LE/h) required for harvesting pomegranate using the manufactured harvesting machine is lower than manual harvesting by 49.70%. This trend results from the fact that harvesting by hand costs more than harvesting with manufactured harvesting equipment, both in terms of list price and daily labor hiring.

Table 6. Cost analysis of pomegranate harvesting using manual and machine

Costs	Manual harvesting	Manufactured machine	Difference	
			amount	%
Hourly Cost, LE/h	75.02	37.73	-37.29	-49.70
Operating Cost, LE/Mg	214.35	42.78	-171.57	-80.04
Fruit damaged Cost, LE/Mg	437.50	76.86	-360.64	-469.22
Criterion Cost, LE/Mg	651.85	119.64	-532.21	-81.65

Source: Own experimental results, calculated following Kepner et al. [14], Hunt [9], and Kumar and Goss [17].

However, compared to manual harvesting, the mean operational cost (LE/Mg) of using a produced harvesting machine is 81.65% lower. This trend can be caused by the reality that harvesting by manufactured harvesting machines is more productive than harvesting manually. These results agreed with Hassan [7].

Fig. 9 shows that the criterion cost is influenced by both cutting disc speed and cutting-edge tilt angle. The criterion cost

values are also affected by the machine productivity and the amount of fruit damaged during the harvesting operation. When the machine productivity increases, the operating cost will decrease, thus reducing the criterion cost, and in addition, the degree of fruit damage revealed the reverse.

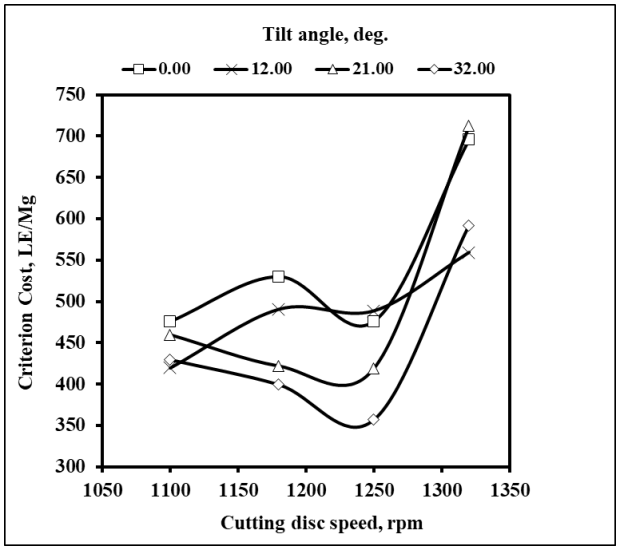


Fig. 9. Effect of cutting disc speed on criterion costs at various cutting-edge tilt angles
Source: Own experimental results.

The results obtained regarding the effects of cutting disc speed on the criterion cost indicated that the cost of the criterion increased when the cutting disc speed increased from 1,100 to 1,320 rpm.

By increasing the cutting disc speed from 1,100 to 1,320 rpm, the criterion cost increased from 475.86 to 695.95, from 419.88 to 558.96, from 459.70 to 712.28, and from 429.41 to 591.81 LE/Mg, respectively, when measured at varied cutting-edge tilt angles of 0, 12, 21, and 32 deg.

It is noticed that the cutting disc speed of 1,250 rpm recorded the minimum criterion cost values under any cutting-edge tilt angle. Because of an increase in the fruit-damaged ratio, the criterion cost values increased when the cutting disc speed was increased from 1,250 rpm to 1,320 rpm.

Concerning the effect of cutting-edge tilt angle on the criterion cost, the results showed that an An increased cutting-edge tilt angle was associated with a decreased criterion cost. Increasing the cutting-edge tilt angle from 0 to 32 deg, measured at different cutting disc speeds of 1,100, 1,180, 1,250, and 1,320 rpm, decreased the criterion cost from 475.86 to 429.41, from 530.15 to 399.31, from 476.03 to 357.06, and from 695.95 to 591.81 LE/Mg, respectively. Because of an increase in machine productivity and a decrease in the ratio of fruit damaged, the criterion cost values decrease as the cutting-edge tilt angle increases.

CONCLUSIONS

Pairing a simple neck-moisture maturity cue with a lightweight, low-cost, battery-powered harvester delivers a practical, field-ready path to more consistent, lower-effort pomegranate harvesting. At the adopted optimal setting—disc speed 1,250 rpm with 21° cutting-edge tilt—the machine balances fruit quality, throughput, and energy use while reducing reliance on manual labor and improving operator safety. The economic advantage is clear: the criterion cost drops to ≈418.94 LE per ton, demonstrating that maturity-guided scheduling with appropriate engineering tuning provides a scalable, locally manufacturable, and cost-effective solution.

ACKNOWLEDGEMENTS

The owner of El Bastain Association, Abu Shalabi, Faqous, Sharkia Governorate, Egypt, confirms that he agreed to conduct the study on his farm.

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EU'S AGRI-FOODS PRODUCTS TRADE WITH COMMON MARKET OF THE SOUTH (MERCOSUR): BETWEEN RECENT FACTS AND EU FARMERS CONCERNS

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Abstract

This paper analyses the evolution of agri-food trade between the European Union (EU) and the Common Market of the South (MERCOSUR) over the period 2014–2024, with a particular focus on trade balances, import's structure, and implications for EU farmers. The study is based exclusively on secondary data and uses official statistics from the International Trade Centre (ITC) Trade Map database and the European Commission's Directorate-General for Agriculture and Rural Development (DG AGRI). The methodological approach combines descriptive analysis of trade values with a structural interpretation of import patterns by product group and Member State, allowing the identification of concentration, asymmetries, and sensitivity to external factors. The results show a persistent and increasing agri-food trade imbalance, with EU imports from MERCOSUR significantly exceeding exports, reflecting strong structural specialisation between the two regions. EU agri-food imports are highly concentrated in a limited number of product groups, notably oilseeds and protein crops, beef, poultry, cereals, and sugar, and are dominated by a small number of Member States such as the Netherlands, Spain, Germany, Italy and Portugal. The analysis highlights pronounced volatility over time, particularly around the COVID-19 period and during the recent global commodity price surge, raising concerns related to market pressure, competitiveness, and resilience for EU farmers. The findings underline the strategic importance of MERCOSUR for the EU agri-food system and provide a descriptive basis for assessing the potential impacts of a future EU–MERCOSUR trade agreement.

Key words: *agri-food imports, trade balance, imports concentration, EU farmers, Mercosur, European Union*

INTRODUCTION

The EU - Mercosur trade in the last decade was developed besides the intensification of negotiations efforts for signing a trade agreement. While assessing the role of trade deal provisions, Gordeev et al. [7] underline that the modern trade agreements are also focusing on agricultural trade and they are including important issues as sanitary measures and rules of origin. From the perspective of EU agriculture, the quantifiable benefits of the Free Trade Agreement between the European Union and Mercosur (Argentina, Brazil, Paraguay and Uruguay) remain limited [3], reflecting both the relatively small share of EU agricultural trade with Mercosur and the agreement's cautious approach to liberalising sensitive agricultural sectors within the EU. Nonetheless, if ratified and complemented by reforms that enhance productivity, sustainability and competitiveness, the agreement could represent an important milestone for EU agricultural policy. In particular, it could support the EU's broader efforts to modernise its agricultural sector, strengthen its integration into global markets, and align trade policy with long-term structural reforms in European agriculture. Even if some studies [5] warned in the past that signing such treaty, the aggregate gains for the EU, would be small, with risky impact on EU agriculture, in 2026 this trade agreement is close to be signed. Recent study put in balance the opportunities and threats for the European farmers and other producers [10], while other authors focused on making comparison between the agricultural potential of the Mercosur versus EU [2]. Safety of animal food imported into the European Union is other concern related with the signing of the EU - Mercosur Agreement [11], since is estimated the EU will import more meat from Mercosur countries [6]. More radical opinions consider

the EU - Mercosur Agreement as compromise which is signed in a wrong moment, since, besides other negative aspects, this will affect both parts agricultural sectors and only the EU imports of beef from Mercosur, will produce huge impact on the EU farmers and markets [4]. The adaptation of the EU agricultural sector to the new trade agreement is seen by some authors in relation with the sustainable concentration of food industry, and the Polish example can be considered [12]. With regard to the impact of the EU–Mercosur Agreement on EU Member States, a recent study highlights that while several old EU countries—such as the Netherlands, France, and Germany—as well as some newer Member States, including Poland and Hungary, display high trade complementarity with Mercosur, the agreement is expected to generate only limited but generally positive macroeconomic effects for other new EU Member States, notably Romania and Bulgaria [8].

Based on data provided by the European Comision [1], we can notice that EU, through Directorate General for Agriculture and Rural Development (DG AGRI), consider in their reports only the relation with the Mercosur 4: Argentina, Brazil, Paraguay and Uruguay, which is used deliberated in order to exclude associate or suspended member (e.g. Venezuela, Bolivia) and to focus on the core economies that account most part of the EU trade flows. In this way they manage also to ensure comparability and consistency of the long-term trade data. This paper aimed to analyse the trade with agriculture products between EU and Mercosur, in order to have a basis of comparison in the feature, if the treaty will entry in force.

MATERIALS AND METHODS

The analysis focuses on the evolution of agri-food trade between the European Union (EU-27) and the MERCOSUR countries over the period **2014–2024**, with particular attention to trade balances, product composition, and country-level patterns. The main data sources are the **International Trade Centre** (ITC) Trade Map database and official publications of the **European Commission Directorate-General for Agriculture and Rural Development** (DG AGRI). ITC data are used to analyse EU imports from MERCOSUR by product category and Member State, expressed in value terms (thousand euros), while DG AGRI data are employed to assess overall agri-food trade balances and long-term structural trends. Product groups analysed include oilseeds and protein crops, beef and veal (fresh, chilled and frozen), poultry meat, cereals and sugar, selected due to their economic importance and relevance for EU farmers. The methodological approach combines **descriptive statistical analysis** with a **structural interpretation of trade patterns**. Descriptive indicators are used to examine the evolution of import values over time, identify major importing Member States, and highlight periods of significant change, such as the COVID-19 shock and the recent commodity price surge. Structural analysis focuses on the degree of concentration across products and countries, identifying asymmetric dependencies and differences in exposure to external suppliers. Special attention is given to distinguishing between changes driven by volume effects and those resulting from price fluctuations, particularly in the most recent years of the period analysed.

RESULTS AND DISCUSSIONS

Overall trade balance. For total trade in goods, the European Union's trade relationship with Mercosur shifted from a positive to a negative balance between 2014 and 2024 (Figure 1). Over this period, EU–Mercosur trade moved from a surplus to a deficit in value terms. Specifically, the EU recorded a trade surplus of EUR 4,522,346 thousand in 2014, which gradually reversed into a trade deficit amounting to EUR 7,359,762 thousand by 2024. This evolution reflects both changing demand patterns and the growing importance of Mercosur as a supplier of key commodities to the EU market. Germany records by far the highest surplus values throughout the period, exceeding Euro 5.7 billion in 2023–2024, which underscores its dominant position in EU–Mercosur trade. Belgium's surplus values show strong volatility but a marked upward

shift after 2020, peaking at over Euro 3.3 billion in 2023 before moderating in 2024. Italy's values fluctuate considerably, including a temporary trade deficit in 2022 (Euro -503.6 million), followed by a rapid return to surplus in 2023–2024.

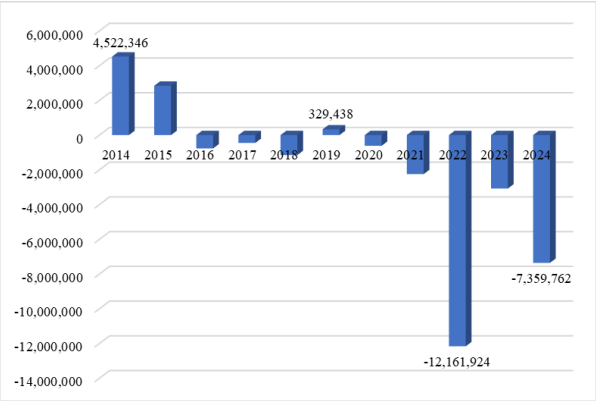


Fig. 1. European Union (EU 27) balance in value between 2014 and 2024 with MERCOSUR (Euro thousand)
Source: ITC [9].

France shows a gradual decline in surplus values starting with 2015, reaching very low levels in 2022, followed by a recovery in 2023 and 2024. Austria maintains relatively lower surplus values compared to other countries, but shows a clear and steady upward trajectory in the recent years (Table 1). Spain records the largest and most severe deficit values, expanding from Euro -442 million in 2014 to over Euro -7.0 billion in 2024, with a particularly sharp deterioration in 2022. The Netherlands maintains consistently high deficit values throughout the period, exceeding Euro -5.8 billion in 2024, reflecting its role as a major EU import and redistribution hub for Mercosur goods. Poland shows a steady increase in deficit values, more than tripling from Euro -1.1 billion in 2014 to approximately Euro -3.1 billion in 2024. Portugal's deficit values intensify notably after 2020, peaking at nearly Euro -3.9 billion in 2022. Bulgaria and Romania show comparatively smaller deficit values but the persistent downward trend suggests a gradual but sustained deterioration of their trade positions (Table 2).

Table 1. Top 5 surplus countries from European Union in the trade exchanges with MERCOSUR between 2014 and 2024 (Euro Thousand)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Germany	3,084,867	3,117,811	1,774,488	2,359,293	3,441,743	4,272,670	3,429,521	4,554,566	3,976,541	5,780,462	5,700,170
Belgium	1,148,057	434,704	275,302	1,207,484	673,995	517,892	1,266,073	1,895,800	2,322,110	3,367,806	2,506,741
Italy	2,029,331	856,260	57,288	563,794	468,905	399,070	416,194	287,542	-503,615	1,123,551	1,241,943
France	2,352,073	2,982,398	2,464,107	1,870,086	1,934,778	1,365,905	703,656	678,307	52,618	852,232	805,756
Austria	506,970	357,835	285,693	378,158	362,912	414,540	369,382	454,444	649,560	703,996	757,550

Source: ITC [9].

Table 2. Top 5 deficit countries from European Union in the trade exchanges with MERCOSUR between 2014 and 2024 (Euro Thousand)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Spain	-442,299	-789,744	-1,203,320	-2,074,352	-2,949,155	-2,338,275	-1,920,976	-2,977,352	-6,733,322	-4,928,641	-7,011,098
Netherlands	-2,754,152	-2,152,507	-1,660,828	-2,321,923	-2,172,271	-2,001,091	-2,754,194	-3,997,365	-5,634,008	-4,452,869	-5,807,925
Poland	-1,065,028	-1,148,182	-1,249,112	-1,408,730	-1,811,683	-1,591,381	-1,497,395	-1,731,313	-2,546,243	-2,585,136	-3,089,122
Portugal	-57,418	-276,828	-641,106	-454,228	-336,505	-468,179	-948,889	-1,958,993	-3,888,179	-2,823,478	-2,695,828
Bulgaria	-48,184	-18,778	-18,393	-15,467	-69,056	-60,162	-89,918	-166,069	-231,541	-364,840	-544,104
Romania	**-53,405**	**-185,278**	**-101,320**	**-174,563**	**-215,246**	**-175,167**	**-177,734**	**-242,183**	**-291,157**	**-194,187**	**-163,265**

Source: ITC [9].

Agri-food trade imbalance and structural asymmetry. During the same period, DG AGRI data indicate a widening imbalance in agri-food trade between the EU and Mercosur. Between 2020 and 2024, EU agri-food exports to Mercosur 4 increased by 6.6%, while EU agri-food imports from Mercosur 4 grew by only 2.7% [1]. Despite the faster growth rate of EU exports, imports remained around seven times larger than exports in absolute value, meaning that export growth was insufficient to reduce the overall agri-food trade imbalance between the two partners. In 2024, EU agri-food exports to Mercosur amounted to almost EUR 3 billion, whereas imports exceeded EUR 19.3 billion. This persistent imbalance is closely linked to the structural specialisation patterns of the two regions. Mercosur functions

primarily as a supplier of agri-food products to the EU, while EU exports to Mercosur are dominated by non-agricultural goods. Agri-food products represent more than 42% of total EU imports from Argentina, Brazil, Paraguay and Uruguay, with the majority of these flows consisting of primary and semi-processed products. By contrast, agri-food products account for only about 6% of total EU exports to Mercosur 4 [1]. Given this structural configuration, the signing and implementation of an EU–Mercosur trade agreement could generate significant changes in agri-food trade values and patterns, effects that will require close monitoring and analysis in the coming years.

Concentration of EU agri-food imports from Mercosur. EU agri-food imports from Mercosur are highly concentrated in a limited number of commodity groups. Oilseeds and protein crops represent approximately 40% of total EU agri-food imports from Mercosur 4, followed by coffee, tea, cocoa, and spices (around 20%) [1]. Other important imported products include beef and veal, fruits and nuts, and processed fruits and vegetables. This concentration reinforces the EU's dependence on Mercosur for specific inputs and commodities essential to its agri-food system.

The products of greatest concern for EU farmers based on DG AGRI data on the evolution of the 15 main EU agri-food imports from MERCOSUR 4 between 2020 and 2024, are those that compete directly with EU production in terms of price and market pressure, those that affect feed input costs in livestock production, and those that are politically sensitive within the Common Agricultural Policy.

Beef and veal imports are of particular concern for EU farmers, both in terms of production costs and quality standards. Even in the absence of a trade agreement, imports of these products from MERCOSUR 4 increased from EUR 967 million in 2020 to EUR 1,415 million in 2024.

Analysing data provided by the ITC, the imports of fresh and chilled bovine meat from MERCOSUR into the EU, we can notice that the imports are concentrated in only a few Member States and remain very limited in most others (Fig. 2).

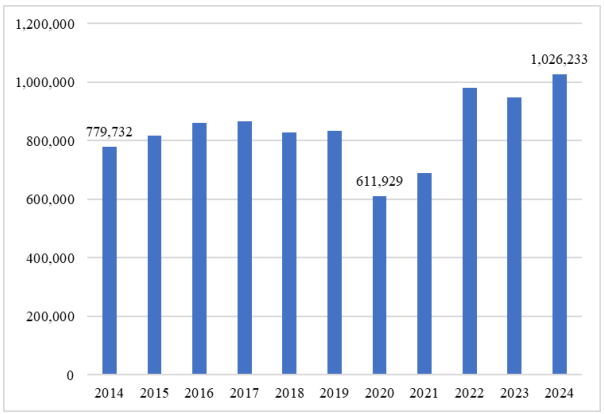


Fig. 2. European Union (EU 27) imports in value for meat of bovine animals, fresh or chilled between 2014 and 2024 with MERCOSUR (euro thousand)
Source: ITC [9].

Table 3. Top 5 importing countries from European Union in the trade exchanges with MERCOSUR for meat of bovine animals, fresh or chilled between 2014 and 2024 (Euro Thousand)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Germany	353,178	358,082	385,981	380,451	353,277	355,285	265,218	285,467	386,915	405,465	423,784
Netherlands	227,682	245,396	253,677	252,724	244,946	245,796	197,256	219,651	309,623	275,203	292,319
Spain	51,467	52,947	54,345	60,328	54,748	52,316	27,584	43,114	71,864	74,645	88,213
Italy	60,107	79,884	82,201	83,741	77,358	87,230	54,203	59,667	77,787	73,469	80,626
Portugal	3,987	3,532	4,619	5,061	6,901	5,695	6,038	10,413	17,482	19,766	35,541

Source: ITC [9].

Large importing countries such as Germany, the Netherlands, Spain and Italy account most of the total import values over the period, indicating a long-term dependence on extra-EU suppliers to cover domestic demand. By contrast, several Member States, including many in Central and Eastern Europe, record consistently low or negligible import levels, reflecting greater reliance on domestic or intra-EU beef production (Table 3).

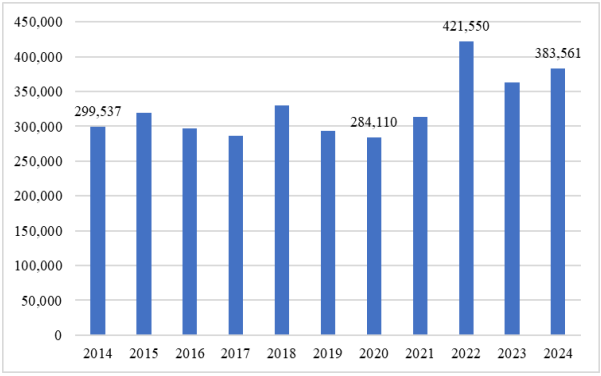


Fig. 3. European Union (EU 27) imports in value for meat of bovine animals, frozen between 2014 and 2024 with MERCOSUR (euro thousand)
Source: ITC [9].

This shows that dependence on Mercosur beef is not the same across the EU, but mainly concerns specific countries, being related with consumption preferences, processing capacity, and trade integration. Imports of frozen bovine meat from Mercosur are also not equally distributed across EU Member States, but they seem to be more widely used than fresh or chilled beef. A limited group of countries, which include Italy, Netherlands, Germany and Spain, represent most of the total import value, reflecting their role, as major processing, distribution, or consumption hubs in the EU. Among these countries, Italy consistently records the highest import values, reflecting its role as a major entry point and distribution hub for meat products within the EU.
This indicates that a significant share of frozen beef entering the EU is first imported through Italy before being processed or re-exported to other Member States (Table 4, Fig. 4).

Table 4. Top 5 importing countries from European Union in the trade exchanges with MERCOSUR for meat of bovine animals, frozen between 2014 and 2024 (Euro Thousand)

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Italy	147,685	167,119	148,708	138,711	166,457	152,002	167,697	180,904	197,326	175,441	200,509
Netherlands	46,991	39,543	38,911	40,367	44,696	40,790	34,861	40,042	48,579	49,784	43,450
Germany	38,994	40,145	42,864	38,156	39,111	39,336	37,390	35,402	55,447	43,982	43,110
Spain	33,241	39,023	33,957	38,689	35,127	27,714	19,294	27,182	48,372	34,436	41,049
Portugal	4,868	6,485	6,085	6,507	14,737	8,204	5,045	6,705	23,452	16,726	15,231

Source: ITC[9].

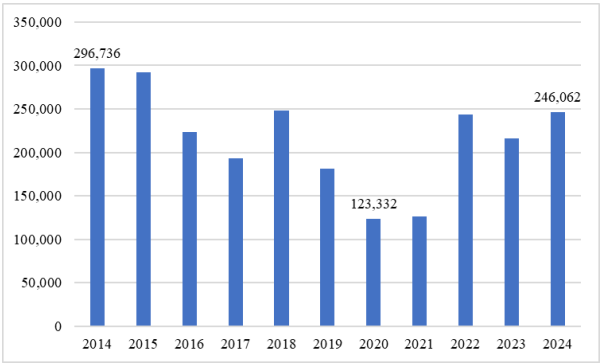


Fig. 4. European Union (EU 27) imports in value for meat and edible offal of poultry between 2014 and 2024 with MERCOSUR (euro thousand)
Source: ITC [9].

Similarly, EU farmers specialising in poultry and egg production are increasingly concerned about rising imports, which grew from EUR 360 million in 2020 to EUR 647 million in 2024. These concerns are intensified by differences in sanitary and phytosanitary standards and production methods between the EU and MERCOSUR countries.

Over the period analysed, based also on ITC data, poultry imports from MERCOSUR into the EU show a clear evolution over time, with distinct phases. Import values increase steadily in the years before 2019, indicating a growing role of Mercosur suppliers in meeting EU demand. In 2020, imports decline noticeably, reflecting disruptions caused by the COVID-19 pandemic, including logistical constraints and reduced demand from food services. After 2020, import values recover across the main importing countries, with growth becoming particularly strong in the most recent years of the period.
This rising trend is especially visible in countries such as the Netherlands, Spain and Germany, while Austria remains at consistently low levels throughout (Table 5). Overall, the data point to a temporary shock followed by a strong recovery, suggesting that poultry imports from Mercosur have regained importance in the EU market over time.

Table 5. Top 5 importing countries from European Union in the trade exchanges with MERCOSUR for meat and edible offal of poultry between 2014 and 2024 (Euro Thousand)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Netherlands	67,556	71,829	69,758	60,683	95,329	62,150	51,789	40,665	62,262	67,247	80,196
Spain	47,820	48,311	38,079	43,136	41,874	36,155	28,555	29,962	60,938	57,966	70,655
Germany	67,036	58,334	51,288	53,030	74,293	56,884	26,271	28,280	68,990	46,650	45,753
Czech Republic	35,073	48,625	19,060	6,328	5,522	5,452	3,936	7,700	11,906	12,723	10,460
Austria	4,214	4,160	5,116	5,526	7,089	4,667	2,107	4,184	9,184	6,211	8,736

Source: ITC [9].

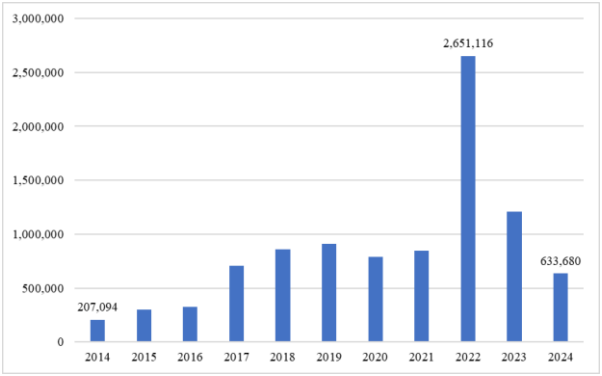


Fig. 5. European Union (EU 27) imports in value for cereals between 2014 and 2024 with MERCOSUR (euro thousand)
Source: ITC [9].

Cereal imports from MERCOSUR also merit attention. Imports reached EUR 2,651 million in 2022, indicating a significant potential to affect EU internal markets. An analyse based only on ITC data shows that the imports of cereals from Mercosur into the European Union show that they varied strongly from year to year. Import values are very high at the beginning of the period, followed by an important decline in 2014, after which imports recovered started with 2016.
In 2020, import values also decline, reflecting disruptions in international trade and market uncertainty, in the context of the COVID-19 pandemic, but starting with 2021 imports recover again, with an exceptionally strong increase in 2022, driven largely by higher prices and supply tensions on global grain markets (Fig. 5, Table 6).

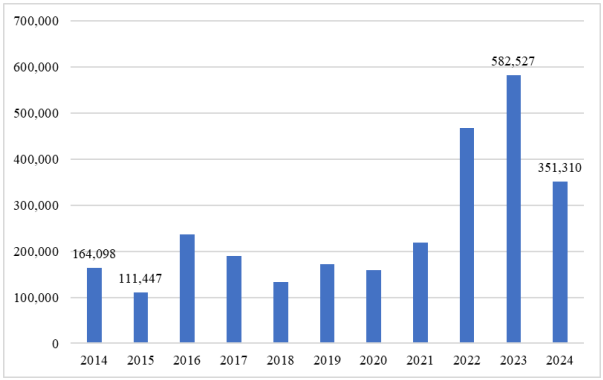


Fig. 6. European Union (EU 27) imports in value for sugars and sugar confectionery between 2014 and 2024 with MERCOSUR (euro thousand)
Source: ITC [9].

In addition to the others groups of products, EU sugar and isoglucose prices may be influenced by increased imports from MERCOSUR, which already reached EUR 582 million in 2023.
Based on ITC data, sugar imports from Mercosur into the European Union show large changes over time, with clear differences between countries (Table 7). At the EU level, import values are high at the beginning of the period, fall sharply after 2013, and then increase again in the following years.

Table 6. Top 5 importing countries from European Union in the trade exchanges with MERCOSUR for cereals between 2014 and 2024 (Euro Thousand)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Spain	47,224	115,889	63,413	386,041	465,825	523,535	405,965	453,475	1,390,601	667,346	272,693
Belgium	11,822	7,068	9,083	9,904	10,633	14,787	18,984	29,900	60,799	52,615	85,670
Netherlands	73,941	67,180	131,190	104,353	137,234	71,177	73,420	97,616	234,633	93,643	69,868
Portugal	22,963	47,644	36,988	95,749	141,751	133,296	127,060	121,861	397,157	162,741	47,737
Italy	11,327	13,585	23,388	29,021	17,606	57,769	57,382	33,230	294,188	86,717	36,270

Source: ITC [9].

Table 7. Top 5 importing countries from European Union in the trade exchanges with MERCOSUR for sugars and sugar confectionery between 2014 and 2024 (Euro Thousand)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Portugal	5,946	340	7,350	11,685	8,927	16,338	13,090	64,076	86,737	166,388	149,373
Spain	28,387	13,866	22,824	27,153	15,802	8,941	33,914	72,999	145,975	162,938	87,945
Italy	12,440	2,753	4,219	4,461	3,045	2,395	9,049	2,741	21,542	45,712	39,547
Bulgaria	2,893	59	6,269	116	118	80	23	71	20,821	78	17,706
France	11,409	9,396	17,009	16,854	18,812	18,494	15,637	14,749	23,841	24,089	15,387

Source: ITC [9].

Among individual Member States, Portugal stands out as the main importer throughout the period, with sugar imports rising strongly after 2020 and peaking in 2022 and 2023, linked to higher global sugar prices, before declining in 2024. Other countries, such as Spain and Italy, also show noticeable increases in recent years, although at lower levels than Portugal. Finally, the indirect effects of rising imports of oilseeds and protein crops are particularly relevant for EU livestock farmers. Growing dependence on external feed inputs can negatively affect cost competitiveness and sectoral resilience.

In 2024, EU imports of oilseeds and protein crops from MERCOSUR-4 reached a record value of EUR 9,847 million, underlining the strategic importance of these flows for the EU agri-food system (Fig. 7).

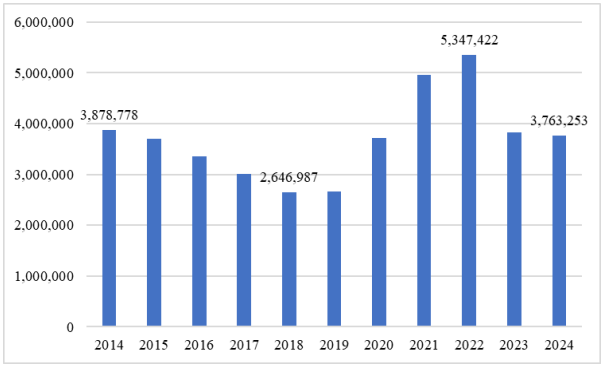


Fig. 7. European Union (EU 27) imports in value for oilseeds and oleaginous fruits between 2014 and 2024 with MERCOSUR (euro thousand)
Source: ITC [9].

Table 8. Top 5 importing countries from European Union in the trade exchanges with MERCOSUR for oilseeds and oleaginous fruits between 2014 and 2024 (Euro Thousand)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Netherlands	1,112,215	1,040,113	1,059,636	869,843	620,150	959,009	1,147,649	1,390,980	1,266,645	1,038,352	940,750
Spain	909,882	965,216	758,199	852,985	716,647	586,916	754,754	1,218,696	1,385,496	924,249	938,898
Italy	327,969	226,290	296,853	273,906	160,853	271,936	409,384	674,155	754,716	683,578	654,541
Germany	1,031,720	892,408	599,206	403,162	492,645	362,326	668,627	857,007	692,850	216,327	357,383
Portugal	163,163	222,472	189,515	198,695	175,048	136,558	237,091	312,276	412,892	303,473	285,990

Source: ITC [9].

The trade value of EU imports of oil seeds and oleaginous fruits from Mercosur from 2014 to 2024, based on data provided by the International Trade Center, shows notable fluctuations over the period analysed. Trade is mainly concentrated in a small number of EU member states, particularly the Netherlands and Spain which account for the largest shares of imports, followed by Italy and Germany. (Table 8).

Import values increased markedly after 2019, reaching a peak in 2022, before declining in the most recent years. It is important to consider Netherlands as a logistic and re-export hub, not only as a consumer, while Spain imports in relation with its expanding livestock, and its reliance on imported feed inputs. Italy the third importer of oilseeds and oleaginous fruits from Mercosur, is rather specialized, with its industry from the North of the country in food and feed processing, which allowed them to double their imports between 2018 and 2022.

CONCLUSIONS

The analysis of agri-food trade between the European Union and MERCOSUR over the period 2014–2024 highlights a persistent and widening trade imbalance, with EU imports consistently exceeding exports in value terms.

The results also show that trade values differ depending on the data source used. DG AGRI data provide an aggregated overview of EU–Mercosur agri-food trade and long-term structural trends, while ITC data offer a more detailed product and country level perspective. As a result, differences in coverage, classification, and aggregation levels lead to variations in reported values, particularly for specific product groups and individual Member States. Despite these differences, both data sources point to a strong concentration of EU imports from Mercosur in a limited number of product categories, notably oilseeds and protein crops, beef and veal, poultry meat, cereals and sugar. Import values for these products show marked sensitivity to external shocks, with a decline in 2020 followed by a strong recovery after 2020 and peak levels recorded in 2022, largely influenced by global price developments. Imports are also unequally distributed across Member States, with countries such as the Netherlands, Spain, Germany, Italy and Portugal accounting for a large share of total import values, often reflecting their role as trade and distribution hubs. Overall, while absolute values may differ between DG AGRI and ITC datasets, the main trends and structural patterns remain consistent, reinforcing concerns among EU farmers, especially in the context of the new EU-Mercosur trade agreement, as increased import pressure could further affect sensitive agri-food sectors.

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REGIONAL DEVELOPMENT MODELS: MECHANIZATION, LAND USE AND EMPLOYMENT IN BULGARIAN AGRICULTURAL REGIONS

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Abstract

This study analyses regional development patterns in Bulgarian agriculture for the period 2016-2023 through a comprehensive examination of the interrelationship between mechanisation, land use and labour employment. Based on official statistical data from the Ministry of Agriculture and Food and the National Statistical Institute for all 28 regions of Bulgaria, localisation coefficients, labour productivity indicators and mechanisation intensity are calculated. The study confirms the hypothesis of deepening regional disparities despite the implementation of the European Union's Cohesion Policy, as the range of the localisation coefficient widens by 16.6% during the observed period. Four main regional patterns are identified: administrative concentration in Sofia capital, intensive production in north-eastern Bulgaria, deindustrialisation in regions such as Targovishte and Kardzhali, and extensive production in the north-western regions. The analysis reveals a technological paradox whereby higher mechanisation does not automatically correlate with higher productivity, as Vidin region achieves the highest productivity of 133.84 hectares per worker despite a 41.67% decline in mechanisation. Four types of regional development trajectories are classified: labour-capital substitution in regions such as Vratsa and Dobrich, extensification in Vidin, stagnation in Plovdiv and deindustrialisation in a number of peripheral regions. The results demonstrate the need for differentiated regional policy that recognises specific development trajectories and addresses the increasing regional fragmentation in the agricultural sector.

Key words**:** *regional development, agriculture, mechanization, location quotient, labor productivity, Cohesion Policy*

INTRODUCTION

Regional disparities in the agricultural sector are the focus of many academic publications, and the factors contributing to their formation and deepening need to be traced [6, 8, 14, 19]. Expectations are that economic differences in the regions will be reduced in the context of the European Union's Cohesion Policy for the period 2014-2020. Subsidisation from the European Agricultural Fund for Rural Development and the European Agricultural Guarantee Fund directly influences economic, social and environmental outcomes in the regions [1, 5, 10]. The uneven distribution of funds underscores significant regional differences, which creates the need for a more equitable and justified approach to increase the economic efficiency of subsidisation and reduce regional disparities. Despite significant investments within the 2014-2020 programming period, empirical data call into question the effectiveness of the measures applied for regional convergence, particularly in light of the structural changes triggered by the COVID-19 pandemic and subsequent economic transformations.

Studies prove that uncertainty is an inherent characteristic of activities concerning the intensification of land use, and justify the need to investigate various alternative options, also taking into account the environmental impact [7, 11]. Analysing different approaches to land use modelling allows assessment of differences and supports decision-making by agricultural holdings. Dynamic models based on simulations are more suitable than empirical and static ones for optimisation.

It should be noted that the application of fallow cultivation practices on the one hand reduces negative impacts on the environment, and on the other improves soil quality and encourages

sustainable agriculture [21]. In the context of Bulgarian agriculture, fallow land dynamics represent an important indicator of land use intensity and farming efficiency at regional level.

Taking into account the fact that the agricultural sector is strategic for Bulgaria's economy, trends concerning mechanisation and land use in Bulgarian farms are tracked by a number of studies in the country [2, 3, 20]. For the period 2000 to 2019, the majority of regions are distinguished by an increase in value added in the agricultural sector, but a characteristic feature of the sector is regional disparities, conditioned naturally by geographical conditions as well. A significant increase in agricultural employment for oilseed crops is observed, which should be linked to the period of Bulgaria's accession to the European Union and targeted subsidisation of particular types of agricultural production. The absence of targeted support for perennial crops and fruit plantations leads to this potential for the country not being utilised. An important role in the transformation of the agricultural sector is played by state policy towards improving resource allocation and sustainable development. In the context of agricultural mechanisation, the lack of innovative technologies in Bulgarian fruit growing must also be noted, which again is an obstacle to the development of the sector [9]. This hampers the competitiveness of production and the benefits of accessibility to international markets.

In the academic literature, there exist numerous studies that trace the impact of regional differences in European Union countries on economic growth and their economies as a whole [4, 16, 18]. Multi-level regression models prove that the resilience of regions at NUTS3 level has a strong dependence on national borders. A high positive effect and economic resilience is observed in rural areas as a consequence of agricultural sector development. Analysis of data for European Union member states justifies the conclusion that the influence of large regional differences has strongly negative consequences on the economies of countries that joined after 2004, whilst this influence for countries that joined earlier is insignificant [16]. Analysis of labour employment in the agricultural sector of European member states demonstrates a decrease, despite the specificity of production activities in the sector. There exists a continuing trend of increasing value added, but corresponding with a decrease in labour input [17].

Despite the wealth of research directed towards individual aspects of regional development in agriculture, there exists a research gap concerning comprehensive analysis of the interaction between mechanisation, land use and labour employment in Bulgarian regions for the period after 2016. More specifically, in-depth studies that integrate these three dimensions into a unified analytical model and trace their dynamics in the context of the new programming period and pandemic challenges are lacking. The questions of different regional development trajectories and the formation of specific adaptation patterns in individual regions also remain insufficiently studied.

The present study aims to identify and typologise regional development patterns in Bulgarian agriculture through comprehensive analysis of mechanisation, land use and labour employment for the period 2016-2023. In this regard, the following research tasks are set: first, to analyse the dynamics of newly registered agricultural machinery by region and its ratio to production indicators; second, to examine the structure and changes in utilised agricultural area and fallow land as indicators of farming intensity; third, to investigate the trend in labour employment and regional specialisation through calculation of localisation coefficients; fourth, to identify and classify different regional development trajectories and construct a typology of regional patterns.

The study tests three main hypotheses. The first hypothesis is that in the period 2016-2023, regional disparities in Bulgarian agriculture are not being reduced but, on the contrary, are deepening, despite the implementation of the European Union's Cohesion Policy. The second hypothesis assumes that mechanisation does not automatically lead to productivity enhancement, as the relationship between technological provision and economic

efficiency depends on multiple contextual factors. The third hypothesis asserts that different regions follow different development trajectories, forming specific patterns of adaptation to changing economic conditions.

MATERIALS AND METHODS

The study is based on analysis of official statistical data for all 28 regions of Bulgaria for an eight-year period from 2016 to 2023. The data for the analyses conducted are obtained from public registers of the Ministry of Agriculture and Food, from the "Agrostatistics" department, BANSIK [12], concerning agricultural arable area and fallow land, and from the "Control and Technical Inspection" department - newly registered agricultural machinery [13]. Information on labour employment in the agricultural sector in the country is used from the official website of the National Statistical Institute, Business Statistics section [15]. The aggregated data are traced at two levels - national and regional, which allows both identification of general trends in Bulgarian agriculture and revelation of specific regional characteristics.

The study's methodology includes a combination of descriptive statistical methods and specialised techniques for regional analysis. To measure the dynamics of key indicators, rates of change and relative shares by region are calculated. Special attention is paid to three groups of indicators. The first group covers data on mechanisation, including newly registered agricultural machinery by year and region, as well as derived indicators for mechanisation intensity calculated as number of machines per thousand employed persons. The second group includes indicators for land use, such as total agricultural land area, utilised agricultural area and fallow land areas, whose ratio serves as an indicator of farming intensity. The third group covers data on labour employment under employment and service contracts in the agricultural sector, expressed as annual average number.

To assess labour productivity, a composite indicator "utilised agricultural area per worker" is calculated, which reflects the volume of arable land per person employed in the sector and serves as an indicator of capital intensity and farm structure. To identify regions with high specialisation in agriculture, a localisation coefficient is applied. The coefficient compares the relative share of employment in the sector for the region to the relative share of employment in the sector for the country. When the coefficient value is above 1.0, this indicates that agriculture has greater significance for this region's economy compared with the national average, with higher values meaning stronger regional specialisation in the agricultural sector.

To trace changes in labour employment and the significance of each region for total employment in the agricultural sector, the localisation coefficient is calculated for all 28 regions by year. This analysis makes it possible to distinguish regions in the country with demonstrated specialisation in the agricultural sector and the regional disparity that emerges. The coefficient's dynamics provides information on positive or negative trends for each region in the observed time interval, whilst the additional interrelationship with cultivated land and available fallow land draws important conclusions about the changes occurring in regional patterns in the agricultural sector in Bulgaria.

Based on the combination of indicators for mechanisation, land use and employment, a typology of regional development patterns is constructed. The classification of trajectories is based on joint analysis of the rate of change in mechanisation and employment, identifying four main types: labour-capital substitution, extensification, stagnation and deindustrialisation. For each region, the percentage change in key indicators between the initial and final year of the study is also calculated, which allows quantitative assessment of the intensity of structural changes. The analytical approach combines chronological and comparative analysis, tracing both the temporal evolution of indicators and differences between regions at a given moment. Special attention is paid to identifying breaks in trends, with the year 2020 standing out as a critical point, probably connected with the impact of the COVID-19 pandemic on the agricultural sector.

RESULTS AND DISCUSSIONS

Mechanization in the agricultural sector by region in the period 2016-2023

Mechanisation in the agricultural sector in Bulgarian regions for the study period is presented in Figure 1.

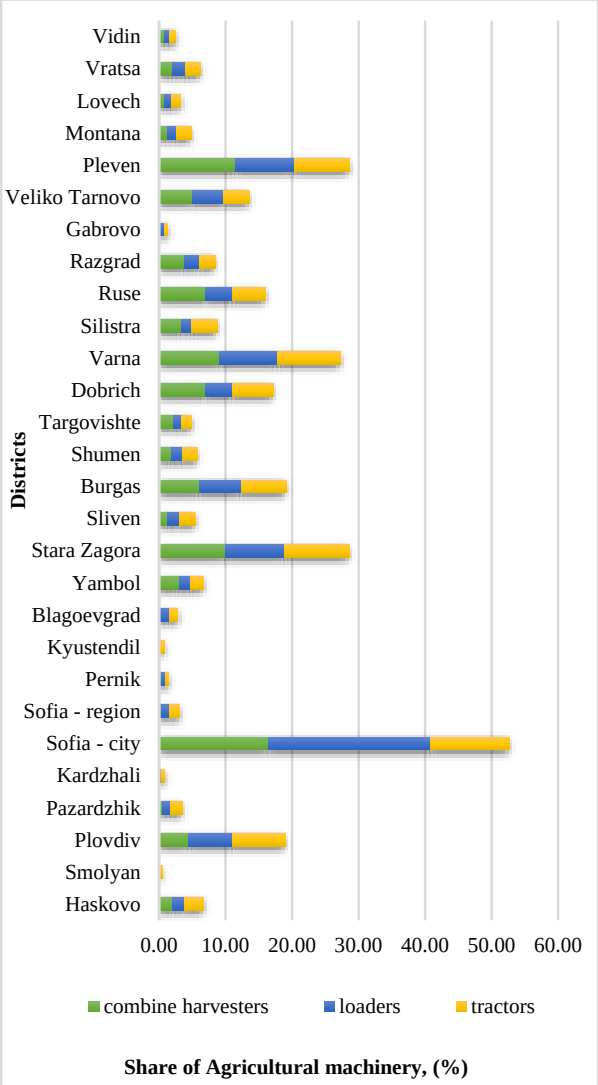


Fig. 1. Registered new agricultural machinery at the regional level in the period 2016 – 2023

Source: Own calculations based on data from the MAF [12].

The calculated shares for each individual region by main types of agricultural machinery demonstrate significant differences in newly registered machinery. Sofia capital region is distinguished by the highest share of newly registered agricultural machinery in the analysed eight-year period, followed by Pleven, Varna and Stara Zagora regions.

The data show a concentration of newly registered equipment in large administrative regional centres in the country, which should be compared with labour employment in the analysed sector of the economy. It is possible that registration of agricultural holdings is carried out in strong administrative centres and does not correspond with the cultivated agricultural land and human resources used.

Land use and structure of arable land

For more detailed regional analysis in the agricultural sector, data on agricultural area should be analysed - total agricultural land area and utilised area (Fig. 2).

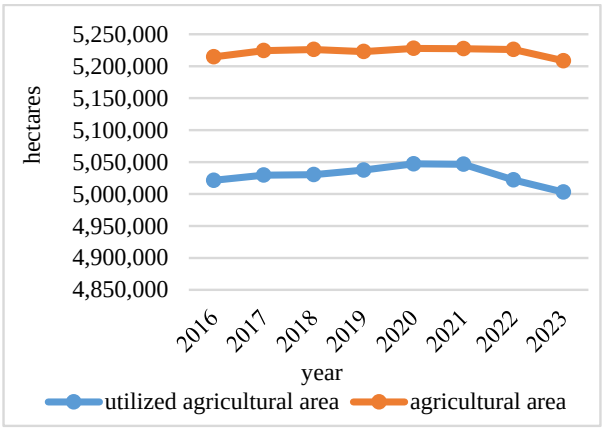


Fig. 2. Agricultural area at national level in the period 2016 – 2023

Source: MAF data [12].

According to available data in the study period, two time intervals with different tendencies stand out: in the first period 2016-2020 there is an increase in cultivated agricultural area of 25,841 hectares, whilst in the period 2020-2023 a decrease of 44,262 hectares is observed.

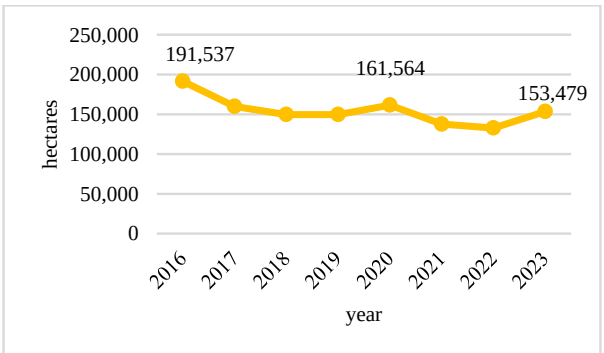


Fig. 3. Fallow lands at national level in the period 2016–2023

Source: MAF data [12].

Regarding available fallow land area, a reduction of 38,058 hectares is noted for the entire observed period (Fig. 3).

The following Figure 4 presents data on utilised agricultural area at regional level. Leading regions are: Dobrich (7.35%), Pleven (6.59%), Plovdiv (5.78%), Burgas (5.62%) and Stara Zagora (5.46%).

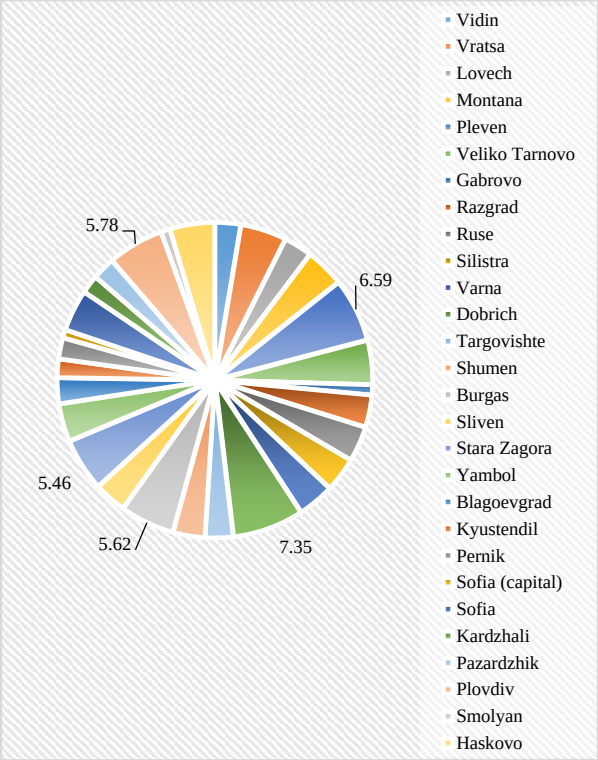


Fig. 4. Share of utilized agricultural area by 2023 (%)
Source: Own calculations based on data from the MAF [12].

For the study period, there are no substantial changes in the share of arable area by region. It should be noted that Sofia capital region participates with a share of 0.84% in total labour employment for the agricultural sector, and these data do not correspond with the newly registered agricultural machinery in the region for the observed interval.

Employment in agriculture

For the observed eight-year period of the study, labour employment in the agricultural sector in Bulgaria records a negative trend. On a national scale, the reduction in those employed in the sector by the end of the period in absolute value is 6,213 fewer employed persons, or a change of 8.67 percentage points. Analysis of data at regional level shows a similar tendency. The majority of regional farms are distinguished by a reduction in labour employment in the agricultural sector. Targovishte region records the most pronounced decrease in those employed in the period - a decrease of 20.67%. Following this tendency are the regions: Kardzhali (-19.93%), Smolyan (-18.89%), Pleven (-15.70%) and Haskovo (-14.73%). With an opposite trend, there are four (4) regions with an increase in the indicator under consideration, but the rates are insignificant. With the highest rate of increase is Pernik region (+5.64%), followed by Blagoevgrad (+1.87%) and Vidin (+1.65%).

Regional specialisation and localisation analysis

In order to distinguish regions with high specialisation in the "Agriculture, forestry and fisheries" sector, a localisation coefficient is calculated for each region by year, presented in Table 1.

The existing regional disparities in the agricultural sector are confirmed by the calculations made. Differences in labour employment are proven by the large range of localisation coefficient values by region (from 0.08 to 4.51). Moreover, in the observed period, regional differences are deepening. Whilst in 2016 the LC range is from 0.08 to 3.87, at the end of the study period in 2023 the LC values are between 0.09 and 4.51.

This analysis leads to the conclusion that as a result of measures implemented in the context of the Cohesion Policy for convergence, there is no reduction in regional disparities; on the contrary, in Bulgarian regions a deepening of differences in the agricultural sector is observed.

Labour productivity and technological provision

The calculated productivity indicators reveal significant regional differences. The "utilised area per worker" indicator for 2023 varies considerably between regions. Vidin region demonstrates the highest productivity of 133.84 hectares per worker, followed by Vratsa region with 127.68 hectares per worker. In contrast, Plovdiv region shows the lowest productivity of 54.40 hectares per worker, whilst the national level is established at 76.47 hectares per worker. The high productivity in north-western Bulgaria with simultaneous

reduction in employment points to processes of consolidation and enlargement of agricultural holdings. This process is accomplished through concentration of land in fewer but larger production units, which leads to an increase in arable area per worker without the need for proportional increase in mechanisation.

Table 1. Localization coefficient for the "Agriculture, Forestry and Fisheries" sector by districts in the period 2016-2023

Year / District	2016	2017	2018	2019	2020	2021	2022	2023
Vidin	1.87	1.95	2.02	2.00	2.12	2.19	2.19	2.19
Vratsa	1.78	1.76	1.77	1.75	1.82	1.83	1.78	1.71
Lovech	1.44	1.49	1.54	1.55	1.54	1.57	1.60	1.66
Montana	1.89	1.92	1.90	1.96	2.01	2.06	2.01	2.14
Pleven	2.20	2.14	2.10	2.10	2.09	2.00	2.04	2.00
Veliko Tarnovo	1.94	1.93	1.92	1.90	1.91	1.96	1.97	1.96
Gabrovo	0.53	0.51	0.52	0.56	0.56	0.53	0.53	0.61
Razgrad	3.28	3.33	3.40	3.28	3.31	3.42	3.28	3.52
Ruse	1.59	1.60	1.66	1.62	1.60	1.61	1.68	1.65
Silistra	3.87	3.87	3.85	4.10	3.95	4.10	4.49	4.24
Varna	0.80	0.82	0.79	0.78	0.79	0.79	0.78	0.77
Dobrich	3.79	3.85	3.97	4.10	4.32	4.44	4.42	4.51
Targovishte	2.70	2.56	2.51	2.60	2.61	2.55	2.65	2.75
Shumen	2.19	2.24	2.23	2.17	2.00	1.97	1.96	2.09
Burgas	1.07	1.13	1.13	1.13	1.17	1.23	1.14	1.12
Sliven	1.86	1.81	1.84	1.88	1.86	1.94	2.00	2.04
Stara Zagora	1.23	1.17	1.23	1.27	1.28	1.27	1.31	1.30
Yambol	2.43	2.67	2.78	2.82	2.75	2.79	2.75	2.72
Blagoevgrad	0.65	0.69	0.73	0.76	0.77	0.74	0.76	0.77
Kyustendil	0.77	0.84	0.84	0.88	0.86	0.84	0.87	0.91
Pernik	0.73	0.79	0.74	0.80	0.81	0.78	0.77	0.82
Sofia	1.26	1.20	1.28	1.28	1.28	1.23	1.26	1.27
Sofia (capital)	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09
Kardzhali	0.94	0.91	0.90	0.90	0.87	0.88	0.89	0.81
Pazardzhik	1.69	1.74	1.70	1.78	1.86	1.71	1.70	1.78
Plovdiv	0.80	0.80	0.80	0.81	0.86	0.84	0.81	0.82
Smolyan	1.10	1.08	1.02	0.94	0.97	0.95	0.97	0.99
Haskovo	1.74	1.76	1.67	1.82	1.73	1.76	1.81	1.74

Source: Own calculations based on data from the NSI [15].

The intensity of mechanisation, measured through the indicator "newly registered machinery per 1,000 workers", reveals an exceptional anomaly in the case of Sofia capital. The region demonstrates a value of 153.57 units of machinery per 1,000 workers, which represents almost a fivefold excess over the national level of 31.18 units. Other regions such as Dobrich, Plovdiv and Vratsa show values in the range of 24-28 units per 1,000 workers, whilst Vidin registers only 7.10 units per 1,000 workers.

Typology of regional development patterns

Based on comprehensive analysis of mechanisation, land use and employment, four main regional development patterns in Bulgarian agriculture can be identified.

The first pattern can be defined as "administrative concentration" and is represented by Sofia capital. It is characterised by high machinery registration with minimal utilised agricultural area and highest technical provision. This pattern reflects the tendency for concentration of registration processes for agricultural holdings and machinery in the capital for administrative reasons, whilst the actual production activity is carried out in other regions of the country.

The second pattern represents "intensive production" and is observed in north-eastern Bulgaria, particularly in Dobrich, Silistra and Razgrad regions. It is characterised by a high localisation coefficient, large share of utilised agricultural area and relatively low fallow land. Dobrich region demonstrates only 1,018

hectares of fallow land, representing 0.28% of utilised area, which is the lowest value in the country. This pattern is distinguished by stable employment with minimal decrease and efficient use of agricultural resources.

The third pattern can be defined as "deindustrialisation of the agricultural sector" and is observed in regions such as Targovishte, Kardzhali and Smolyan. It is characterised by drastic reduction in employment in the range of 19% to 21% and decreasing localisation coefficient. This pattern reflects a process of outflow of labour force from agriculture towards other economic sectors or migration outside the region.

The fourth pattern represents "extensive production" and is observed in regions such as Vidin and Montana. It is characterised by an increase in area per worker due to outflow of employed persons and decreasing mechanisation. Vidin region demonstrates a decline in mechanisation of 41.67% whilst simultaneously increasing productivity through extensive expansion of arable areas.

Dynamics of changes and development trajectories

The classification of regions by development trajectories reveals four types of dynamic processes. The "labour-capital substitution" trajectory is observed in regions such as Vratsa and Dobrich, where growth in mechanisation of 28-33% accompanies reduction in employment in the range of 3% to 8%. This process testifies to successful modernisation, whereby technologies substitute manual labour and increase productivity.

The "extensification" trajectory is represented by Vidin region, where the decrease in mechanisation of 41.67% combined with slight increase in employment of 1.65% leads to a paradoxical result. Despite decreasing technical provision, productivity grows through extensive expansion of arable areas per worker to the highest national level of 133.84 hectares.

The "stagnation" trajectory is illustrated by Plovdiv region, where minimal changes in employment and mechanisation around -1.5% are observed with the lowest productivity of 54.40 hectares per worker. This pattern reflects a lack of significant investments and structural changes in the sector.

The "administrative growth" trajectory is represented by Sofia capital, where growth in both employment and mechanisation is recorded. This pattern, however, is artificial and reflects primarily registration processes rather than real production development.

Deepening of regional disparities

The empirical data confirm the deepening of regional inequalities in the agricultural sector during the studied period. The widening of the localisation coefficient range from 3.79 in 2016 to 4.42 in 2023 represents an increase in inequality of 16.6%. The concentration of specialisation is expressed in the fact that the three leading regions demonstrate localisation coefficient values above 3.5, whilst Sofia capital shows a value of 0.09, which is 48 times lower than Dobrich region.

Differences in productivity are also significant. Whilst Vidin region reaches 133.84 hectares per worker, Plovdiv region registers only 54.40 hectares per worker, which represents a difference of 2.46 times. These data testify to deep structural fragmentation of Bulgarian agriculture, whereby different regions follow different development trajectories with limited convergence.

Testing of research hypotheses

The empirical data provide convincing evidence in support of the first hypothesis of the study concerning the deepening of regional disparities in Bulgarian agriculture. The widening of the localisation coefficient range from 3.79 in 2016 to 4.42 in 2023, representing an increase of 16.6%, demonstrates that despite the implementation of the European Union's Cohesion Policy, regional inequalities not only are not being reduced but are deepening. The concentration of specialisation in three leading regions with a localisation coefficient above 3.5, whilst simultaneously weakening the significance of other regions with a coefficient below 1.0, confirms the process of regional polarisation in the agricultural sector.

The second hypothesis concerning the lack of automatic connection between mechanisation and productivity also finds full confirmation in the analysed data. The paradoxical case of Vidin region, where the drastic reduction in

mechanisation of 41.67% accompanies the achievement of the highest productivity of 133.84 hectares per worker, clearly demonstrates that technological provision in itself does not guarantee economic efficiency. In contrast, Plovdiv region shows relatively stable mechanisation but the lowest productivity of 54.40 hectares per worker. These empirical findings reveal the complexity of the interrelationship between capital intensity and production efficiency, which depends on multiple contextual factors including farm size, production specialisation and agricultural land quality.

The third hypothesis regarding the formation of different regional development trajectories and specific adaptation patterns is confirmed by the four identified types of development. The "labour-capital substitution" trajectory in regions such as Vratsa and Dobrich, the "extensification" pattern in Vidin, the "stagnation" in Plovdiv and the "deindustrialisation" in Targovishte, Kardzhali and Smolyan represent qualitatively different strategies of adaptation to changing economic conditions. This diversity of patterns refutes the universal assumptions of Cohesion Policy and confirms the necessity for a differentiated, contextually sensitive approach to regional development in agriculture.

CONCLUSIONS

The present study confirms the hypotheses set forth concerning the deepening of regional inequalities and the lack of automatic connection between mechanisation and productivity in Bulgarian agriculture for the period 2016-2023. The analysis of regional development patterns in Bulgarian agriculture for the period 2016-2023 reveals a complex and contradictory picture. Despite the implementation of the European Union's Cohesion Policy with the aim of regional convergence, the empirical data demonstrate a deepening of regional disparities in the agricultural sector. The widening of the localisation coefficient range by 16.6% and the significant differences in productivity between regions confirm the ineffectiveness of the universal approach to regional development.

The four main regional patterns identified reflect different strategies of adaptation to changing economic conditions. The intensive production pattern in north-eastern Bulgaria demonstrates successful integration of technological modernisation and efficient resource use. In contrast, the extensive production pattern in north-western Bulgaria achieves productivity enhancement through area expansion with decreasing mechanisation, which raises questions regarding long-term sustainability.

Particularly concerning is the manifestation of the deindustrialisation pattern in a number of regions, where the drastic reduction in employment is not compensated by corresponding technological modernisation. This process leads to depopulation of rural areas and loss of production capacity in agriculture.

A technological paradox is present - higher mechanisation does not always lead to greater productivity, which calls into question the effectiveness of current investment priorities. The example of Vidin region is telling, where the highest productivity is achieved with the strongest decline in mechanisation. This underscores the need for a more flexible approach to technological modernisation that is adapted to local characteristics. The results of the study show that a differentiated regional policy is necessary, taking into account the different development paths of agriculture in individual parts of the country. The unified "one model for all" principle does not work in conditions of increasing regional fragmentation. Each of the established development patterns requires specific policies and measures corresponding to its characteristics and challenges.

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UNDERSTANDING FARMERS' APPROPRIATION OF AGRICULTURAL INSTITUTIONAL INNOVATIONS: INSIGHT FROM BENIN, WEST AFRICA

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Abstract

This study assessed the appropriation by Beninese farmers of major institutional reforms undertaken in 2016 to transform Benin's agriculture into a high-performing and resilient sector against exogenous shocks. Employing a descriptive approach and a logistic regression model applied to cross-sectional data collected from 1,501 farmers in 85 villages, the research examined the appropriation of the reforms of Territorialization of agricultural development and Agricultural sector governance. The findings reveal significant resignation among farmers due to insufficient consideration of their voices. Appropriation is influenced by socio-economic factors such as literacy levels, diversification of agricultural activities, peer networks as a source of information, soybean cultivation (an alternative to cotton), access to agricultural services, understanding the importance of reforms, and the formulation process. Age influences the appropriation of Territorialization of agricultural development, while membership in a farmers' organization and cotton cultivation affect the appropriation of Agricultural sector governance. These results highlight the need for a strengthened participatory approach, supported by information sessions and community dialogues, to optimize reform adoption and enhance their impact on Benin's agricultural sector performance. This study offers crucial insights for agricultural policies in sub-Saharan Africa, where similar reforms are often implemented to bolster the resilience and performance of agricultural sectors.

Key words**:** *institutional reforms, agricultural development, innovation adoption, sub-Saharan Africa*

INTRODUCTION

Agricultural policies are instrumental in shaping farm investments and practices, with both intended and unintended consequences for the productivity and sustainability of food and agriculture [8]. Recognizing this, public interventions in agriculture are increasingly designed and implemented to provide guidance, manage anticipated or ongoing actions, and address systemic and specific challenges [31]. Developed nations have significantly advanced their agricultural sectors through robust policies aimed at optimizing resource utilization and operationalizing institutional, technological, and innovative frameworks to mitigate sector challenges [31].

In Benin, since 2016, institutional reforms have been pursued to revitalize the national economy, focusing on diversifying export crops and enhancing domestic raw material processing. Key reforms, such as the Territorialization of agricultural development and Agricultural sector governance, have been implemented to rationalize the institutional landscape [40, 1]. The Territorialization reform aims to guide decision-makers' interventions through Agricultural Development Poles, maximizing productivity and production by leveraging agroecological aspects, agrarian histories, and sector-specific potentials [40]. The Agricultural sector governance reform seeks to streamline resources and enhance sector efficiency and performance through institutional consolidation.

These public interventions inevitably elicit responses from farmers, the primary end-users of such reforms. While extensive literature exists on agricultural policy processes, including the European Union's Common Agricultural Policy (CAP) [26, 4] and African agricultural policies [2, 13], prior research has predominantly focused on policy-making [41], intervention evaluation [9], influencing factors [25], and the linkage between continental/regional and national policies [42]. The importance of contextual understanding for policy implementation, uptake, and impact is emphasized by [25]. However, the behavioral responses of stakeholders affected by these policies, particularly their willingness to adopt reforms, remain critical for policy success [17]. The innovations that are inclusive can promote socio-economic growth and encourage active participation of local communities in the processes within sub-Saharan Africa [19, 32]. Therefore, this study investigates the appropriation of the Agricultural Sector Governance and Territorialization of Agricultural Development reforms by farmers in Benin. The farmers' reaction toward these major institutional innovations aimed to transform Benin's agriculture into a high-performing and resilient sector, capable of withstanding exogenous shocks, presents a significant area for analysis. In line with [21], who emphasized the crucial need for context-specific methodologies and knowledge within local settings, this paper assesses how these reforms have been adopted by farmers in Benin.

Drawing on [41] assertion that effective agricultural policy agenda setting requires input from citizens, stakeholders, political pressures, and experts, this paper examines whether this normative prescription aligns with the reality of Benin's reforms. Specifically, it explores how farmers' appropriation of these institutional reforms can be explained. Building on the concept of appropriation as defined by [35], this study interprets appropriation as the set of behaviors through which Beninese farmers respond to these two institutional reforms, thereby contributing to the social construction of their reality. By examining the social status of agricultural sector actors and their perceptions of these reforms, this research aims to provide an authentic, contextually informed perspective. The lack of African scholars' contributions to innovation research and the dominance of Eurocentric frameworks, as highlighted by [21], underscores the importance of this study. Ultimately, this paper seeks to contribute to the ongoing discourse on innovation in African agriculture, ensuring that future reforms are better tailored to the specific needs of Beninese farmers.

Theoretical considerations

This research is grounded in two key theoretical frameworks: Anthony Giddens' theory of structuration [14] and Michel de Certeau's theory of social appropriation [7]. Giddens' theory of structuration, operating within a political sociology perspective, posits that societal changes impact organizational structures through recursive processes [29]. Understanding the appropriation of public actions, according to this theory, necessitates a focus on social interactions, actors' experiences, autonomy, and competencies [14]. The perceived dysfunctions or resistances should be viewed as dynamic stages of usage modification and appropriation, rather than static problems [37]. Appropriation, in this context, refers to the ways in which facts or objects are used, adapted, and reproduced within specific socio-cultural contexts [34]. Actors' responses to change are thus context-dependent, shaped by their intrinsic dispositions and the interplay between structure and agency [20].

The analytical focus shifts from actions to actors, aligning sociological research with the theory of appropriation, which is often employed in social psychology. Unlike innovation diffusion approaches that emphasize user profile disparities, appropriation theory highlights the social construction of usage through the meanings attributed by users [30]. This perspective underscores the agency of individuals in creatively and subversively engaging with imposed systems and structures [11]. Everyday practices are viewed as active and strategic engagements, not merely passive consumption [27].

Social appropriation, as defined by [30], involves analyzing the formation of users' viewpoints. It is characterized as a complex process of interpretations, attitudes, and behaviors through which actors respond to change [34].

In the context of this study, applying these theories to understand the appropriation of institutional reforms by farmers in Benin requires a focus on individual perspectives and intrinsic characteristics.

These characteristics, including profiles, experiences, perceptions, and reactions, will be used to assess farmers' knowledge, understanding, adherence, and support for the reforms related to the Territorialization of agricultural development and Agricultural Sector Governance (Fig. 1).

This framework facilitates a nuanced examination of how farmers navigate and adapt to structural changes within the agricultural sector, providing insights into the social construction of reform implementation.

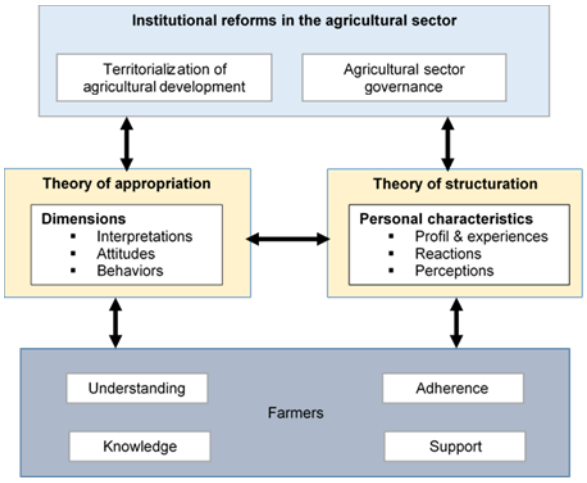


Fig. 1. Conceptual Framework of Appropriation of Agricultural Reforms.
Source: Authors' preparation.

MATERIALS AND METHODS

Study area and sampling

This nationwide study was conducted across 85 villages, distributed among the seven Agricultural Development Poles (Fig. 2). Structured interviews were carried out with 1,501 agricultural household heads, with the sample size determined using the formula by [15], a method commonly applied in agricultural surveys.

$$n = \frac{t_{\alpha}^{2} p(1-p) deff}{d^{2}}(1+h) \text{.....(1)}$$

The sample size was calculated using the following parameters: a confidence level of α=5%; a quantile of order (1 – α)=1.96; a non-response rate of h=3%; p=0.5, representing the proportion of agricultural households; a cluster effect of $deff$=1.5; and a precision of d=5%.

Data collection methods and tools

This research employed a complementary approach, utilizing both secondary and primary data. Secondary data were gathered through a literature review of scientific publications, study reports, and information briefs on the research topic.

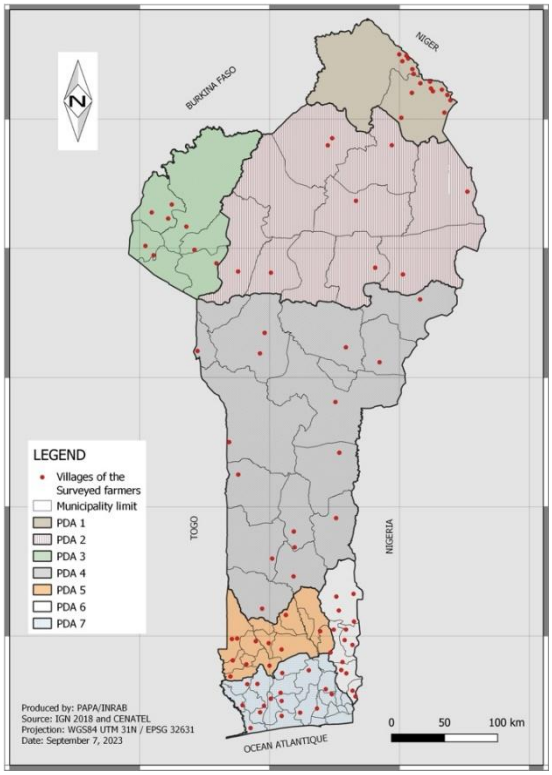


Fig. 2. Location of study sites
Source: Authors' preparation.

Primary data were collected via structured individual interviews with agricultural producers, using a pre-tested questionnaire.

The study explored three dimensions of reform appropriation: interpretation, attitude, and behavior, as defined by [30].

Ten (10) items were used to assess farmers' appropriation of the reforms: four items related to the interpretation of the reforms, three to farmers' attitudes towards the reforms, and

three to their behaviors in relation to the reforms.

Each item was evaluated by farmers using a five-point Likert scale, ranging from -2 (strongly disagree) to 2 (strongly agree), with a neutral point of 0.

The volatility is higher when the variation coefficient is higher.

Data analysis methods and tools

The analysis of farmers' appropriation of institutional reforms adopted a descriptive approach, based on the calculation of a weighted average score. This score, obtained using the formula $s = \frac{1}{N}\sum_{i=1}^{k} xi * n$ (where xi represents the modalities of the Likert scale and n their absolute frequency), falls within the interval [-2; 2]. A score close to 2 indicated a positive opinion, a score close to -2 indicated a negative opinion, and a score close to 0 indicated a lack of significant trend [6].

Table 1. Reforms appropriation evaluation grid

Average Score	Opinion	Dimensions		
		Interpretation	Attitude	Behavior
[-2, 0[	Negative	"Limited knowledge or understanding"	"Limited adherence"	"Limited support"
0	Neutral	"Moderate knowledge or understanding"	"Moderate adherence"	"Moderate support"
]0, 2]	Positive	"Good knowledge or understanding"	"Strong adherence"	"Strong support"

Source: Adapted from Ramdé et al. (2020).

The evaluation grid for reform appropriation is presented in Table 1.

Furthermore, a Logit model was employed to analyze the determinants of reform appropriation among farmers. This model is frequently used to relate a binary dependent variable to continuous or categorical explanatory variables [22]. In this study, the dependent variable was defined based on previous research [30], which concluded that appropriation can only be measured through actors' behavior. Behavior is perceived as a factual reflection of actors' cognitions (interpretations) and attitudes (affections) towards reforms. Consequently, an average appropriation index at the behavioral dimension level, ranging from [0, 1], was generated for each farmer by summing the number of items with positive points (agree or strongly agree) and dividing by the total number of items.

$$Im = \frac{Number\ of\ positive\ Items\ -\ Number\ of negative\ items}{Number\ of\ total\ d'items} \quad \text{.....(2)}$$

For example, if a farmer agreed or strongly agreed with 2 items, their average index is 2/3=0.66. An average index greater than or equal to 0.6 is interpreted as reform appropriation [35].

Let Y be a binary dependent variable, taking the value 1 if a farmer has an average index greater than or equal to 0.6, and 0 otherwise; X is a vector of independent variables that influence Y. The Logit model is based on the logistic distribution function, defined as:

$$P(Y = 1|X) = \frac{1}{1 + e^{-(\beta_0+\beta_1X_1+\beta_2X_2+\cdots+\beta_kX_k)}} \quad \text{.....(3)}$$

where: $P(Y = 1|X)$ is the conditional probability that Y equals 1, given the values of X; e is the base of the natural logarithm; $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ are the model coefficients; $X_1, X_2, \ldots, X_k$ are the independent variables.

Additionally, the logit function $\log(\frac{P}{1-P})$ is used to transform the conditional probability into a linear function of the independent variables.

$$\text{logit (p)} = \log(\frac{p}{1-p}) \quad \text{.....(4)}$$

With p being the probability of the studied phenomenon. The Logit model can be mathematically expressed as:

$$\text{logit (p)} = \beta_0 + \beta_1X_1 + \beta_2X_2 + \cdots + \beta_kX_k \quad \text{.....(5)}$$

The model coefficients were estimated using the maximum likelihood method [12]. The variables expected to explain reform appropriation are presented in Table 2.

Table 2. Annual variation coefficient

Variables	Nature	Categories
Age of the farmer	Quantitative	---
Literacy	Binary qualitative	1=Yes; 0=No
Number of years spent in school	Quantitative	---
Activity diversification	Binary qualitative	1=Yes; 0=No
Membership in a farmers' organization (FO)	Binary qualitative	1=Yes; 0=No
Membership of the FO board	Binary qualitative	1=Yes; 0=No
Change in status/structuring after 2016 within the FO	Binary qualitative	1=Yes; 0=No
Formalization of the farm	Binary qualitative	1=Yes; 0=No
Knowing private extension service providers	Binary qualitative	1=Yes; 0=No

Cotton farming	Binary qualitative	1=Yes; 0=No
Cashew farming	Binary qualitative	1=Yes; 0=No
Soybean farming	Binary qualitative	1=Yes; 0=No
Source of knowledge of the reform: Peers	Binary qualitative	1=Yes; 0=No
Access to fertilizers	Binary qualitative	1=Yes; 0=No
Access to agricultural extension	Binary qualitative	1=Yes; 0=No
Access to phyto treatment products	Binary qualitative	1=Yes; 0=No
Understanding the content of the reform	Binary qualitative	1=Yes; 0=No
Understanding the importance/necessity of the reform	Binary qualitative	1=Yes; 0=No
Exclusive approach in formulation/design	Binary qualitative	1=Yes; 0=No
Increase in production and income	Binary qualitative	1=Yes; 0=No

Source: Authors' preparation.

RESULTS AND DISCUSSIONS

Socio-economic characteristics of the farmers

The surveyed farmers were predominantly male, with a relatively young average age of 46 years (Table 3). Over half of the respondents had received formal education, averaging 8 years of schooling, while one-third were literate. Furthermore, nearly half were members of a Farmer Organizations that had undergone structural changes post-2016.

Table 3. Characteristics of the farmers

Socio-economic Characteristics	Modalities	Average
Gender	Male	96.60%
	Female	3.40%
Age (in years)		45.79 (11.94)
Formal Education (% Yes)		51.43%
Average Years of Schooling		7,55 (3,76)
Literacy (% Yes)		33.51%
Secondary Activity (% Yes)		48.77%
Member of Farmer organizations (% oui)		42.50%
Change in the FO status/structuring after 2016		43.73%
Knowledge of the Territorialization of Agricultural Development reform (% yes)		16.92%
Knowledge of Agricultural Sector Governance reform (% yes)		45,90%

Source: Authors' calculation.

Regarding institutional reforms, farmers demonstrated greater familiarity with Agricultural Sector Governance than with Territorialization of Agricultural Development. Training workshops led by extension agents, peer-to-peer exchanges, and radio broadcasts were the primary sources of information on these reforms. In contrast, social networks and television played a less significant role (Figure 3).

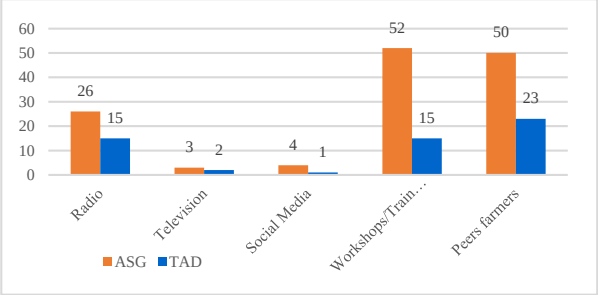


Fig. 3. Sources of knowledge on institutional reforms
Source: Authors' Computation.

Appropriation of institutional reforms by farmers

The evaluation of farmers' interpretation of institutional reforms, conducted using four indicators, reveals limited comprehension (Table 4). Specifically, farmers exhibited a negative tendency regarding their "knowledge of the development process," "understanding of the content," and "participation in the development" of both reforms. However, over half of the farmers displayed a positive perception of the utility of the Territorialization of Agricultural Development, compared to only one-tenth for Agricultural Sector Governance.

The assessment of farmers' attitudes towards the reforms demonstrated a stronger endorsement (¾ of the surveyed farmers) of the necessity to improve the agricultural sector through enhanced governance. Conversely, farmers were less favorable towards the establishment of agricultural development hubs. Similarly, the majority of farmers considered the formulation process of both reforms to be exclusive. Nevertheless, more than half of the farmers believed that territorialization would increase agricultural production and income. This attitude contrasts with that observed for Agricultural Sector Governance.

Finally, the analysis of farmers' behavior in response to the reforms, based on three indicators, indicated low appropriation rates (20% for territorialization and 7% for Agricultural Sector Governance). However,

farmers expressed a sense of resignation, perceiving their voices as inconsequential.

The appropriation of reforms by farmers was assessed based on their behavior towards these reforms. The results indicate that farmers expressed a strong negative sentiment regarding their exclusion from the development of both reforms. This finding corroborates the conclusions of [41], who highlighted the instrumentalization of stakeholder participation in the agricultural sector, leading to low adherence, particularly in the implementation of reforms. As [33] asserted, reform cannot be limited to the intentions and actions of governing bodies but must include a synergy of action from all stakeholders involved, from conception to evaluation. Furthermore, the research revealed a limited knowledge of the reforms among farmers. Similar trends concerning reforms in education were observed [35]. Supporting [10], these authors emphasized the necessity of transparent information for the recipients of change to prevent misunderstandings, rumors, and anxiety, and to ensure a better understanding of the change.

Moreover, the results reveal significant support from farmers for Agricultural Sector Governance, perceived as beneficial for the sector. This observation aligns with [8], who affirmed that well-designed and implemented agricultural policies enhance agricultural sustainability and performance. Conversely, the evaluation of Territorialization of Agricultural Development by surveyed farmers was negatively connoted. Additionally, a consensus emerged regarding the exclusive nature of the approach adopted during the design of both reforms. The absence of a participatory approach in the development of agricultural policies in Benin had been observed [39]. To address this gap, [18] advocated for inclusive participation of all actors, equipped with diverse resources and action logics, throughout the decision-making process, to facilitate acceptance and involvement in the change. Furthermore, very few farmers supported the institutional reforms in the agricultural sector. It was also found that students showed little support for the LMD system reform in Burkina Faso [35]. Despite this, farmers rarely criticized the two reforms because they felt resigned. Their discourse reflects a sense of inability to influence the course of the decision regarding the reforms. This stance confirms that of [10], for whom the failure of changes is often due to poor consideration of the human factor, which constitutes the cornerstone of any change.

Determinants of the appropriation of the reforms

The factors influencing the appropriation of the two reforms under investigation are presented in Table 5. The goodness-of-fit test (Chi-squared statistic) associated with each model indicated that the estimations were globally significant at the 1% level. Literacy, soybean cultivation, access to agricultural services (agricultural advisory and treatment products), and the comprehension of the importance or necessity of the reform positively influenced the appropriation of the Territorialization of Agricultural Development reform. Conversely, the age of the farm manager, diversification of income sources, information received from peer farmers, and the perception that the formulation process was exclusive had a negative effect on the appropriation of Territorialization of Agricultural Development.

Regarding Agricultural Sector Governance, its appropriation by farmers was determined by literacy, diversification of economic activities, cotton and soybean cultivation, access to fertilizers, and the perception of a positive effect of the said reform on agricultural production and income. In contrast, farmer membership in an agricultural producer organization, information obtained through peers, and exclusion in the design process negatively influenced the appropriation of Agricultural Sector Governance. The findings reveal a diversity of factors explaining the appropriation of reforms introduced in the Beninese agricultural sector. The most significant factors are the intrinsic characteristics of farmers, their social network, cultivated crops, and farmers' interpretations and attitudes towards the reforms.

Table 4. Appropriation of institutional reforms by farmers

Items	Strongly Disagree (=-2)	Disagree (=-1)	Neither Disagree nor Agree (=0)	Agree (=1)	Strongly Agree (=2)	Total	Mean Score
Territorialization of Agricultural Development (TAD) reform							
Participation in development	144	108	0	0	2	254	-1,54
Knowledge of development process	102	148	1	2	1	254	-1,37
Understanding of the reform content	60	154	9	0	31	254	-0,83
Understanding of the reform utility	12	41	32	156	13	254	0,46
Importance/relevance of the reform	30	139	24	50	11	254	-0,50
Exclusive formulation/design process	28	25	5	139	57	254	0,68
Increase in production and income	13	74	10	145	12	254	0,27
Open criticism	34	155	5	50	10	254	-0,60
Farmer resignation	4	60	22	133	35	254	0,53
Support the reform	31	159	11	46	7	254	-0,63
Agricultural Sector Governance (ASG) reform							
Participation in development	416	309	14	6	2	747	-1,51
Knowledge of development process	332	394	16	3	2	747	-1,41
Understanding of the reform content	266	435	26	18	2	747	-1,27
Understanding of the reform utility	177	405	75	75	15	747	-0,88
Importance/relevance of the reform	30	89	55	476	97	747	0,70
Exclusive formulation/design process	42	39	19	392	255	747	1,04
Increase in production and income	161	429	58	84	15	747	-0,85
Open criticism	93	333	27	241	53	747	-0,23
Farmer resignation	10	49	36	466	186	747	1,03
Support the reform	205	461	28	36	17	747	-1,07

Source: Author's calculation.

Table 5. Determinants of Reform Appropriation by Farmers

Variables	TAD	ASG
Age	-0.07**	0.01
Literacy	3.66***	0.56***
Years of Schooling	-0.01	0.01
Engagement in Secondary Non-Agricultural Activities	-1.39**	0.35**
Membership in Agricultural Producer Organization	-0.88	-0.72***
Source of Reform Knowledge: Peers	-3.72***	-0.88***
Cotton Cultivation	0.14	0.45**
Cashew Cultivation	0.06	0.22
Soybean Cultivation	2.05**	0.61**
Access to Fertilizers	3.13***	0.74***
Access to Agricultural Advisory Services	3.58***	-0.12
Access to Treatment Products	3.15**	-0.35
Understanding of Reform Content	0.34	0.19
Perceived Importance/Necessity of Reform	8.74***	-0.10
Perception of Exclusive Formulation/Design Process	-2.47***	-0.58**
Perceived Increase in Production and Income	0.32	1.03***
Constant	-9.02***	-0.00
Number of observations	***224***	***747***
Wald-LR chi2 (df)	***181.98******	***114.77*****
Pseudo R2	***0.65***	***0.15***

Note: *, ** and *** denote significance at the 10%, 5%, and 1% levels, respectively
Source: Author's calculation.

Regarding the characteristics of farmers, it was observed that the age of the farmer is negatively correlated with the appropriation of the Territorialization of Agricultural Development reform. This result is explained by the fact that older individuals resist change more than younger ones, due to their life experience and attachment to established habits and values [16]. Moreover, literate farmers adhered more to the reforms. This category of farmers had a greater capacity to access and understand information related to new policies and could be actively involved in the consultation and implementation processes of reforms directly concerning them. Literate farmers generally have a better understanding of the issues, which helps them make informed decisions, facilitates their adherence, and strengthens their sense of ownership [24]. In contrast, the influence of farmers' engagement in secondary non-agricultural activities on reform appropriation is mixed. It positively influences the "Agricultural Sector Governance" reform by providing additional financial resources [5]. However, it hinders the appropriation of the "Territorialization of Agricultural Development" reform due to farmers' reluctance to modify their production system, as this reform may impede their secondary non-agricultural activities.

The farmers' social network has a negative influence on the appropriation of reforms in the agricultural sector, notably explained by the

resistance of members of agricultural producer organizations. These resistances are due to the divergence of interests and objectives pursued by the reform and those pursued by the organizations. Similarly, the negative influence of "peers" as a source of knowledge on reform appropriation is explained by the degree of trust in information obtained from this channel rather than other sources. However, the literature shows that membership in a producer organization facilitates the appropriation of innovations through exchanges and sharing of experiences among farmers [24]. Producer organizations facilitate policy appropriation through their participatory consultation [28].

The results also indicated that farmers cultivating cotton and soybeans are more likely to support agricultural reforms. Indeed, reforms are more favorable to industrial crops, which are better targeted by public policies in the agricultural sector (notably subsidies, provision of inputs on credit, low-interest loans, etc.). Farmers cultivating these crops are therefore more inclined to accept and support the reforms. Similarly, farmers' access to agricultural services positively influences reform adoption. This result is justified by the fact that access to agricultural services is perceived as a positive effect of the changes made in the sector. Access to agricultural services strengthens farmers' institutional capacity by facilitating their integration into support and communication networks, a key element for reform appropriation [23].

Finally, farmers' attitudes, expressed by statements such as "the reforms were necessary for the sector" and "with the reforms, my agricultural production has increased," positively influence reform appropriation. The more favorably farmers perceive the reform, the more they invest in it. According to [3], a person's belief in their ability to achieve a goal determines their motivation and commitment. Similarly, [35] showed a correlation between the positive perception of reforms and the support they receive. Concerning [36] thesis, the relative advantage of reforms over existing solutions increases farmers' adherence. Furthermore, farmers' perception of the reform development process influences their adoption. In other words, the more farmers feel excluded, the more negatively connoted their appreciation of the reforms is. The exclusion of stakeholders hinders their understanding of the issues and challenges of the reforms, thereby reducing their adherence. Land reforms introduced without the involvement of local farmers create uncertainty about their rights and the impact of laws on their activities [38].

CONCLUSIONS

This study has illuminated the complex dynamics surrounding the appropriation of agricultural reforms in the Beninese context, revealing a significant disparity between policy intent and farmer engagement. Specifically, research has demonstrated that farmers possess a limited knowledge and understanding of the institutional reforms implemented, which acts as a fundamental impediment to their effective appropriation. Furthermore, the analysis showed that intrinsic farmer characteristics, social networks, cultivated crops, and individual interpretations and attitudes are important in shaping reform support. The study shows the value of using mixed methods that fully catch farmers' subtle views by putting together quantitative studies of what affects appropriation and qualitative understandings into farmer opinions and experiences. Future research should also track how institutional innovations adoption and effect change over time through longitudinal studies, and participatory research methods should be used to empower farmers in the evaluation process. This research reinforces the importance of social capital as well as information asymmetries in completely shaping reform outcomes. Future theoretical work should investigate how formal institutions and informal ones work together on agricultural reform, especially looking at how farmer organizations play a part.

The results show that the stakeholders involved should get information about institutional changes. Using a number of varied communication channels appropriate for the context, like radio as well as local language resources, in addition to farmer-to-farmer outreach, remains important as far as rural

communities are concerned. The study additionally stresses the need for reform development processes that are fully all-embracing and participatory.

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AGRICULTURAL LAND MARKET CIRCUIT IN THE REPUBLIC OF MOLDOVA: ANALYSIS AND FORECASTS

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Abstract

The evolution of the value of agricultural land is influenced by a range of socio-economic factors, including the standard of living of the rural population and the national demographic, economic, and political context.The Republic of Moldova is a predominantly agrarian country, where agricultural land constitutes the most important natural resource. In this context, the development and implementation of a complex system of rights, restrictions, interests, obligations, and responsibilities is necessary to ensure the efficient use of land. The establishment of such a system requires a thorough analysis of the market value dynamics of agricultural land, as well as the size of the areas included in the market circuit. The present study aims to analyze the dynamics of the agricultural land market in the Republic of Moldova over the past 25 years and to identify the main factors that underpin its efficient development. The present study is based on the analysis of previous research conducted by both domestic and foreign authors, as well as on the use of systematized data from the Real Estate Register. From a methodological point of view, there were applied: statistical data analysis, graphical trend analysis, systemic analysis of ongoing processes and phenomena and also synthesis of the main aspects and results. The value trends of agricultural land and the factors influencing them were identified. The study also highlighted the main issues related to the agricultural land market and formulated recommendations for regulatory measures. The evolving value of agricultural land can serve as an important indicator of the social, economic, and ecological development of local communities, as well as of the country as a whole. The liberalization of land transactions, particularly for agricultural land, is a critical factor for the efficient functioning of the land market, with complex and multidimensional implications for the agricultural economy and society as a whole. This process can generate both positive effects, such as more efficient land use and increased investment, and negative effects, manifested in the excessive concentration of land ownership, land speculation, and the exacerbation of socio-economic imbalances in rural areas.

Key words**:** *transactions, market price, agricultural land, land market, valuation of agricultural land plots*

INTRODUCTION

A quarter of a century (1999–2024) has passed since the initiation of the development process of the agricultural land market in the Republic of Moldova. Considering that the agricultural sector contributes over 10% to the national GDP, and that agricultural land constitutes the country's most important natural resource, monitoring trends and the dynamics of key indicators is essential for assessing the current state and development prospects of the land market, regarded as a strategic segment of the overall market management mechanism. Furthermore, land sale and purchase transactions, conducted through direct negotiations between owners and buyers, provide an objective and reliable basis for determining the market prices of these lands. As a result, the costs of other forms of trading in agricultural areas, including exchanges of agricultural land, donations, changes in the purpose of the respective lands etc., are objectively and reasonably assessed.

Consequently, as a result of a diverse range of land transactions conducted across the entire territory of the Republic of Moldova over the past 25 years, under conditions of a free and equitable market, favorable conditions have been created that have, de facto, stimulated the execution of a significant number of

transactions, through which agricultural land plots have been transferred from one generation of farmers to the next. As previously noted, the revitalization of the agricultural land market and the emergence of the first sale and purchase transactions of such land in the Republic of Moldova were recorded beginning in 1999 [7]. However, the actual development of the agricultural land market can be situated in 2000, following the completion of the first stage of the land reform, when the National "Land" Program was successfully implemented and the property rights of hundreds of thousands of local landowners were registered in the Real Estate Registry.

Although during the operation of the above-mentioned program, drastic measures were taken to prevent over-parceling of agricultural land. During the stage of agricultural land privatization carried out between 1998 and 2000 in the Republic of Moldova, the average size of agricultural land allocated per person included in the privatization list was recorded at 1.7 hectares, in accordance with the provisions of the Land Code. According to the data from the first (and, indeed, only) General Agricultural Census, in the 2011 there were 902,214 agricultural holdings, of which only 3,609 were holdings as legal entities, the rest – 898,605 holdings – without legal personality. In total, agricultural holdings owned 2,243,540.02 hectares, of this, the utilized agricultural area (UAA) amounted to 1,940,135.56 hectares, corresponding on average to 2.15 hectares per agricultural holding [10, 6]. For comparison, it should be noted that at the beginning of the agrarian reform implemented in the Republic of Moldova during 1998–2000, within the framework of the National "Land" Program, the agricultural activity was concentrated within approximately 1,000 large agricultural enterprises (kolkhozes and/or sovkhozes), so the total number of agricultural holdings during the reform years increased hundreds of times [3, 4, 5, 2].

Racul and Cimpoies (2012) highlighted that the factors which determine the land market for agricultural purposes in Republic of Moldova are linked to land quality, fertility, productivity, geographical position, proximity to local or national roads and owners' economic status [11].

Racul et al (2013) referred to the creation of a Land Bank or Investment funds to improve the land buy/sell transactions transaction system, develop financial tools necessary for increasing land market efficiency [12].

Turetchi and Turechi (2022) analyzed the evolution of land fund in the 22 and 21 centuries in the Republic of Moldova. In the year 2021, they affirmed that in the country there were 1,283,239 landowners, 307,783 farms, working 1,376.1 thousand ha, meaning an average farm size 1.66 ha/farm [14].

The objective of this research is to analyze the evolution of the agricultural land market in the Republic of Moldova over the past 25 years (1999–2024) and to identify the main challenges and solutions for its efficient functioning in the future.

In this context, the primary aim of the study stems from the need for a detailed analysis of the agricultural land market's development during the specified period, highlighting the main trends and growth patterns, as well as its connections with other segments of the market economy, particularly the capital and labor markets.

MATERIALS AND METHODS

This study focuses on the analysis of the agricultural land market in the Republic of Moldova over a 25-year period, beginning in 1999. The research aims to identify the main dysfunctions of the land market and to formulate strategic directions and solutions for its efficient and sustainable development over the medium and long term.

The study is based on the national legal framework governing land relations, as well as on detailed, systematized, and processed statistical data sourced from the Real Estate Registry. The systematized data were analyzed for the entire territory and structured according to the development regions of the Republic of Moldova. In this study, the following key indicators were examined: the area of agricultural land involved in the transaction process and the average sale-purchase price per

hectare of agricultural land. The study also includes a comparative analysis of international experience, highlighting the role of the land market as a critical factor in promoting social, economic, and environmental development in countries.

To accomplish the proposed objectives, a range of scientific research methods were applied, including: statistical observations and analysis of data, graphical analysis of evolutionary trends, statistical indices, grouping, extrapolation, methods of analysis and synthesis, comparisons, along with other systemic and complementary approaches.

The selection and application of these research methods were determined by the specific nature and complexity of the issues under investigation.

RESULTS AND DISCUSSIONS

The 2030 Agenda for Sustainable Development [15] acknowledges that social and economic development is fundamentally dependent on the sustainable management of limited natural resources, with land constituting a key component of this system. As the primary sector of the national agro-food complex, agriculture in the Republic of Moldova currently provides over 18.5% of available employment and contributes 10.1% to the country's gross domestic product (GDP). Obviously, taking into account the processing of agricultural raw materials in industrial enterprises, the transportation of agri-food products and/or materials, their marketing, etc., the total contribution of the agricultural sector to the country's economic activity is much more considerable. To support the agricultural sector to be at an expected level of economic efficiency, annual investments in this area have been strongly sustained by the state.

In recent years, investments have consistently exceeded 3.0 billion MDL (at current prices). Over the past quarter-century (1999–2024), a significant share of the total investment flow in this sector has been directed toward the acquisition of agricultural land, given that its market value has experienced continuous growth during the period under analysis.

In the context of a comprehensive analysis of the revitalization process of the agricultural land market in the Republic of Moldova, it is important to note that, for more than a decade (the 1990s), there were unsuccessful attempts to replace this market with artificial economic mechanisms and instruments.

The widespread use of various forms of agricultural land lease is taken into account, primarily - operated within economically inefficient agricultural enterprises, regardless of whether they are collective farms (private structures) or state farms - state enterprises.

Operating under a common slogan (Lease - the path to abundance) small, medium or large groups of lessees, some of which are based on family relationships (the so-called - family lease), compared to over-bureaucratized enterprises, such as collective farms and state farms themselves, have indeed demonstrated much better operating results. Thus, these entities, as time has shown, became the primary initiators of the privatization process for all forms of agricultural assets, particularly agricultural land, livestock complexes, and agri-technical equipment. Although the weighted average area of agricultural land in the Republic of Moldova at that time was only 1.7 ha for a single person, in most cases this piece of land was divided into at least 3 separate plots: arable land, vineyard and/or orchard plantation. In some cases, part of orchards or vineyards areas were strongly differentiated by age and they were also divided.

It follows that it is necessary to emphasize that, in addition to its primary function—the orderly transfer of agricultural land from one generation of farmers to the next—the agricultural land market in the Republic of Moldova is currently successfully implementing the second stage of land reform, namely the process of consolidating agricultural land based on private ownership.

The physical and economic indicators reflecting the efficient functioning of the land market in the Republic of Moldova over the past 25 years are presented in Table 1 and illustrated graphically in Figure 1.

A generalized analysis of the data compiled in Table 1 and Figure 1 shows that, over the entire

period of land market development, a total of 427,048.1 hectares of agricultural land, representing 19% of the total area (excluding the territories on the left bank of the Dniester), were involved in the civil market through sale and purchase transactions.

Table 1. Main physical and economic characteristics of the functioning of the agricultural land market in the Republic of Moldova

Years	Area ha	Amount of transactions, MD lei	Average Price MD lei/ha
1999	6,342	21,562,800.0	3,400.0
2000	7,338.0	27,055,206.0	3,687.0
2001	8,539.0	25,258,362.0	2,958.0
2002	1,616.0	5,071,008.0	3,138.0
2003	32,323.0	119,368,839.0	3,693.0
2004	43,878.0	141,111,648.0	3,216.0
2005	21,825.0	104,279,850.0	4,778.0
2006	28,096.0	195,688,640.0	6,965.0
2007	16,303.2	155,527,637.0	9,539.7
2008	35,145.4	299,104,926.7	8,510.5
2009	25,214.0	224,689,518.2	8,911.3
2010	19,021.2	313,896,287.3	16,502.5
2011	19,930.0	267,938,920.0	13,444.0
2012	10,159.0	139,371,321.0	13,719.0
2013	12,906.0	216,627,210.0	16,785.0
2014	15,652.7	311,117,380.7	19,851.0
2015	18,379.9	326,375,435.2	17,669.0
2016	18,201.0	410,550,857.0	22,556.5
2017	18,082.0	494,651,941.2	27,356.0
2018	16,349.6	322,561,659.6	19,729.1
2019	17,215.8	405,304,693	23,542.6
2020-2021*	4,190.4	209,851,112	50,078.9
2022	11,483.3	638,597,140.1	55,610.8
2023	9,805.0	936,012,186.7	95,462.7
2024	9,052.6	1,236,504,312.4	136,590.7
Total	**427,048.1**	**7,225,517,231.5**	-

* The deviations observed in the data for 2020–2021 can be attributed to the impact of the COVID-19 pandemic.
Source: [13].

At the same time, the market value of one hectare of agricultural land during the analyzed period increased more than 40.1 times, reaching 136,590 MDL, equivalent to 7,613.75 USD, according to the official exchange rate as of April 1, 2025.

Within market-based land relations, the land market constitutes a key instrument that enables participants to freely exercise their rights in the process of transferring and acquiring land ownership [18].

Much more important, however, is the fact of the differentiation of market prices not in time, but in space.

If, for example, the range of prices (maximum price/minimum price) for the sale-purchase of agricultural land in the first years of the operation of the land market at the district level was 7.9 times, then in the last year of analysis this indicator became equal to 31.75 times (Chisinau municipality, including Ialoveni district versus Căinari district).

More detailed regional data on the main indicators: area of land sold-purchased, average price of a hectare sold-purchased and total amount of transactions in 2024, are reflected in Tables 2 and 3.

The zonal (geographical) aspect of the functioning of the land market in 2024 is presented in Table 4 (Fig. 2 and Fig. 3).

The land market has also been examined by the author in previous publications [16,17], with a focus on sale–purchase transactions. Encouraging investment in the agricultural sector, aimed at motivating farmers to utilize and cultivate larger areas of agricultural land, remains a major priority.

Research shows that agricultural land located near urban areas commands the highest prices, while land in rural areas generally exhibits lower price levels.

Furthermore, agricultural land in regions with a more developed agricultural sector is traded at higher prices.

The market value of agricultural land is significantly influenced by soil fertility as well as the location of the land relative to market outlets. A study on the stages of evolution of the agricultural land market in the Republic of Moldova [8] examines the processes that have fundamentally shaped the rural land market, highlighting the need to improve or develop a regulatory legal framework in line with the current needs of societal development.

The lack of transparency in the agricultural land transaction process, combined with limited access to reliable data sources on transactions, currently constitutes a significant constraint in the context of implementing modern valuation models [1]. To enhance transparency and efficiency in the real estate market, the Information System (IS) “Registry of Real Estate Prices” [9] was established. It serves as a centralized mechanism for collecting, storing, updating, and accessing data on sale and rental prices, land areas, property listings, and public property valuation reports.

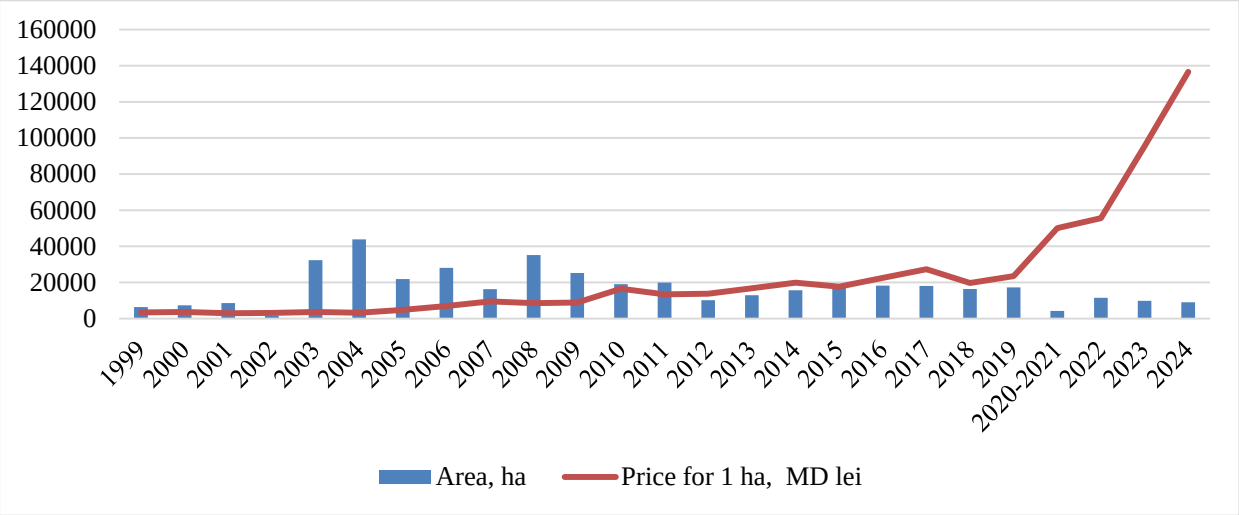


Fig. 1. Graphical representation of the main indicators of the functioning of the agricultural land market in the Republic of Moldova
Source: [13].

Table 2. Key Indicators of the Functioning of the Agricultural Land Market in 2024, by Regions of the Republic of Moldova

Regions (geographical areas), districts	Area, ha	Amount of transactions, MD lei	Price for 1 ha, MD lei
NorthernRegion			
Briceni	432.12	22,429,829.40	51,906.90
Dondușeni	303.86	26,475,196.96	87,128.30
Drochia	496.10	22,188,761.46	44,726.37
Fălești	404.43	34,360,943.0	84,962.36
Florești	115.43	12,255,979.69	106,172.77
Glodeni	280.27	22,060,781.37	78,713.53
Ocnița	224.94	19,446,083.99	86,451.44
Râșcani	419.84	21,452,097.46	51,096.03
Sângerei	170.21	33,339,740.67	195,878.30
Total	**2,847.19**	**214,009,414.0**	**75,165.15**
Central Region			
Anenii Noi	578.98	63,455,599.22	109,598.82
Călărași	202.77	11,693,447.87	57,667.56
Criuleni	191.07	25,268,464.31	132,246.33
Dubăsari	226.69	47,756,575.83	210,665.19
Nisporeni	144.16	10,231,406.41	70,973.26
Rezina	67.31	21,661,392.26	321,805.33
Șoldănești	206.81	10,637,915.43	51,438.83
Telenești	124.65	6,549,314.0	52,541.42
Total	**1,742.45**	**197,254,115.3**	**113,205.18**
Southern Region			
Cantemir	91.42	4,184,241.4	45,768.98
Căinari	70.79	1,907,687.59	26,947.02
Căușeni	298.56	17,302,502.91	57,954.06
Ceadir Lunga	151.97	7,459,642.2	49,086.41
Cimișlia	220.35	20,920,317.88	94,939.37
Comrat	177.33	13,123,476.53	74,004.16
Leova	40.00	2,852,974.7	71,324.01
Taraclia	65.50	7,763,133.66	118,516.24
Ștefan Vodă	76.60	9,873,721.59	128,902.28
Vulcanesti	29.15	1,447,292.26	49,652.72
Total	**1,221.68**	**86,834,990.72**	**71,078.43**
GENERAL TOTAL	**5,811.32**	**498,098,520.1**	**85,711.83**

Source: [13].

Table 3. Analysis of the Functioning of the Land Market in Urban and Suburban Regions of the Republic of Moldova, 2024

Regions (geographicalareas), municipalities (districts)	Area, ha	Amount of transactions, MD lei	Price for 1 ha, MD lei/ha
Northern Region			
mun :Bălți	24.11	3,439,670.07	142,674.58
mun. Edineț	727.25	34,422,051.03	47,332.11
nun. Soroca	432.25	30,757,578.13	71,156.39
Total municipal agricultural land	**1,183.61**	**68,619,299.23**	**57,974.73**
Central Region			
mun. Chișinău, inclusiv r-l Ialoveni	630.47	539,377,457.5	855,511.30
mun. Hâncești	113.19	11,241,293.0	99,314.18
mun. Orhei	312.95	17,982,558.07	57,460.78
mun. Strășeni	175.66	19,154,019.31	109,039.31
mun. Ungheni	166.86	9,315,165.09	55,825.66
Total municipal agricultural land	**1,399.14**	**597,070,492.9**	**426,741.09**
Southern Region			
mun. Cahul	478.01	24,539,050.56	51,336.14
or. Basarabeasca	180.56	48,176,949.57	266,825.53
Total municipal agricultural land	**658.56**	**72,716,000.13**	**110,416.11**
GENERAL TOTAL	**3,241.31**	**738,405,792.3**	**227,810.90**

Source: [13].

Table 4. Analysis of Data on the Development of the Agricultural Land Market in the Republic of Moldova by Area, 2024

Regions (geographical areas)	Area, ha	Transaction amount, MD lei	Price, MD lei/ha
General total for the NORTH area	4,030.80	282,628,713.2	70,117.34
General total CENTER area	3,141.59	794,324,608.3	252,841.77
General total for the SOUTH area	1,880.24	159,550,990.9	84,856.63
TOTAL Republic of Moldova *	**9,052.63**	**1,236,504,312.0**	**136,590.68**

* with the exception of the administrative-territorial units on the left bank of the Dniester.
Source: [13].

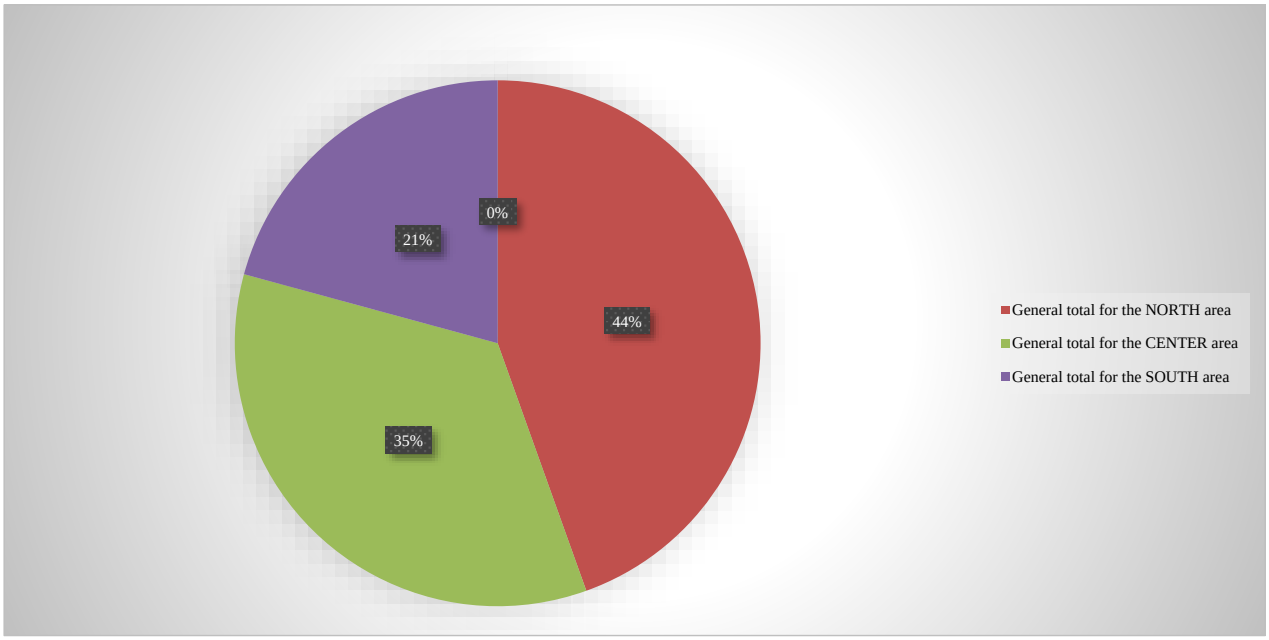


Fig. 2. Geographical Distribution of Traded Agricultural Areas in the Republic of Moldova, 2024 (ha)
Source: [13].

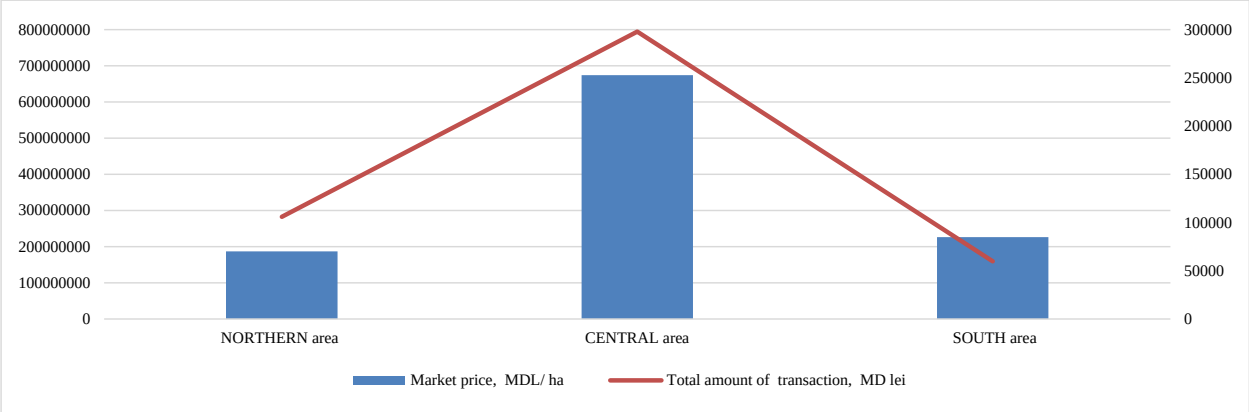


Fig. 3. Market Value (Moldovan Lei/ha) and the Total Amount Resulting from Agricultural Land Sale-Purchase Transactions (Moldovan Lei) by Geographic Zones of the Republic of Moldova, 2024
Source: [13].

The purpose and necessity of the IS "Registry of Real Estate Prices" include:
-Monitoring real estate valuation activities.
-Ensuring interoperability with other information systems for improved data management.
-Preventing artificial under- or overvaluation of properties by verifying the accuracy of declared transaction prices.
-Collecting data required for developing and calibrating valuation models used for fiscal purposes.
-Efficiently storing and managing valuation reports of public property.

CONCLUSIONS

A quarter of a century after its operation in the current format, the free agricultural land market in the Republic of Moldova, analyzed and evaluated in this article, provides a clear picture of its level of economic efficiency and the social, demographic, ecological, and other impacts resulting from the peaceful revitalization of this key segment of the general market economy mechanism.
In any case, forecasts and intimidations such as the very privatization of agricultural land constitutes the complete destruction of local agriculture, will cause over-parceling of land and the impossibility of processing it with modern technical means, etc., have become unfounded.
Obviously, any reform, along with its positive effects, also incurs some additional expenses, the objective assessment of which deserves a separate study.
The analysis of the evolution of the agricultural sector indicates a significant decline in the number of active workers, accompanied by an expansion of the average agricultural land area managed per farmer. At the onset of the agrarian reform in 1988, the agricultural sector (agriculture, hunting, and forestry) employed 749 thousand individuals, each cultivating an average of 2.86 hectares of agricultural land. By 2023, the total number of farmers had decreased to 185 thousand, while the average agricultural area cultivated annually per farmer increased to 11.6 hectares, representing an approximate 4.1-fold increase compared to the pre-reform period. Despite this substantial reduction in agricultural labor, the total utilized agricultural area remained relatively constant, reflecting an intensified process of land concentration within larger agricultural holdings.
So, hundreds of thousands of individuals were released from the agricultural labor field, who, being included among workers in other areas of economic activity, ensured the increase in efficiency and total production volume either in industry or transport, trade, capital construction, etc.
Furthermore, a close relationship is observed between market price levels and the size of agricultural land plots traded. An increase in the market price of agricultural land is associated with a reduction in the average size of land plots involved in purchase and sale transactions, a trend illustrated in Table 1 for the last two years. In this context, a period of price stabilization for

agricultural land in the Republic of Moldova is anticipated in the coming years.

Previous research conducted by the authors has highlighted the existence of a diversified structure of agricultural land transactions on the national land market during the period under analysis, which can be summarized as follows: sale-purchase – 33.7%, inheritance – 34.6%, donations – 15.6%, pledge, including mortgage – 3.2%, long-term lease – 12.4%, exchange and others – 0.5%

In turn, a total of 1,234,243.06 ha or 63.6% of the entire area of agricultural land in exploitation has passed through various forms of trading over the last quarter of a century.

In light of the above, the following recommendations can be formulated:

1. Ensuring the free, open, and transparent development of the agricultural land market, through the involvement of specialized public institutions in the creation, management, and dissemination of an accurate, comprehensive, and continuously updated information database, accessible to all participants in purchase and sale transactions.
2. Recognition and monitoring by public authorities of the process of agricultural land concentration in the private ownership of a limited number of individuals, as this phenomenon may lead to the monopolization of agricultural land resources and create conditions conducive to the emergence of large-scale (latifundia-type) holdings. This phenomenon is contrary to the interests of the rural population and the harmonious development of village communities, thereby necessitating intervention through appropriate legal regulations, including the review of the regulatory framework and, where applicable, the establishment of limits on the maximum allowable private ownership of agricultural land.
3. Restrict foreign individuals from acquiring ownership rights over agricultural land.
4. To address the persistent demographic imbalances in rural areas, it is necessary to create, for a defined period, preferential conditions for young people in the process of purchasing agricultural land. Such measures may include concessional loans, subsidies, tax incentives, and other support instruments, which, in order to ensure the effectiveness and coherence of public intervention, should be integrated into a clearly defined state program aimed at revitalizing rural areas.

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SENSOR PERCEPTIONS OF ARONIA - FLAVOURED BUFFALO YOGHURT

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Abstract

The purpose of this study is to investigate consumer perceptions of a newly developed functional dairy product—buffalo yoghurt enriched with aronia juice—across different age groups. Consumer-oriented research plays a crucial role in understanding dietary preferences and purchasing behavior, thereby guiding innovations in the food industry. In this study, respondents evaluated both visual and sensory characteristics of yoghurt samples supplemented with 3% and 5% aronia juice. The results highlight that fruit-enriched buffalo yoghurt is perceived positively, with particular appreciation for its nutritional benefits, unique taste, and health-promoting qualities. Aronia, rich in anthocyanins and polyphenols, enhances both the functional and sensory attributes of yoghurt, contributing to its antioxidant value and consumer appeal. Findings indicate strong interest in purchasing such a product, confirming the importance of early consumer feedback in product development. This research supports the market potential of aronia-flavored buffalo yoghurt as a novel functional food that aligns with modern health-conscious trends.

Key words**:** *buffalo milk, aronia juice, consumer preferences*

INTRODUCTION

As consumers become more health - conscious, the demand for proven health foods is also increasing. Among them, yoghurt is globally recognized as an option that provides easy access to a wide range of nutrients such as proteins, minerals, vitamins, probiotics (Gómez-Gallego et al., 2018) [18]. Yoghurt has a positive effect on the treatment of diseases including obesity, allergies, inflammation of the intestinal tract, colon cancer, cardiovascular disease and *Helicobacter pylori* infection (Aslam et al., 2020; Karwowska et al., 2019; Mozaffarian & Wu, 2018; Yang et al., 2020) [2, 28, 37, 51]. These qualities help improve human health and reduce the risk of disease (Hobbs et al., 2019; Wang et al., 2013) [21, 50]. It has been established that the addition of various fruits to yoghurt (in the form of juice, pulp or puree) improves both the nutritional and functional characteristics of yoghurt, as well as the shelf life and acceptance by consumers (Salwa et al., 2004; Fazilah et al., 2018; Stinco et al., 2019) [42, 15, 44]. Turkmen et al. (2019) found that food is nowadays also seen as a tool to optimize body weight [47]. With regard to these functional characteristics expected by the consumers a range of new fermented dairy products enhanced with plant-derived ingredients have been introduced to the market (Iriondo-DeHond et al., 2018) [25].

As stated by Das et al. (2019) milk products do not appear as food source rich in phenolic components [11]. *Aronia melanocarpa* is a fruit that contains a large amount of anthocyanins and polyphenols (Kokotkiewicz et al., 2010) [31]. The fruit has a high antioxidant capacity due to the content of a large amount of phenolic compounds (Kim et al., 2018) [30], which have been found to reduce oxidative stress in humans (Denev et al., 2012) [12]. Aronia berries are popular in Europe, where they are used as a functional food ingredient and as a colour additive (Kokotkiewicz et al., 2010; Gurčík et al., 2023) [31, 20]. It can be applied directly to dairy products to improve nutritional quality and sensory qualities (Nguyen & Hwang, 2016; Jurikova et al., 2017; Kim et al., 2018) [38, 27, 30]. In addition, inclusion of fruits like *Aronia*

melanocarpa in yoghurt enhances the stability of the product and its microbiological safety as stated by Cusmenco et al. (2021) showing a synergism with *Streptococcus thermophiles* and *Lactobacillus delbrueckii subsp. bulgaricus* [10].

Because food choice is a complex process that is influenced by personal impression, environment, and food-related factors and their interactions (Hsu & Kao, 2009; Köster, 2009) [22, 32], consumers may have different consumption goals even for one same product. Consumers often choose different yoghurt flavours to satisfy different needs (Gullo et al., 2019) [19], including their favorite tastes (Hsu & Lin, 2006; Kim et al., 2002) [23, 29].

Incorporating the opinion of potential users early in the new product development process has been identified as one of the critical factors (Cooper, 1999; Bhuiyan, 2011; Van Kleef et al., 2005; Morgan et al., 2018) [9, 4, 48, 36].

The purpose of the study is to investigate various aspects considered to be decisive in the perception of a new product - buffalo yoghurt with aronia, by potential consumers. This would contribute to the improvement of product concepts during the early stage of new product development.

MATERIALS AND METHODS

Preparation of the Yoghurt

Fresh milk. The study was performed with buffalo milk, obtained from purebred Bulgarian Murrah buffaloes from II lactation, reared in the herd of the private farm in Dimitrievo village. Milk samples were obtained in the morning and the evening, proportionally to the milk yield, according to rules for milk sampling.

Starter cultures. A starter culture, containing *Streptococcus thermophilus* and *Lactobacillus delbrueckii ssp. bulgaricus* (Lactina 17, Bankya, Sofia, Bulgaria) ready for direct vat inoculation were used for yoghurt preparation. The buffalo's yoghurt was prepared in laboratory conditions.

Yoghurt preparation. The milk was pasteurized (95°C/30 min), cooled to 45°C, and inoculated with 1.5% yoghurt culture consisting of *Lactobacillus delbrueckii ssp. bulgaricus* and *Streptococcus thermophilus* (Lactina 17, Bankya, Sofia, Bulgaria). The raw milk was divided into three lots – control and 2 experimental. Prior to adding the starter, 3 and 5 g/kg fruit juice from aronia was added to the experimental milk samples. The samples were then cultivated at 42°C until coagulation, then cooled and stored in a refrigerator at 4–6°C.

Design of the Survey

The developed milk product was evaluated by respondents of different age groups to find out how its characteristics are perceived by consumers. For this purpose, an anonymous survey was prepared on the territory of Trakia University-Stara Zagora in the period February - September 2021. After distribution of a written announcement about the tasting of the developed milk product, employees and students of the university, who voluntarily expressed a desire to participate in the research, tasted yoghurt with the addition of 3% and/or 5% aronia juice and anonymously filled in the prepared questionnaire. The respondents were informed that all data will be only reported in the aggregate. They were able to withdraw from the survey at any time without giving a reason. The products tested were safe for consumption. The study did not need approval from Ethics Committee.

A total of 26 completed questionnaires were received, in which the questions were grouped into several sections. The first section (includes questions numbered 1 and 2) concerns the demographic characteristics of the respondents such as age and gender. The second section (questions 3 to 8) is related to the dietary habits and preferences of the respondents regarding dairy products - milk consumption; type of milk consumed (fresh, sour, both types); source of the consumed milk (store, farm, own home production); time of day to consume milk (morning, evening, at other times); liking milk with added fruit and/or flavourings; preferences regarding additives in milk (chocolate, strawberry, aronia, other additives, no additives). The third section of questions (numbered 9 to 12) examines the visual perception of the product by consumers prior to tasting based on colour, texture, uniformity and externally noticeable defects. The fourth section (questions 13 to 15) ascertains the

consumer's perception of the product after tasting in terms of its aroma, texture and taste. The last part of the survey (questions 16 to 19) establishes the general assessment of the developed dairy product with additives - liking by consumers (on a five-point Likert scale); interest in purchasing the product; product flaws according to individual taste; type of flavoured product (with 3% or 5% aronia juice added).

Statistical analysis

For statistical analysis, SPSS was performed on five batches. The obtained data were subjected to statistical processing (IBM SPSS-Inc., 2019, SPSS Reference Guide 26 SPSS, Chicago, USA). The investigated parameters were subjected to descriptive analysis (frequency distribution), Student t-test and Chi-square analysis. A two-sided $p<0.05$ was considered significant (CI 95%).

RESULTS AND DISCUSSIONS

The demographic profile of the respondents is presented in Table 1.

Age variations are presented in two groups, with the majority of respondents falling into the group under 24 years old (76.9%), representing students.

There is no drastic difference in the distribution by gender, with women making up 57.7% and men - 42.3%.

The habits of the respondents related to the consumption of milk in their country are of interest, as more than half of them, 53.8%, include in their diet both pasteurized milk and yoghurt, as the main source of dairy products on their table are shops (76.92 % of respondents), and for few of them - direct supply from a farm (3.84%) or homemade (3.84%).

The respondents mainly consume pasteurized milk or yoghurt in the morning (42.31% of respondents), a smaller share of them (11.54%) consume milk in the evening, while almost a third (30.77%) include milk in their diet at different times during the day.

The survey of consumers' personal preferences regarding the inclusion of additional ingredients in milk with a change in aroma and taste shows that the majority of them, 88.46%, like such additives.

Table 1. Demographic profile and habits for milk consumption* of the participants in the survey

Respondents` Demographics	Count	Percentage
Age (years)		
1) 19-24	20	76.9
2) 30-60	6	23.1
Gender		
1) Male	11	42.3
2) Female	15	57.7
Milk consumption		
1) Pasteurized milk	3	11.54
2) Yoghurt	9	34.6
3) Both types	14	53.8
Source of the milk consumed		
1) Market	20	76.92
2) Farm	1	3.84
3) Homemade	1	3.84
4) More than one	4	15.38
Daytime of milk consumption		
1) Morning	11	42.31
2) Evening	3	11.54
3) Other time of the day	8	30.77
4) More than one	4	15.38
Liking of added flavours to milk products		
1) Yes	23	88.46
2) No	3	11.54
Preferences for flavours in milk products		
1)Chocolate	0	0
2) Strawberry	8	30.77
3) Aronia	2	7.69
4) Other – forest fruits, banana, peach	6	23.08
5) More than one	7	26.92
6) No added flavours	2	7.69
New product tasted		
1)With 3% added aronia	14	53.8%
2)With 5 % added aronia	12	46.2%

*Values may not total 100% for each variable because of nonresponders and rounding of values
Source: Authors` research.

The main flavours preferred by the respondents were strawberry (30.77%), berries (23.08%), aronia (7.69%) or several different flavours from those mentioned (26.92%). The share of respondents who do not like additives to milk is insignificant - 7.69%. These results show that yoghurt consumption is, on the one hand, a factor influenced by age and gender, and on the other, it depends on consumer habits (source of supply and presence of supplement). Our findings are in line with those found by Allen (2012) on Canadian yoghurt consumer preferences [1]. Similar to our findings Kumari et al. (2020) pointed out the demand for new flavours and healthy products with reduced sugar content expressed by dairy consumers [33]. The preferences for added fruit contents to yoghurt could be indirectly explained by the

conscious choice of fruit sweetness to replace sugar due to health concerns as added sucrose to milk was found to increase caries risk (Zohoori et al. 2020) [52].

None of the sour milks offered for tasting has a negative rating for unpleasant taste. Most tasters found that the taste of both yoghurt variants with 3 and 5% addition of aronia juice was pleasant. *Lactobacillus bulgaricus* plays a major role in the development of the organoleptic properties of yoghurt (Marty-Teysset et al. 2000) [35]. In fact, according to Tamime and Robinson (1999) [46] and Sudheer et al. (2006) [45], the lactic acid produced during yoghurt preparation helps to break down the casein micelles, resulting in the formation of a gel, giving the yoghurt a characteristic and distinct flavour, contributing to the flavour and aroma of the yoghurt.

Examining the relationship between the demographic profile and the eating habits of the respondents and their visual and organoleptic perceptions of the developed milk product with added aronia juice through the chi-square analysis, it turns out that for 6 out of a total of 7 studied characteristics, a statistically significant relationship is found ($p<0.05$).

Colour is an important characteristic in the selection of yoghurt-milk products, it reflects the degree of consumer preference (Pathare et al. 2013; Reshmi et al. 2012; Chye et al. 2012) [39, 41, 8]. The data analysis shows that there is a strong relationship between the visual perception of the colour of the product and the age of the respondents ($\chi2$ =15.484; df=6; Crammer`s V=0.772; p=0.017), the type of milk consumed by them ($\chi2$ =31.825; df=12 Crammer `s V=0.0.782; p=0.001), as well as the time of day when they consume milk ($\chi2$ =34.543; df=18; Crammer`s V=0.665; p=0.011) (Table 2).

In similar sensory analysis in other studies (Feknous et al. 2021) [16] it was found that the flavoured yoghurts did not receive negative rating as to an unpleasant colour; although some of our respondents perceived the colour of the product with added aronia content as unpleasant, their share was quite low (3.8% of all).

Table 2. Relationship between the demographic profile and the eating habits of the respondents and their colour perceptions of the tasted buffalo yoghurt with aronia

Age	**Colour perception of the milk product vision**									
	Attractive	Dark	Light pink/purple	Pleasant	Specific colour	Unpleasant	Nonanswered	Total	Chi-Square	Sig.
19-24 years	7.7%	7.7%	7.7%	42.3%	7.7%	3.8%	0%	76.9%	15.484	0.017
30-60 years	0%	0%	11.5%	0%	3.8%	0%	7.7%	23.1%		
Total	7.7%	100%	19.2%	42.3%	11.5%	3.8%	7.7%	100%		
Type of milk consumed										
Milk	7.7%	0%	3.8%	0%	0%	0%	0%	11.5%	31.825	0.001
Yoghurt	0%	0%	15.4%	7.7%	3.8%	0%	7.7%	34.6%		
Both	0%	7.7%	0%	34.6%	7.7%	3.8%	0%	53.8%		
Total	7.7%	7.7%	19.2%	42.3%	11.5%	3.8%	7.7%	100%		
Daytime of milk consumption										
Morning	0%	3.8%	7.7%	19.2%	11.5%	0%	0%	42.3%	34.543	0.011
Evening	0%	0%	3.8%	0%	0%	0%	7.7%	11.5%		
Other time	7.7%	0%	7.7%	15.4%	0%	0%	0%	30.8%		
More than one answer	0%	3.8%	0%	7.7%	0%	3.8%	0%	15.4%		
Total	7.7%	7.7%	19.2%	42.3%	11.5%	3.8%	7.7%	100%		

Source: Authors` research.

Perception of the vision of the product before tasting is strongly negatively influenced by the age of the respondents (r= -0.7255, p= 0.008), as the colour of the product before tasting is perceived as pleasant by people of a younger age.

Gender differences also influence personal perceptions, with female respondents finding the colour of the offered product with added aronia juice as attractive (t[26]= -6.5133; p=0.000) and after tasting describing its taste as sweet (t[26]= -4.5233; p=0.000). A statistically significant difference is also found in the group of respondents who mainly consume yoghurt and those who find the colour of the product attractive (t[26]= -2.8587; p=0.006) and its taste as sweet (t[26]= -2.756; p=0.008). There is a similar relationship between the investigated indicators of attractive colour (t[26]= -3.0664; p=0.004) and sweet taste (t[26]= -3.0071; p=0.004) and respondents who have a habit of consuming milk in the evening.

The aroma indicator of the dairy product offered for tasting also turns out to be significantly influenced by some of the

respondents' personal characteristics such as the type of milk they consume ($\chi 2$ =14.051; df=4; Crammer's V=0.520; p=0.007) with a strong negative correlation showing, that those who mainly consume cow's yoghurt find the aroma of the offered product pleasant (r= -0.8783, p= 0.000) (Table 3).

Table 3. Sensor perception of the aroma of the newly developed buffalo yoghurt with aronia and its connection to the consumers` preferred type of milk

Type of milk consumed		**Aroma perception of the tasted milk product**				
	Pleasant	Specific	Unable to determine	Total	Chi square	Sig
Milk	3.8%	7.7%	0%	11.5%	14.051	0.007
Yoghurt	27.0%	0%	7.7%	34.6%		
Both	50.0%	3.8%	0%	53.8%		
Total	80.8%	11.5%	7.7%	100.0 %		

Source: Authors` research.

The t-test also confirmed a statistically significant difference between the classification of the aroma as pleasant and the group of cow's milk yoghurt-preferers (t[26]= 4.0407; p=0.000) and those who tasted the new product with 3% aronia addition (t[25]= 7.7161; p=0.000).

Our observations are consistent with the study of Galeboe et al. (2018) [17] who found that inclusion of fruit content improved the aroma of yoghurt of different from cows dairy animals whose milk usually has specific aroma and flavour and lower consumers' acceptance.

Taste and texture are the most important qualities of yoghurt for consumer acceptance. Many factors affect the flavour and texture of yoghurt, such as starter, incubation temperature, process conditions, and different milk components used in production (Madora et al. 2016) [34].

Consumers' perception of the texture of the tested product with added aronia flavour was strongly influenced by their personal characteristics (Figure 1). It turns out that the perception of the texture of the product differs significantly between consumers, with a significant difference in the group of women (t[26]= -13.4538; p=0.000) and those who consume yoghurt (t[26]= -11.1209; p=0.000). p=0.000).

The acceptance of yoghurt based on its high quality of texture could be enhanced by adding specific fruit content which affects good texture of the product as stated by Sansawat et al. (2022) [43]. Chadare et al. (2019) recommended some functional milk products subjected to food-to-food fortification with plant and fruit derivate to be sensory evaluated at different rates of added fortifying ingredients [7].

Such sensory analyses found that consumers attributed higher scores for texture, aroma and colour to flavoured yoghurt with highest values of added components of plant origin (Wairimu et al. 2022) [49]. Focused especially on buffalo yoghurt with incorporated bioactive plant-derived substances Dhawi et al. (2020) [13] found that at the final stage of tasting the various buffalo yoghurt samples retained high acceptability. On the contrary, we found significant differences in the preferences for our new product in favor of the samples with lower concentration of fruit content (3% aronia juice included) and the consumers` perception of texture with separated whey (t[26]= -12.876; p=0.000), sweet taste (t[26]= -4.665; p=0.000), and overall liking (t[26]= -11,738; p=0.000).

The high levels of texture parameters for the buffalo yoghurts could be related to the higher levels of protein and total solids in buffalo milk. Firmer and more consistent, viscous and cohesive yoghurts are more accepted by consumers, and hence, are considered to have high textural quality (Patrignani et al. 2006) [40]. Positive effect on the texture of buffalo yoghurt was attributed also to added ingredients in different concentration (3% and 5%) leading to creamy mouth-feel and a homogenous good texture as described by Huang et al. (2020) [24].

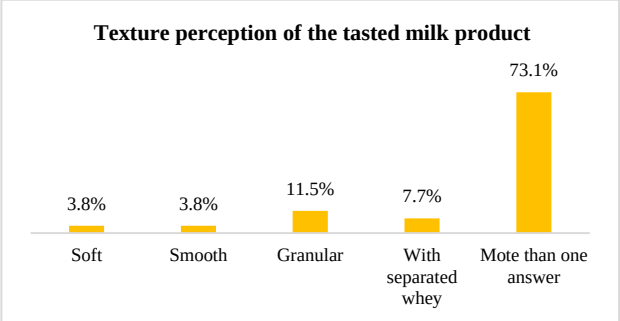


Fig. 1. Respondents` texture perception of the tasted yoghurt
Source: Authors` research.

Comparing the offered yoghurt with added aronia with the ideal dairy product according to their personal preferences, consumers found certain disadvantages, and their perceptions were moderately related to the type of milk they usually consume ($\chi 2$ =21.275; df=12; Crammer's V=0.640; p =0.047) and more specifically – the consumption of yoghurt (t[26]= -2.2496; p=0.003) (Table 4).

Table 4. Respondents` eating habits and their perceptions of the disadvantages of the tasted buffalo yoghurt with aronia flavour

Type of milk consumed	**Consumer`s perception of the product disadvantiges**									
	Frui	Gra nula	No defe	Not eno	Stro	Unp leas	Non -	Total	Chi square	Sig.
Milk	0%	0%	7.7%	0%	3.8%	0%	0%	11.5%	21.275	0.047
Yoghurt	3.8%	0%	11.5%	11.5%	0%	7.7%	0%	34.6%		
Both	0%	3.8%	3.8%	7.7%	0%	30.8%	7.7%	53.8%		
Total	3.8%	3.8%	23.1%	19.2%	3.8%	38.5%	7.7%	100.0%		
Liking of milk with added flavours										
Yes	0%	3.8%	23.1%	19.2%	3.8%	38.5%	0%	88.4%	26.000	0.000
No	3.8%	0%	0%	0%	0%	0%	7.7%	11.5%		
Total	3.8%	3.8%	23.1%	19.2%	3.8%	38.5%	7.7%	100.0%		

Source: Authors` research.

The dependence of this indicator on the general attitude of the respondents towards milk with additives is extremely strong ($\chi 2$ =26.000; df=6; Crammer's V=1.000; p=0.000), more precisely the group of respondents who like the additional flavours (t[26]= -5.9697; p=0.000).
As visible from Table 4 the level of sweetness of the product is an important factor for consumers` perceptions which found confirmation in the study of Johansen et al. (2010) [26] who stated that sweetness of flavoured yoghurt impacted the product acceptance. Moreover, less sweet and plain yoghurts were rated as least preferred after taste by Dias et al. (2020) [14].
The final assessment of the participants in the study after a visual and organoleptic examination of the offered product is based on various factors, of which their personal preferences regarding the types of added flavours are statistically significant ($\chi 2$ =44.764; df=20; Crammer's V=0.656; p=0.001) (Table 5). A statistically significant relationship was found between the gender of the respondents and the evaluation of the tasted product, with women stating that they liked yoghurt with added aronia (t[26]= -12.2022; p=0.000).

Table 5. Overall acceptance of the tasted buffalo yoghurt based on the respondents` preferences for added flavours

Preference for added flavours		**Overall consumer`s perception of the tasted milk product**						
	Dislike it	Like it	Like it very much	Neither like nor dislike	Not answered	Total	Chi square	Sig.
Chocolate	0%	0%	0%	0%	3.8%	3.8%	44.764	0.001
Strawberry	0%	15.4%	11.5%	3.8%	0%	30.8%		
Aronia	0%	0%	7.7%	0%	0%	7.7%		
Other flavours	0%	7.7%	0%	15.4%	0%	23.1%		
More than one	3.8%	11.5%	0%	11.5%	0%	26.8%		
No added flavours	0%	3.8%	0%	3.8%	0%	7.7%		
Total	3.8%	38.5%	19.2%	34.6%	3.8%	100.0%		

Source: Authors` research.

Data analysis found that there was a moderate negative correlation between Type of dairy products consumed and Intention to purchase the tasted product (r= -0.6299, p= 0.028), with respondents who consume more yoghurt being more likely to buy the tasted product if it is available on the market. This purchase intention could be linked to the increased demand for functional yoghurts by consumer as stated by Dhawi et al. (2020) [13] who studied the characteristics of buffalo yoghurt fortified with bioactive components of plant origin. Earlier studies on buffalo milk products also indicated that the higher the respondents' level of Product Knowledge is, the higher their Intention is to buy these products (Cazacua et al. 2014) [6]. Still, consumer purchasing preference was found to be positively affected by the availability of the dairy products in terms of convenience (Bahety et al. 2022) [3].
The statistical dependencies found in this study between demographic variables, sensory perceptions, and purchasing intentions can be further explained with regard to the consumer behavior theory. Based on the theory of planned behavior, sensory experiences are found to influence consumers' attitudes toward a product, which in turn leads to modification of purchase intentions and behaviors (Köster, 2009) [32]. The strong relationship between age, milk consumption habits, and visual perception of product color (χ^2=15.484; p=0.017) supports the argument that consumer evaluation processes are not entirely objective but they are also formed by personal

experiences and contextual expectations (Hsu & Kao, 2001; Gullo et al., 2019) [22, 19]. Similarly, the statistical results linking gender and habitual milk consumption patterns with perceptions of aroma and texture of the buffalo yoghurt with aronia, indicate that these specific sensory attributes serve as key evaluation criteria that activate respondents` reactions towards product acceptance (Bolini et al., 2025) [5]. The observed correlation between yogurt consumption frequency and purchase intention of the new product, corresponds to previous research emphasizing that familiarity and prior product knowledge are strong predictors of purchasing decisions, especially in dairy markets (Cazacua et al., 2014) [6].

The results obtained on the perception of the manufactured buffalo yoghurt with aronia by the potential consumers show that the sensory evaluation stimulates purchase intention more than external cues such as brand name or packaging labels, especially when consumers have the opportunity to taste the product. Such primary effect of the yoghurt sensory quality on the purchase intent is also confirmed by Johansen et al. (2010) [26].

CONCLUSIONS

Consumer perception research is fundamental to understanding consumer buying habits and desires, which in turn contributes to industry marketing opportunities.

The combination of yoghurt and juice represents a new direction in the development of dairy products with fruit additives. New dairy products with added nutritional value meet consumer demand for a healthy lifestyle. Yoghurt milks produced with aronia juice represent an example of a dairy product with a very high nutritional and functional value, which is highly appreciated by potential consumers.

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EFFECTS OF CROP DIVERSIFICATION ON FOOD SECURITY STATUS OF CASSAVA-BASED FARMING HOUSEHOLDS IN OGUN STATE, NIGERIA

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Abstract

The reliance of Nigerian smallholder farmers on a narrow range of crops has heightened their vulnerability to food insecurity. This study investigated how crop diversification influences the food security status of cassava-based farming households in Ogun State. Using a multi-stage sampling approach, 240 cassava-based farmers were selected across the Ijebu Ode and Abeokuta ADP zones. Primary data on socio-economic characteristics, level of crop diversification, and household food consumption were collected through a semi-structured questionnaire. The analysis of data was carried out using descriptive statistics, the Herfindahl-Hirschman Index (HHI), the Foster–Greer–Thorbecke (FGT) Index, and a logit regression model. The results showed that 63.8% of the farmers were male, 90.0% married, and 40.0% had secondary education, with an average age of 50 years, 21 years of farming experience, 1.7 hectares of farmland, and a household size of five persons. More than half (52.5%) had access to credit, 75.0% belonged to cooperative associations, and 85.0% accessed extension services. HHI results reveal that 60.0% of farmers were highly diversified, with an average HHI index of 0.099. FGT results reveal that 83.8% of households were food insecure, while 16.2% were food secure. Logit regression results showed that household size ($\beta = -0.256$, $p<0.05$), crop diversification ($\beta = 0.365$, $p<0.01$), and access to credit ($\beta = 1.563$, $p<0.01$) significantly influenced household food security. The study concluded that crop diversification alone did not ensure food security and recommended credit support, extension training on crop combinations, and family planning to enhance food security.

Key words**:** *crop diversification, food security, Logit regression and cassava-based farming, Nigeria*

INTRODUCTION

Agriculture remains a cornerstone of Nigeria's economy, supporting the livelihoods of nearly 70% of the population and contributing about 24% to the national gross domestic product [34]. Among staple crops, cassava (*Manihot esculenta*) is of strategic importance. Nigeria is the largest producer globally, with an annual output exceeding 60 million metric tons [15]. Cassava provides a vital source of carbohydrates and income for millions of households and serves as the basis for widely consumed food products such as garri, fufu, and starch. Despite its economic and nutritional significance, cassava-based farming households in Nigeria, particularly in Ogun State, remain vulnerable to food insecurity [8].

According to the World Food Summit of 1996, food security is achieved when all people, at all times, are able to obtain adequate, safe, and nutritious food that satisfies their dietary requirements and supports an active and healthy lifestyle. Yet, this remains a challenge for rural households in Nigeria, where inadequate access to agricultural inputs, poor infrastructure, climate variability, and market instability persist [30]. In cassava-producing regions such as Ogun State, many households depend heavily on mono-cropping. This reliance on a single crop exposes farmers to production and market risks, undermines income stability, and restricts dietary diversity. Crop diversification has been increasingly recognized as a viable pathway to enhance food security. By cultivating a variety of crops, farming households can spread production

risks, improve soil health, control pests and diseases, and stabilize household income. Diversification also contributes to dietary diversity, thereby addressing both the availability and utilization dimensions of food security as affirmed [19] in Malawi. Empirical studies have demonstrated that diversification strengthens household resilience to shocks and positively influences food security outcomes as specified [3] in Benin, [18] in Zimbabwe, [11] in Ghana, [20] in Bangladesh and [22] in Cameroon.

In spite of its recognized potential, there is still limited evidence on how crop diversification contributes to improving food security among cassava-based farming households in Nigeria. This research seeks to fill that gap by assessing the effects of crop diversification on the food security status of cassava-based farming households in Ogun State. The study provides empirical insights that can guide policy interventions aimed at reducing food insecurity in rural areas and supports the realization of the Sustainable Development Goals, particularly those centred on eradicating hunger and poverty through sustainable agricultural development.

MATERIALS AND METHODS

Study Area

The study was conducted in Ogun State, Nigeria, which lies between latitudes 3°30′ N and 4°30′ N and longitudes 6°30′ E and 7°30′ E, and comprises 20 Local Government Areas. The state is located in the humid tropical lowland zone and experiences two distinct seasons. The dry season lasts from November to February, while the rainy season covers the remaining months of the year. Annual rainfall ranges between 1,200 mm in the north and 1,470 mm in the south, while temperatures vary from 23°C in July to 32°C in February. Vegetation cover includes derived savannah in the north, rainforest in the central zone, and mangrove swamp in the south. The state covers 16,762 square kilometers, shares borders with the Republic of Benin, Lagos, Ondo, and Oyo States, and had a population of 3,751,140 according to [21]. For agricultural administration, the Ogun State Agricultural Development Programme (OGADEP) divides the state into four zones: Abeokuta, Ijebu-Ode, Ilaro, and Ikenne. Ogun State was purposively selected for the study because of its prominence in cassava cultivation and its contribution to national food supply [10].

Data Collection

Primary data were obtained using a semi-structured questionnaire. Information was gathered on household socio-economic and farm characteristics, as well as institutional factors influencing crop diversification. Household characteristics included age, gender, marital status, household size, education, and farming experience. Farm characteristics included farm size and production output. Institutional factors covered access to extension services, credit, and cooperative membership. Data were also collected on the quantity and prices of food items purchased by farmers.

Sampling Procedure

The study adopted a multi-stage sampling approach in selecting respondents. In the first stage, two zones of OGADEP, Abeokuta and Ijebu Ode, were purposively chosen because of their high concentration of cassava farmers. At the next stage, three blocks were randomly selected from each zone, which were Ilugun, Opeji, Ilewo, Isoyin, Ala, and Ijebu Igbo. This was followed by the random selection of four circles from every block, giving a total of 24 circles. In the final stage, 240 cassava farmers were proportionately drawn from the circles based on the number of cassava farmers in each.

Analytical Techniques

Descriptive statistics, including frequencies, percentages, means and standard deviations, were employed to present a summary of the socioeconomic characteristics of the farmers.

Herfindahl Hirschman Index (HHI)

The Herfindahl index (HH) measures crop concentration as the sum of the squares of the acreage or revenue proportion of each crop in the total cropped area or revenue [4]:

$$P\alpha = \frac{1}{n}\sum_{i=1}^{q}\{\frac{z - yi}{z}\}\alpha \dots \dots (2)$$

where: Yj = area/revenue share occupied by the jth crop in total area/total revenue Y. J = total

number of crops, that is, when maximum diversification occurs. The index ranges from 0 (specialization) to 1 (complete diversification). A value above zero indicates diversification.

Foster-Greer-Thorbecke (FGT) Index

This study employed per capita household expenditure as an indicator of welfare and as the basis for establishing the insecurity line. The Foster-Greer-Thorbecke (FGT) index was applied to measure the levels of insecurity among the respondents, in line with the approaches of [16] and [17]. The index is generally expressed as:

$$PCE = \frac{TCE}{HHS} \dots\dots\dots (3)$$

where: Pα = FGT Index where $0 < P \leq 1$; n = total number of respondents which refers to the farm households sampled; q = number of respondents whose expenditure falls below the insecurity line, that is, the insecure households; z = insecurity line; yi = per capita household expenditure of the ith respondent; and α = non-negative parameter that captures the degree of insecurity aversion.

Construction of the Food Insecurity Line

The food insecurity line is defined as the minimum per capita expenditure below which a household is regarded as food insecure. In line with previous studies, per capita expenditure was chosen instead of income because it provides a more reliable and stable measure over time [17]. For this study, the food insecurity line was established at two thirds of the mean per capita household expenditure (MPCHE) in the study area. Households with per capita expenditure below this benchmark were considered food insecure, whereas those with values above the threshold were regarded as food secure. The line was computed as:

$$MPCHE = \frac{THHE}{TNR} \dots\dots\dots (4)$$

$$PL = \frac{2}{3} \times MPCHE \dots\dots\dots (5)$$

$$F_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \dots + \beta_n X_n + \varepsilon_i \dots (6)$$

where: PCE = Per Capita Expenditure, TCE = Total Consumption Expenditure, HHS = Household Size, THHE = Total Household Expenditure, TNR = Total Number of Respondents, MPCHE = Mean Per Capita Household Expenditure, and PL = Food Insecurity Line.

Logit Regression Model

To identify the determinants of household food security, a binary logit regression model was applied, following the approach of [32]. The model is expressed as:

$$F_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \dots + \beta_n X_n + \varepsilon_i \dots (6)$$

where: Fi = food security status of the ith household, taking the value of 1 if food secure and 0 if food insecure; X1 = age of the household head measured in years; X2 = gender of the household head, coded as 1 for male and 0 for female; X3 = level of education measured by the number of years spent in school; X4 = marital status of the household head, coded as 1 if married and 0 otherwise; X5 = household size, expressed as the total number of individuals living together; X6 = farming experience in years; X7 = access to credit, coded as 1 for households with access and 0 otherwise; X8 = extension agent contact measured by the number of visits; X9 = membership of a cooperative association, coded as 1 for members and 0 otherwise; X10 = crop diversification index; and ε = error term. The dependent variable was binary, coded as 1 if a household was food secure and 0 otherwise. The probability that a household is food secure is expressed as:

$$P(F_i = 1) = \frac{e^{Zi}}{1 + e^{Zi}} \dots\dots (7)$$

$$where\ Z_i = \beta_0 + \sum_{j=1}^{10} \beta_j X_j \dots\dots (8)$$

The logit model was employed because it is appropriate for binary dependent variables and offers consistent and efficient estimates of the probability of food security status as influenced by household, farm and institutional characteristics.

RESULTS AND DISCUSSIONS

Socio-economic Characteristics of Cassava-based Farming Households The findings on the socio-economic characteristics of cassava-based farming households are displayed in Table 1.

Table 1. Socio-economic characteristics of cassava-based farming households

Variable	Frequency	Percentage	Mean	Standard deviation
Age				
≤40	45	18.75	50	11.36
41-50	87	36.25		
51-60	60	25.00		
61-70	39	16.25		
>70	9	3.75		
Total	240	100.00		
Gender				
Female	87	36.25		
Male	153	63.75		
Total	240	100.00		
Marital Status				
Married	216	90.00		
Single	6	2.50		
Widow/Widower	18	7.50		
Total	240	100.00		
Household size (persons)				
1-3	45	18.75	5	1.89
4-6	144	60.00		
7-9	42	17.50		
10-12	9	3.75		
Total	240	100.00		
Educational level				
No formal education	18	7.50		
Primary	93	38.75		
Secondary	96	40.00		
Tertiary	33	13.75		
Total	240	100.00		
Farming experience (years)				
1-10	51	21.25	21	12.10
11-20	78	32.50		
21-30	57	23.75		
31-40	42	17.50		
>40	12	5.00		
Total	240	100.00		
Access to credit				
No	114	47.50		
Yes	126	52.50		
Total	240	100.00		
Farm size in acres				
≤2	81	33.75	4.32	3.54
3-4	63	26.25		
5-6	51	21.25		
>6	45	18.75		
Total	240	100.00		
Access to extension agents				
No	36	15.00		
Yes	204	85.00		
Total	240	100.00		
Membership of cooperative society				
No	60	25.00		
Yes	180	75.00		
Total	240	100.00		

Source: Field survey data analysis, 2024.

The age distribution of respondents revealed that 36.25% were within 41–50 years, 25% between 51–60 years, 20% above 60 years, and 18.75% were 40 years or younger, with a mean age of 50 (±11.36) years. This suggests that the average cassava-based farmer in Ogun State is still within the productive age bracket, though their productivity may have begun to decline, potentially affecting diversification and food security outcomes. This finding aligns with [8],

[13], and [30], who emphasized that most cassava farmers in Southwest Nigeria are in their active years. The gender distribution indicates male dominance (63.75%) compared to females (36.25%), which may be attributed to the demanding nature of activities involved in cassava-based farming. Although the dominance of male farmers aligns with earlier findings [27], [30], and [7], the relatively low participation of women could negatively affect household food and nutrition security considering their crucial role in food provisioning.

Marital status showed that 90% of the respondents were married, 7.5% were widow/widowers, and only 2.5% were single. This implies that married farmers often have larger households, which can provide more labour for farming activities. This supports the findings of [7], [2], and [8]. Household size averaged 5 persons, with 60% of households having 4–6 members, 18.75% with 1–3, 17.5% with 7–9, and 3.75% with 10–12 members. Larger households provide family labor for cultivation, enabling diversification and ensuring food availability, though they also increase consumption needs. This result corroborates [2], [13], and [8], who observed that large farm households often utilize family labor to reduce costs and expand operations.

In terms of education, 40% had secondary education, 38.75% primary, 13.75% tertiary, while only 7.5% had no formal education, suggesting high literacy (92.5%) among cassava-based farmers. Education improves the capacity to adopt new technologies, diversify crops, and manage farm resources efficiently, consistent with [7] and [2]. Farming experience was also substantial, averaging 21 (±12.10) years, with 32.5% having 11–20 years, 23.75% with 21–30 years, 21.25% with 1–10 years, 17.5% with 31–40 years, and 5% with over 40 years' experience. Long-term farming experience enhances knowledge, adoption of diversification strategies, and mentoring of younger farmers, thereby improving productivity and food security [7] and [8].

Resource access further shaped production outcomes. More than half (52.5%) of the farmers had access to credit, enabling investment in diverse crops, equipment, and inputs that support diversification and efficiency, confirming [8] and [2]. Farm size averaged 4.32 (±3.54) acres, with 33.75% cultivating ≤2 acres and 26.25% managing 3–4 acres, classifying most as smallholders (<2 ha). This limited scale likely constrains diversification and food security, in line with [5] and [31]. Extension services were accessible to 85% of respondents, facilitating adoption of modern farming practices, which strengthens diversification and further improves food security [13] and [35]. Cooperative membership was also high (75%), enhancing access to inputs, credit, training, and collective bargaining, thereby reinforcing food security and diversification outcomes [8], [2], and [7].

Crop Diversification among Cassava-Based Farmers

Table 2 presents the distribution of other crops cultivated by cassava-based farmers alongside cassava. The findings indicate that maize was the most common complementary crop, cultivated by 55% of the respondents. A smaller proportion of farmers diversified into rice (3.75%), yam (1.25%), potatoes (5.00%), and vegetables (2.50%). Furthermore, 15% of the farmers reported cultivating other crops such as plantain and pineapple, while 17.50% of the respondents did not cultivate any crop besides cassava, thereby practicing cassava mono-cropping. This result corroborates [29], who reported that arable crop farmers were more diversified in their cropping pattern.

Level of Crop Diversification of Cassava-Based Farmers

Table 3 displays the findings on crop diversification as measured by the Herfindahl Hirschman Index (HHI). The analysis shows that 60.00% of farmers practiced high diversification, 22.50% engaged in medium diversification, while 17.50% exhibited low diversification. The mean HHI value of 0.099 indicates low crop concentration, which, when expressed as a crop diversification index (CDi = 1 – 0.099 = 0.901), reflects an average diversification level of about 90%. This suggests that the majority of cassava farmers cultivated several crops in addition to cassava. Such high diversification enables farmers to

mitigate production risks, maximize the use of land, labor, and other inputs, and maintain soil fertility. It also contributes to pest and disease management, yield stability, and resilience against market and climatic shocks, while enhancing household food and nutrition security through varied diets [19].

These findings are consistent with those of [14], [29], and [28], who reported widespread adoption of diversified cropping systems among Nigerian smallholders. However, they contrast with [26], who observed that farmers in the North Central zone often specialize due to agro-climatic limitations.

Table 2. Distribution of cassava-based farmers according to crops grown besides cassava

Crops grown besides cassava	Frequency	Percentage
Maize	132	55.00
Rice	9	3.75
Yam	3	1.25
Potatoes	12	5.00
Vegetables	6	2.50
Other crops (plantain and pineapples)	36	15.00
No other crop (cassava only)	42	17.50
Total	**240**	**100.00**

Source: Field survey data analysis, 2024.

Table 3. Distribution of cassava-based farmers according to their level of diversification (HHI)

Level of crop diversification	Frequency	Percentage
Low diversification/high concentration (>0.25)	42	17.50
Medium diversification/medium concentration (0.15-0.25)	54	22.50
High diversification/ low concentration (<0.15)	144	60.00
Total	**240**	**100.00**
Mean HHI	0.099	
Standard deviation	0.107	
Minimum	0.000	
Maximum	0.407	

Source: Field survey data analysis, 2024.

Food Security Estimates and Indices of Cassava-Based Farming Households

Table 4 presents the Foster-Greer-Thorbecke (FGT) estimates of food security among cassava-based farming households. The results reveal that the average monthly household food expenditure was ₦51,866.25 (±17,443.98), while the average per capita monthly expenditure was ₦10,699.57 (±3,991.88). The estimated food security line, serving as the benchmark for categorizing households, was ₦7,133.05 per person per month. These figures indicate that households devote a substantial share of their income to food, reflecting both the centrality of food in household budgets and the prevailing high cost of food. While the relatively high per capita expenditure suggests reasonable access to food, the large proportion of income spent highlights household vulnerability, as it constrains savings and investments in other welfare enhancing areas such as education, healthcare, and agricultural inputs.

Furthermore, the food security indices presented in Table 4 offer a more detailed understanding of the distribution of food security among households. The headcount ratio indicates that 83.7% of cassava-based farming households experienced food insecurity, whereas 16.3% were classified as food secure. The depth and severity indices were 0.020 and 0.003 respectively, suggesting that although a large proportion of households fell below the food security threshold, the average deficit was relatively modest and the intensity of food insecurity remained low. This suggests that most households experience moderate rather than extreme food insecurity, and that targeted interventions such as financial support, food subsidies, or productivity enhancing programs could effectively lift many households above the

food security threshold. These results align with the studies of [25] and [27], which similarly documented significant food insecurity among cassava farmers in rural areas of South West Nigeria.

Table 4. FGT estimates and indices of food security among cassava-based farming households

Variable	Mean (₦/month)	Std. Dev.	Min	Max
Food expenditure	51866.25	17443.98	23650	90600
Per capita food expenditure	10699.57	3991.877	5840	28800
Food expenditure line	7133.05	0.000	7133.05	7133.05
Headcount	0.837	0.370	0.000	1.000
Depth	0.020	0.048	0.000	0.181
Severity	0.003	0.007	0.000	0.033

Source: Field survey data analysis, 2024.

Food Security Status of Cassava-based Farming Households

Table 5 presents the distribution of cassava-based farming households according to their food security status. The findings indicate that most (83.75%) of households were food insecure, while only 16.25% were food secure. This indicates that most households spent below the monthly food expenditure line of ₦7,133.05, the benchmark used to classify food insecurity.

This high incidence of food insecurity highlights the vulnerability of cassava-based households, even in the presence of crop diversification strategies. The evidence suggests that diversification alone may not guarantee food security, particularly where incomes from diversified crops are constrained by low market prices, high production costs, and limited access to profitable markets. In addition, diversification in many cases is practiced on a small scale, which restricts the potential to generate meaningful surpluses and additional household income. The limited uptake of improved agricultural technologies and inputs further exacerbates these challenges, leading to lower productivity and reduced capacity to achieve sustainable food security.

These results align with the findings of [23], who observed elevated levels of food insecurity among farming households in North Central Nigeria. They also support the evidence presented by [1], [6], and [27], which similarly documented ongoing food insecurity among cassava producing households in Southwest Nigeria.

Table 5. Food Security Status of Cassava-based Farming Households

Food Security Status	Frequency	Percentage	Cumulative Percentage
Food insecure	201	83.75	83.75
Food secure	39	16.25	100.00
Total	240	100.00	

Source: Field survey data analysis, 2024.

Effects of Crop Diversification on Food Security Status of Cassava-Based Farming Households

The results of the logistic regression analysis presented in Table 6 indicate that household size, crop diversification, access to credit, and marital status have a significant impact on the food security status of cassava-based farming households. The model diagnostic statistics (LR chi^2, Prob > chi^2) confirm overall goodness of fit and significance at the 1% level.

The marginal effect of household size shows that an additional household member reduces the likelihood of food security by 0.029 units, implying that larger households face greater pressure on available food resources. This outcome aligns with previous findings [24], [25], [12], [1], [29], and [27], which consistently reported that household size negatively affects food security. In contrast, crop diversification has a positive and statistically significant impact, with a one unit increase leading to an improvement in

household food security of 0.042 units. This finding implies that diversification promotes better dietary quality and supports nutritional adequacy, consistent with the results reported by [18], [3], [19], [29], and [20].

Similarly, access to credit improves household food security by 0.18 units, suggesting that credit availability provides the resources needed to diversify production, acquire inputs, and stabilize income. This corroborates earlier evidence [9], [1], [3], [25], and [19], that financial inclusion enhances both diversification practices and food security outcomes.

Marital status also had a positive effect, with married household heads recording a 0.007 unit increase in food security likelihood compared to their unmarried counterparts. This reflects the benefits of pooled resources, household labour, and a stronger prioritization of food security within married households. The result supports [33] and [1], who observed that marriage improves food security outcomes through resource consolidation and cooperative decision-making.

Table 6. Logistic regression estimate of effects of crop diversification on the food security status cassava-based households

Variable	Coef.	Std. Err.	z	P>z	dy/dx
Age	0.025	0.019	1.350	0.178	0.003
Level of education	-0.051	0.043	-1.180	0.239	-0.006
Gender	0.389	0.470	0.830	0.408	0.045
Household size	-0.256**	0.134	-1.910	0.056	-0.029
Number of extension visits	0.005	0.021	0.220	0.826	0.001
Crop diversification score	0.365***	0.135	2.690	0.003	0.042
Membership of association	-0.385	0.452	-0.850	0.395	-0.044
Access to credit	1.563***	0.488	3.200	0.001	0.180
Marital status	0.064*	0.680	0.090	0.925	0.007
Farming experience	0.107	1.106	0.097	0.923	0.027
Constant	-2.045	1.673	-1.220	0.222	
Diagnostic statistics					
LR chi^2 (10)	34.27***				
Prob > chi^2	0.0002***				
Pseudo R^2	0.1609				
Log likelihood	-89.3741				

Source: Field survey data analysis, 2024
***, ** and * indicates significant at 1, 5 and 10% respectively.

CONCLUSIONS

This study investigated how crop diversification influences the food security status of households engaged in cassava production in Ogun State, Nigeria. The results offer important insights into the factors affecting household food security within a system that is largely dependent on cassava cultivation. The analysis of food security indicated that most households, accounting for 83.75%, spent less than the monthly food expenditure threshold of ₦7,133.05, highlighting the widespread incidence of food insecurity among cassava-based farmers. This finding suggests that although these farmers engage in crop diversification, it has not resulted in substantial improvements in household food security. Factors such as low crop market prices, high production costs, and the limited scope of diversification activities may contribute to this outcome.

The logistic regression results further highlight the specific socioeconomic and institutional factors shaping household food security. Household size was found to negatively influence food security, as each additional member reduced the likelihood of being food secure by 0.029 units, reflecting the pressure of consumption needs on household income. In contrast, crop diversification had a positive and significant impact, with each additional unit associated with a 0.042 unit increase in food security, highlighting its contribution to dietary

variety and nutritional adequacy. Similarly, access to credit enhanced food security by 0.18 units, underscoring the importance of financial inclusion in supporting investment in diverse agricultural production, the adoption of modern inputs, and the stabilization of household income. Marital status contributed positively, with married household heads recording a 0.007 unit increase in food security compared to unmarried counterparts, underscoring the benefits of pooled resources and collaborative household strategies.

Overall, the findings suggest that crop diversification, though beneficial, must be complemented with supportive measures such as improved access to credit, family planning, input subsidies, and functional produce markets to unlock its full potential in achieving food security. Policymakers should therefore design interventions that strengthen farmers' capacity to diversify profitably, enhance value addition to cassava and associated crops, and expand access to inclusive rural financial services. Addressing household size pressures through family planning awareness and nutrition-sensitive agricultural policies will also be crucial in mitigating food insecurity. In conclusion, while cassava remains a vital staple in Ogun State, achieving household food security requires a holistic approach that integrates crop diversification, institutional support, and socioeconomic considerations. Such a strategy will not only reduce the vulnerability of cassava-based farming households to food insecurity but also enhance their resilience and contribution to Nigeria's broader food system.

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AGRICULTURAL CHALLENGES: WHAT RISKS DO SMES FACE IN NORTHWESTERN ROMANIA?

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Abstract

This study investigates the numerous risks faced by small and medium-sized enterprises (SMEs) in the agricultural sector of Northwestern Romania. Based on a comprehensive survey, the research identifies key threats to operational stability and profitability in agricultural businesses. The results indicates the probability of facing financial, climatic, and market-related risks, highlighting the variety of challenges that SMEs has to manage. The assessment of these risks underscores the need to implement effective risk management strategies and provides the foundation for developing organizational processes focused on resilience. The findings also emphasize the need for proactive public efforts to prepare measures to protect agricultural enterprises from a wide range of threats.

Key words**:** *resilience strategies, crisis management, adaptive capacity*

INTRODUCTION

The significance of agriculture in the EU derives from the economy's dependence on it. [3, 11, 17]. It creates jobs in rural areas, protects biodiversity, improves food security and significantly aids environmental sustainability [4]. Small and medium-sized enterprises (SMEs) in this sector are essential for promoting economic development in emerging regions. They address critical issues such as unemployment, food insecurity, inadequate income, and substandard nutrition. In countries like Romania, where agriculture is essential for community well-being and regional development, the impact of SMEs is considerable due to agriculture's contribution to resilience and economic growth [1]. Notably, Romania stands out within the EU as the nation with the highest number of agricultural holdings. As of 2020, the European Union had a total of 9.1 million farms. Romania hosted just under one third of these, with 31.8% of the EU's farms located within its borders [9].

However, Romania's agricultural landscape is characterized by significant land fragmentation coupled with insufficient collaborative efforts [19]. This fragmentation has resulted in a dualistic agricultural structure predominantly composed of small-scale subsistence farms, with a limited number of enterprises equipped to effectively compete in the market [13]. The majority of the agricultural businesses in the region are small-scale and family-operated, frequently reliant on conventional farming techniques. These firms generally lack access to modern technology, advanced equipment and research-driven methodologies. Relying on outdated methods has a negative impact on productivity, competitiveness and environmental resilience [21]. Moreover, the issues of fragmented land ownership and inadequate organizational infrastructure further exacerbate these difficulties.

The primary limitation of operating on plots smaller than 5 hectares restricts owners' ability to generate enough income and profit to invest in modern technology. [2, 16]. Access to financial resources represents another critical barrier; rural communities frequently encounter challenges in obtaining credit, navigating EU funding programs, and securing subsidies that could alleviate financial constraints [20]. In contrast, larger farms tend to exhibit greater sustainability and competitiveness, highlighting the need for structural reforms to address the challenges inherent in this fragmented land structure. To promote a more effective agricultural landscape, it is essential to implement reforms and increase investment in the agricultural

sector, thereby enhancing both productivity and market readiness [22]. The competitiveness of Romania's agricultural sector is closely intertwined with the nation's overall economic development. Significant structural changes particularly in land ownership and agricultural practices have had a profound impact on the agricultural landscape [18]. Furthermore, the implementation of economic reforms, alongside the repercussions of the economic crisis, has exacerbated regional disparities, resulting in varying levels of agricultural competitiveness across different areas [24].

Although small and medium-sized enterprises (SMEs) in the agricultural sector play a crucial role in stimulating economic growth and addressing pressing challenges such as unemployment and food security, they face a variety of significant obstacles that impede their operational effectiveness. Empirical research has identified several factors contributing to the slow growth rates of Agri-SMEs, including limited access to financial resources, inadequate levels of financial inclusion, heightened competition, insufficient capacity to adopt innovative technologies, suboptimal data management practices, and elevated transaction costs in relation to their operational scale. Furthermore, shortcomings in entrepreneurial competencies and ineffective financial management practices exacerbate the difficulties faced by these enterprises in achieving long-term sustainability [1], [8].

As governmental policies progressively transition from compensating agricultural losses to promoting private market solutions for farmers, there is an escalating necessity for the adoption of effective risk management practices within agricultural operations [14]. The risk management strategies implemented by agricultural producers frequently reflect their perceptions of potential hazards and the opportunities that are accessible to them [15]. In contexts characterized by uncertainty, the development of comprehensive risk management capabilities is critical for preserving operational integrity and fulfilling strategic objectives [25].

In order to align with European Union standards, there exists an urgent need to enhance agricultural efficiency and modernize farming methodologies, thereby ensuring both competitiveness and food security [6] [14].

Approximately 45% of Romania's population resides in rural areas, where agriculture continues to be a crucial source of income for several families [10], hence underscoring the significant importance of farming in Romania's countryside [12]. Nonetheless, the industry persists in confronting entrenched challenges that limit innovation and constrain its capacity for growth [7] [5]. The North-West region exemplifies these dynamics strongly. Approximately 47.4% of the population resides in rural areas, where agriculture is essential to local economies, contributing roughly 45.8% of rural income [23].

This study examines the risks confronting agricultural SMEs in Northwestern Romania, with the objective of outlining measures for better governance and the development of more resilient businesses.

MATERIALS AND METHODS

Study Design

This study adopted a quantitative methodology, utilizing a structured survey to assess the perceptions of risks and the interest in developing various resilience strategies among agricultural SMEs in North-West Romania. The questionnaire was carefully crafted to gather important information on risk management perspectives and practices.

Sample Selection

The research concentrated on agricultural SMEs located in the North-West area of Romania, particularly in the counties of Cluj, Bihor, Bistrita-Nasaud, Maramures, Satu Mare, and Salaj. The selection process initially utilized the ListaFirme.ro database, applying filters for the agricultural sector (CAEN code 01) to identify relevant companies. However, the publicly available information on this platform proved limited, particularly in terms of contact details.

To address this limitation, a more comprehensive database was purchased from the Client Solutions Group website

(https://www.clientsolutions.ro/) [26], which included detailed information on 4,445 SMEs companies from the targeted area. Of these, 1,335 had email addresses, while the remainder were listed with phone numbers. Email invitations to participate in the survey were sent to all companies with available email addresses, resulting in 41 completed responses. To increase the response rate, 40 companies were additionally contacted by phone, generating 19 further completed surveys. In total, 60 valid responses were collected for analysis. Participants were assured of confidentiality and encouraged to provide honest and thoughtful answers.

The survey was structured around four key thematic areas:

(i)**Likelihood of encountering risks:** Participants were requested to evaluate the probability of facing various specified risks, evaluated on a scale from 1 (extremely unlikely) to 5 (very likely). This was designed to quantify risk perceptions and identify the most pressing threats.

(ii)**Experience with crisis situations:** Respondents were queried about their experiences with crisis situations in the past five years, specifically whether they had encountered any crises and, if so, to categorize the types of risks faced. This aspect aimed to contextualize their individual experiences within the broader agricultural environment.

(iii)**Impact of crisis situations:** Participants estimated the percentage of total losses incurred due to crises as it relates to their annual revenue during the year of the crisis. This question aimed to ascertain the financial impact of risk events on their operations.

(iv)**Assessment of resilience:** Finally, respondents were asked to evaluate their enterprise's resilience in the face of risk, providing a rating from 1 to 5, where 1 indicates the lowest level of resilience and 5 represents the highest. This component sought to gauge the perceived capacity of Agri-SMEs to withstand and adapt to adverse circumstances. The structured approach of dividing the questions into these four topics allowed for a thorough exploration of the challenges and resilience strategies of agricultural SMEs. Data collected from these questions will facilitate a nuanced analysis of the overarching themes of risk management and resilience within the sector.

Data analysis

Data analysis utilized descriptive statistical methods to identify trends and patterns within responses, providing a comprehensive understanding of prevailing attitudes and strategies in risk management. This structured approach ensured a thorough exploration of challenges and resilience strategies among agricultural SMEs.

Ethical Considerations

Ethical approval was obtained, and informed consent was secured from all participants. Confidentiality and data privacy were rigorously maintained throughout the study.

Limitations

The limited sample size may constrain the generalizability of results. Future research with larger sample sizes is recommended to further validate these findings.

RESULTS AND DISCUSSIONS

This section presents the findings obtained from the survey conducted among agricultural small and medium-sized enterprises (SMEs) located in North-West Romania regarding their perceptions of risk and resilience strategies. The survey was structured around four key thematic areas: the likelihood of encountering risks, experiences with crisis situations, the financial impact of these situations, and the perceived resilience of the enterprises.

(i)**Likelihood of encountering risks:** Participants evaluated the likelihood of facing various specified risks on a scale from 1 (very unlikely) to 5 (very likely). The distribution of risk perceptions across various contexts indicates that agricultural SMEs in North-West Romania consider several risks, including climate change impacts, price fluctuations, market access challenges, and personnel retention issues, as moderate to highly probable. This underscores an urgent need for comprehensive risk management strategies tailored to their specific operational realities. The prevalent perception of these risks highlights a critical requirement for bolstering resilience and adaptability within the

agricultural sector to safeguard it against uncertainties and support sustainable development (Fig. 1).

(ii)**Experience with crisis situations:** When asked about their experiences over the past five years, 80% of respondents indicated that they had encountered a crisis situation (Fig. 2), suggesting that exposure to at least one significant disruption is a common occurrence among agricultural SMEs in the region. The most frequently reported types of risk were market/price risk (78.8%) and production risk (76.9%), followed by financial risk (36.5%). In addition, institutional risks—such as political or legislative instability—were identified by 15.4% of respondents, while human/personal risks (e.g., accidents, illness, divorce) were mentioned by 9.6%. This distribution highlights the predominance of operational and market-related vulnerabilities, while also drawing attention to less frequent but notable contextual and personal challenges. These findings emphasize the need for comprehensive risk management strategies that address both economic and socio-institutional dimensions (Fig. 3).

(iii)**Impact of crisis situations:** Participants were asked to estimate the percentage of total losses due to crisis situations relative to their annual revenue. The data indicated that 38,3% of respondents reported losses of less than 10% of their annual revenue, 46,7% of respondents indicated losses between 10% and 30%, and 38,3% of respondents experienced losses over 30%. This distribution reveals a relatively balanced segmentation between enterprises exhibiting lower financial exposure and those reporting moderate to severe disruptions. While a portion of agricultural SMEs appears to maintain a degree of financial resilience, the prevalence of medium and high-impact losses suggests that a considerable share remains susceptible to crisis-induced vulnerabilities. These findings underscore the need for comprehensive resilience-building policies, including the development of adaptive financial instruments, risk forecasting tools, and targeted institutional support, particularly for enterprises situated in higher-risk categories (Fig. 4).

(iv)**Assessment of resilience:**

When asked to assess their own resilience, 6.7% of respondents considered their businesses to be *very resilient*, while 16.7% rated themselves as *resilient*. In contrast, only 1.7% reported *no resilience*, and 13.3% indicated *very low resilience*. A significant majority—61.7%—characterized their resilience as *moderate*. These findings suggest that although a small segment of agricultural SMEs perceives itself as well-prepared to manage disruptions, most enterprises acknowledge only a moderate or limited ability to cope with adverse conditions. This self-assessment reflects a general awareness of structural or operational vulnerabilities and highlights the need for tailored capacity-building initiatives. Strengthening internal risk management practices, increasing access to advisory support, and promoting adaptive strategies may be crucial to improving the sector's overall resilience (Fig. 5). The following figures offer a visual synthesis of the survey results, illustrating participants' perceptions of key risk categories, their experiences during crisis events, the financial impacts of those events, and their self-evaluations of resilience. These visualizations aim to support a clearer understanding of the risk landscape confronting agricultural enterprises.

Question 1: Please rate the likelihood of facing one of the risks mentioned below (1 - very unlikely, 5 - very likely).

Options:

-Climate change-induced risks (erosion, decline in organic matter, salinization, loss of soil biodiversity, landslides, desertification, flooding, etc.)
-The fluctuating prices of raw materials
-The fluctuating prices of the products you sell
-Health issues affecting crops/animals
-Instability of agricultural policy
-Sudden changes in demand (sharp decrease/increase)
-Difficulties in marketing the production
-Difficulties in retaining personnel.

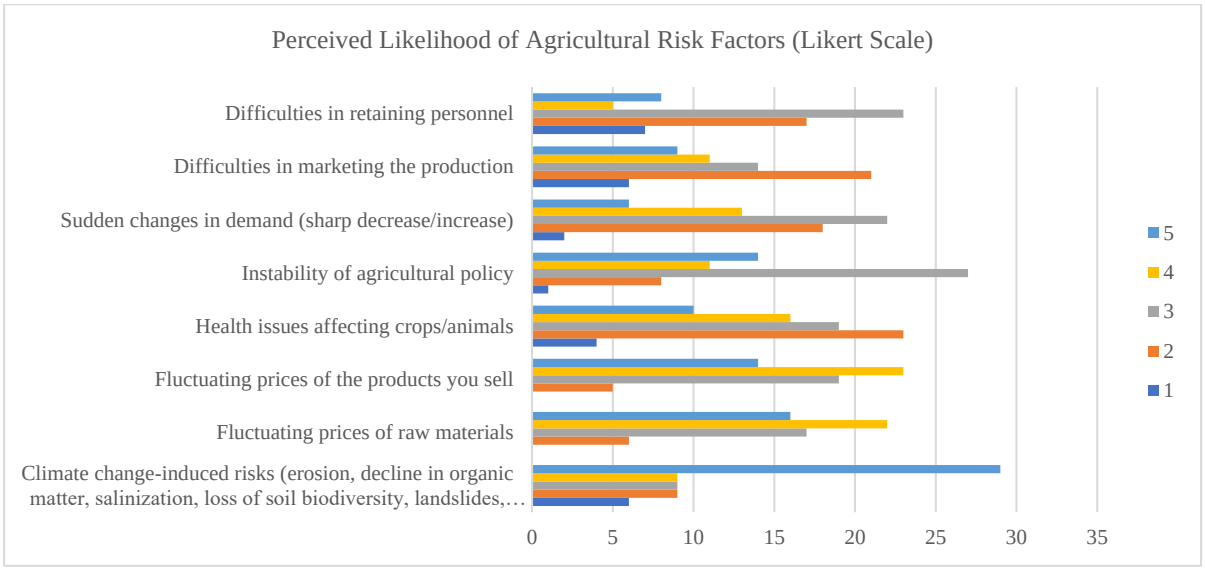


Fig. 1. Risk likelihood distribution
Source: Author's own creation based on the survey results.

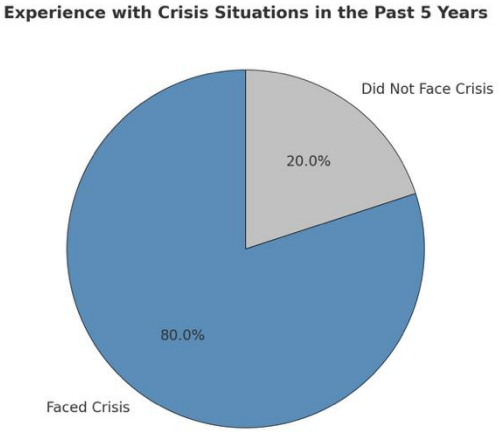


Fig. 2. Experience with crisis situations
Source: Author's own creation based on the survey results.

Question 2: Have you faced crisis situations in the last 5 years?
Options: Yes / No
Question 3: To which category do the risks you have encountered belong?
Options:
-Production risk (the quantity and quality of production have been affected by climatic conditions / the use of fertilizers, etc.)
-Market/price risk (uncertainty of prices/demand)
-Financial risk (loans / financial obligations)
-Institutional risk (political / legislative instability)
-Human/personal risks (accidents, illnesses, divorce)

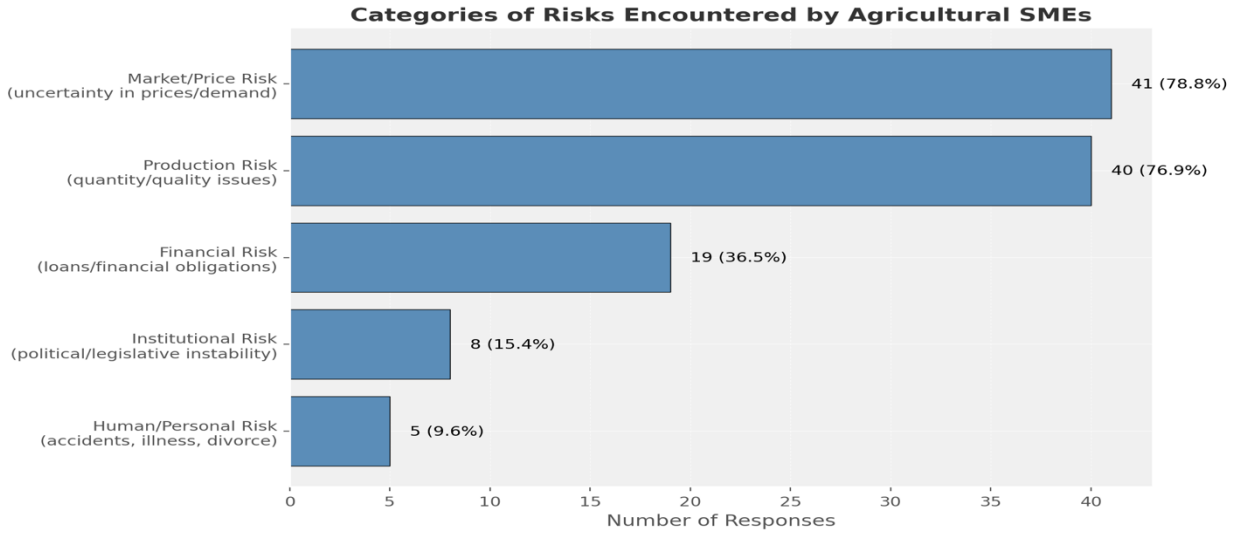


Fig. 3. Categories of risks encountered
Source: Author's own creation based on the survey results.

Question 4: What percentage of your total losses generated by crisis situations represented your annual revenue (in the year the crisis occurred)?
Options:

- < 10%
- >10%- =<30%
- >30%

Question 5:
To what extent do you consider your enterprise to be resilient when exposed to risk situations? Please rate it on a scale from 1 to 5, where 1 represents the lowest level of resilience and 5 represents the highest level.
Options: Likert scale from 1 to 5.

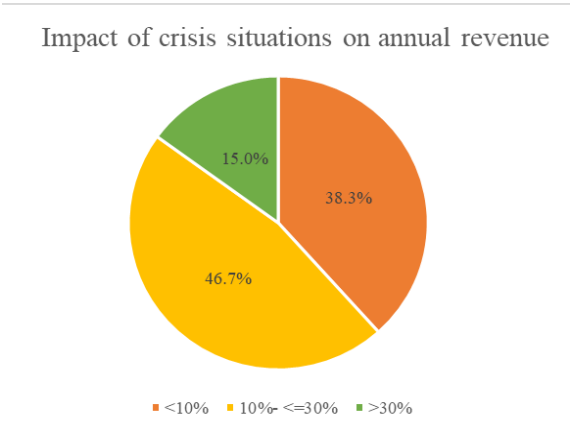


Fig. 4. Impact of crisis situations on annual revenue
Source: Author's own creation based on the survey results.

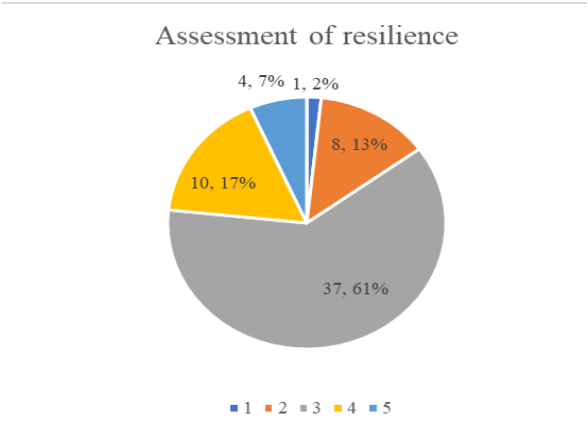


Fig. 5. Assessment of resilience
Source: Author's own creation based on the survey results.

The study results provide substantial insights into the difficulties encountered by agricultural SMEs in Romania's North-West area. The study reveals that a significant percentage of respondents recognize various risks as common, especially those linked to market volatility and environmental changes. This increased risk awareness highlights the necessity for tailored risk management frameworks that serve to the distinct operational realities of these organizations.
The significant number of respondents indicating previous exposure to crisis situations emphasizes an urgent necessity for creation and proposal of effective and flexible crisis response strategies. Although certain businesses demonstrate significant resilience, the findings indicate ongoing vulnerabilities throughout the sector, implying that improved institutional support and focused resource allocation are crucial for enhancing adaptive capacities.
The assessment of resilience further demonstrates that numerous SMEs perceive themselves as inadequately prepared to deal with emerging risks. This finding underlines the necessity of customized risk mitigation methods, supported by efforts to develop a culture of resilience through capacity building, inter-organizational collaboration, and strategic investment in situational awareness.
This study's findings suggest the creation of robust support frameworks and legislative measures to enhance the long-term sustainability and resilience of agricultural SMEs in the context of being exposed to environmental and economic uncertainties. Future research should investigate sector-specific solutions and propose methodological approaches to enhance risk governance and crisis adaptation within this sector.

Implications

This study's results highlight the importance of its findings for stakeholders in the agriculture sector, especially for broader interpretation and practical application. A comprehensive awareness of these consequences is crucial, as they provide significant insights for directing future research, driving the creation of applied projects, and contributing in evidence-based policy making. By acknowledging the potential findings and application of the study, stakeholders have more information to make informed decisions and execute initiatives that improve sectoral resilience and sustainability. The results of this research yield several

implications, emphasizing the importance of tailored strategies and collaborative efforts to effectively address the unique challenges faced by agricultural enterprises in North-West Romania.

Policy development

The findings of this study highlight the necessity for policymakers to gain insight into the current perceptions and practices of risk management among agricultural SMEs. Such understanding can guide the formulation of targeted policies that directly address the specific challenges these enterprises encounter, thereby promoting a more resilient agricultural sector. It is essential for policymakers to prioritize the development of frameworks that support effective risk management strategies, tailored to the unique conditions of the local agricultural landscape.

Capacity building

There exists a distinct requirement for capacity-building initiatives designed to educate agricultural entrepreneurs on best practices in risk management. Training programs that emphasize risk assessment, effective communication with stakeholders, and crisis management can enhance the competencies of SMEs, enabling them to respond more adeptly to potential threats.

Collaboration with agricultural groups and educational institutions can facilitate the creation of workshops and resources that advance this purpose.

Enhanced stakeholder collaboration

These findings highlight the necessity of establishing collaborative initiatives across different government departments, business associations, and financial institutions. To improve risk management strategies and offer vital support to agricultural small and medium-sized firms (SMEs) facing complex challenges, it is possible to build collaborative networks to promote the exchange of knowledge and resources.

Awareness raising

Developing a culture of risk awareness is crucial. This research serves as a catalyst for information dissemination by providing insight on potential threats and the advantages of proactive risk management. By raising awareness, stakeholders can encourage small and medium-sized firms (SMEs) to implement and prioritize resilient risk mitigation strategies.

Future research directions

This research provides a robust basis for future research in agricultural risk management. By providing an exhaustive framework and essential insights, it promotes deeper research into the topic and motivates researchers to expand upon its conclusions. The work acts as an inspiration for enhancing both theoretical and practical comprehension, facilitating the continual improvement of risk management strategies in the agriculture sector.

Evaluation of policy impact

Policymakers are encouraged to implement systematic methods for evaluating the long-term success of risk management programs. Ongoing assessment can produce practical input, facilitating prompt adjustments and ensuring that policies stay aligned with the changing requirements of the agricultural industry.

CONCLUSIONS

This study provides critical insights into the risk perceptions and resilience strategies of agricultural SMEs in North-West Romania. The findings reveal that a significant proportion of respondents recognize various risks, particularly those associated with market fluctuations and the impacts of climate change. This heightened awareness underscores an urgent necessity for the development of effective risk management frameworks that are specifically tailored to the unique challenges faced by these enterprises.

Furthermore, the substantial incidence of reported crisis experiences highlights the pressing need for comprehensive crisis management strategies. While many SMEs exhibit a degree of resilience, the data also indicates vulnerabilities within a subset of these enterprises, suggesting that enhanced support and resources are essential for strengthening their adaptive capacity. The prevalent self-assessment of resilience reveals that a considerable majority of respondents feel inadequately equipped to confront forthcoming challenges. This finding emphasizes the

importance of fostering a culture of resilience through targeted training initiatives and collaborative efforts among stakeholders.

The results of this study have notable implications for policymakers, who need to cultivate a sophisticated comprehension of current risk management techniques inside agricultural SMEs. This understanding is crucial for developing targeted policies that tackle the specific issues faced by these firms, so promoting a more resilient and sustainable agricultural industry.

There is an urgent necessity for capacity-building efforts that provide agricultural entrepreneurs with the tools and knowledge essential for efficient risk management. Training programs focused on essential competencies—such as risk assessment, strategic planning, and stakeholder engagement—can enable SMEs to respond more effectively to new challenges.

The study emphasizes the importance of collaboration across multiple stakeholders. Enhancing collaborative networks across governmental entities, industry associations, and financial institutions can promote the sharing of knowledge and resources, hence improving risk management procedures throughout the sector.

The development of a risk-aware culture within the agricultural community is equally essential. The findings of this research can establish a basis for awareness initiatives that motivate SMEs to emphasize proactive and effective risk mitigation techniques.

Future research could expand on this study by exploring specific tactics that enhance resilience and adaptation. It should evaluate the effectiveness of different risk management strategies in mitigating the numerous threats faced by agricultural operations.

This research enhances the comprehension of agricultural risk management and indicates critical areas for strategic intervention, so contributing to the long-term profitability and sustainability of SMEs in a progressively volatile environment.

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PRODUCT POLICY EVALUATION IN TRADITIONAL FOOD RETAIL SUPPORTING RURAL DEVELOPMENT: "BĂCĂNIA LA STAN" CASE STUDY

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Abstract

This study explored how "Băcănia LA STAN" applies the marketing mix, focusing on product policy and its impact on consumer perception. A survey of 115 respondents showed strong appreciation for product quality and authenticity but highlighted concerns about assortment variety and stability, especially off-season. Prices were seen as medium to high compared to supermarkets, though still lower than typical specialty stores. The demographic analysis revealed a younger, lower-income audience, suggesting a gap with the intended target segment. To address these findings, recommendations include expanding and stabilizing the assortment, adjusting prices to reflect value, refining communication strategies, and strengthening loyalty programs. Together, these steps can help improve brand positioning and support sustainable growth

Key words**:** *product policy, traditional food, consumer perception, specialty retail, rural development*

INTRODUCTION

In the current economic and social climate, more and more consumers are turning their attention to food products that are traditional, natural, and locally sourced [7]. This growing interest is closely tied to a stronger focus on health, rising concerns about the environment, and a desire for products perceived as more valuable and authentic, all factors that play a major role in the choice to buy organic foods [8, 10]. The change we see is important as individuals adopt more handmade items instead of factory made products. This is because people are attempting to define themselves with their preferences and values [5].

Short food supply chains assure are fast tools as traditional, natural and healthy foods to arrive directly to consumers [3, 12]. This is a new and the most efficient marketing strategy as fresh products to reach the customers and assure a direct income to local producers [4, 12].

Local gastronomic points [11] are of high attraction for consumers keen to buy healthy traditional food products and this contribute to the rural development.

Local grocery shops, known in Romania as "băcănii", have stepped up to meet this demand of the city rezidents, acting as a crucial link between small local producers and customers looking for healthier and more authentic alternatives. By highlighting transparency and emphasizing the local story behind each product, these shops are able to build trust with their customers. This trust is particularly important since people's confidence in organic and traditional foods is strongly shaped by their age and by how authentic they believe the products to be [1].

Marketing plays an essential role in this whole process. It is no longer just about simple advertising but has become a key strategic tool that helps shape a brand's position in the market and supports long-term growth. The marketing mix, which includes product, price, place, and promotion, allows businesses to better understand and respond to what modern consumers care about, such as health and environmental impact [7], [8]. It also helps businesses adjust their product selections and pricing strategies to suit different groups of

buyers [5]. Among these elements, product policy stands out as particularly important, as it influences both how valuable customers perceive a brand to be and the emotional connection they feel toward it [6]. Earlier research indicates that consumers link traditional and natural items with elevated quality, nostalgia, and some form of cultural attachment [5]. In Romania, there is a reinforced interest in local food stimulated by national policies designed to assist small-scale producers and advocate for local and regional specialties. Despite this progress, there are still challenges when it comes to making consumers aware of these products, convincing them of their value, and encouraging them to pay premium prices [9].
Băcănia LA STAN [2], situated in Bucharest, the capital of Romania, is a strong example of this trend. Founded in 2024, the store specializes in selling authentic and traditional products. The selections focus on health and well-being, sustainability, and preserving culinary heritage. What makes the shop unique is the precise markings, selective distribution, and advertising based on real stories and genuine traditions.
This study aims to explore how "Băcănia LA STAN" uses the marketing mix, with a particular focus on its product policy and how this supports its brand positioning. To understand this, a quantitative survey was carried out among 115 respondents to learn more about their perceptions, motivations, and possible obstacles to buying.
This research focuses on seeing how consumers perceive both the products and the overall marketing strategy of the store. It also looks at what influences their buying decisions, such as product features, price sensitivity, and the brand image. Based on these findings, the study suggests some ideas for improving the product policy and for building stronger customer loyalty.

MATERIALS AND METHODS

A quantitative descriptive research design was chosen to better understand how customers perceive "Băcănia LA STAN's product policy and overall marketing approach. The main data collection tool was a structured questionnaire created using Google Forms. This questionnaire included a total of 19 questions, divided into four main sections: socio-demographic characteristics, purchasing behavior and motivations, perceptions of product assortment and quality, as well as brand image and loyalty intentions. By organizing it this way, the study aimed to capture a more complete picture of how consumers relate to the store and what factors shape their buying decisions.
The survey was conducted during a span of ten days, from April 29 to May 8, 2025. It was disseminated both online through the store's social media platforms and offline by displaying a QR code linked to the survey at the checkout area of the physical store.
The total number of valid responses collected was 115. The sample gained was diverse in the aspects of age, income, and educational background which gave a deeper understanding of consumer perspectives.
In addition to summarizing the answers from the Likert scales, the study also used graphs like bar charts and pie charts to present the data visually, along with descriptive statistics such as frequencies and percentages. Variables related to purchasing motivation such as local origin and the traditional way of producing the products, were analyzed to see if there were significant connections between them. To examine these possible associations, Spearman's rank correlation coefficient was used.

RESULTS AND DISCUSSIONS

The analysis of the survey data provides useful insights into how consumers see and respond to Băcănia LA STAN's marketing strategy, with a particular focus on its product policy. The discussion below outlines the most relevant results, each one linked to specific questions from the survey.
About brand awareness, at Q1, a significant majority of respondents (92%) reported that they had heard of Băcănia LA STAN. This high recognition rate indicates that the brand enjoys strong visibility and is already well-established in the minds of local consumers.

At Q2, respondents were asked whether they had ever purchased products from the store. The results showed that 66 people shop there frequently and 37 occasionally. In total, over 89% of participants had made at least one purchase, which reinforces the relevance and reliability of their subsequent responses. For the purpose of further analysis, only these 103 valid responses were retained.

Connection between product authenticity and trust in local stores (Q3 and Q4)

Questions 3 and 4 were designed to find out how much importance consumers place on authenticity and local origin, as well as how much they trust local grocery shops. Using Spearman's rank correlation coefficient, the analysis revealed a strong positive relationship (rho = 0.691). In other words, people who value authentic and locally sourced products tend to have greater trust in specialized stores like "Băcănia LA STAN".

This suggests that, for these consumers, authenticity goes beyond just the physical product. It also reflects the overall shopping experience and the emotional bond they develop with the store. Trust appears to be built not only through product quality but also through transparency and the local story behind each item. In this way, authenticity becomes a key factor that strengthens customer loyalty and deepens their connection to the brand (Table 1).

Table 1. Correlation results for Q3 and Q4

Spearman's rank correlation coefficient (rho)	0.691
Degrees of freedom (df)	101
Calculated t-value (tcalc)	9.606
Critical t-value (α = 0.05, two-tailed)	1.984
p-value (significance)	6.6E-16

Source: Author's own research (2025).

The results (p-value < 0.05) support the idea that consumers who care about product authenticity are also more likely to trust specialized local stores, such as Băcănia LA STAN. This finding suggests that strengthening aspects like authenticity and transparent sourcing can play a direct role in building consumer trust and encouraging long-term brand loyalty [1].

Regarding motivations for choosing local products (Q5), freshness was the most frequently selected reason (30%), followed by the desire to support local producers (24%). Health-related benefits (23%) and authentic taste (23%) were also important factors. These findings reveal that both practical and emotional considerations shape consumer choices.

At Q6, trust in product selection was evaluated using a 5-point Likert scale. A total of 67 respondents selected the highest level of trust, while 26 chose level 4.

This means that over 83% of customers place high trust in the store's careful product curation, supporting the hypothesis that a well-chosen assortment strengthens customer loyalty.

Perceived assortment limitations and seasonal availability (Q7)

The answers to Question 7 show that some respondents believe the product assortment at Băcănia LA STAN is not always enough or consistent, especially outside the main seasons. The overall average score for all product-related criteria was 1.34, which suggests a generally positive view, but also points out areas where the assortment could be improved. Out of all the criteria, product quality got the highest score (1.57), which shows that consumers truly value the focus on authenticity and high standards.

On the other hand, the lower scores for sufficiency (1.21), variety (1.30), and stability (1.22) indicate that there is room to make the assortment more diverse and consistent throughout the year (Table 2).

It should be noted that these lower scores are not unusual for specialty shops like "băcănii". Many traditional products, especially fresh fruits and vegetables, depend heavily on seasonality and are harder to keep in stock all year round [7].

Reducing these assortment gaps could help minimize the effects of seasonal fluctuations, better meet consumer expectations, and contribute to stronger customer loyalty over time.

Table 2. Evaluation of product selection by respondents

Product selection criteria	Strongly disagree (-2)	Disagree (-1)	Neutral (0)	Agree (+1)	Strongly agree (+2)	Mean scores
Sufficient	3	4	6	45	45	1.21
Meets needs	1	2	9	46	45	1.28
Carefully chosen	3	4	3	32	62	1.44
Varied	2	3	10	35	53	1.30
Stable	2	3	14	35	49	1.22
High quality	2	1	7	19	74	1.57

Source: Author's own research (2025).

Q8 explored customers' willingness to recommend Băcănia LA STAN to others. An overwhelming 71% indicated they would definitely recommend it, and 27% said they probably would. These figures reflect a high level of satisfaction and brand advocacy among existing customers.

On Q9, which measured satisfaction with product diversity, 53 respondents gave the maximum score and 38 selected level 4. This shows that the store's product range is perceived as sufficiently diverse and well-suited to client expectations.

Preference for product categories (Q10)

According to the responses to Question Q10, cold cuts and cured meats stood out as the most preferred product category among participants.

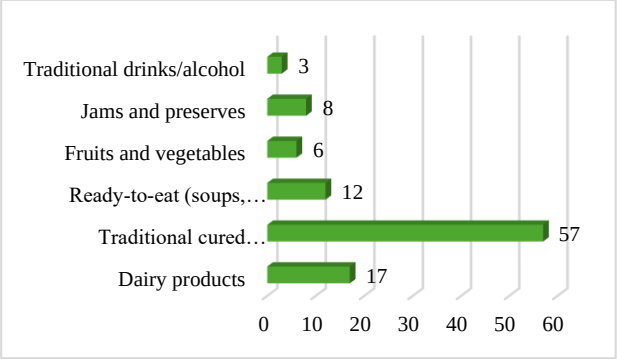


Fig. 1. Preferred product categories among "Băcănia LA STAN" customers
Source: Author's own research (2025).

This preference likely reflects the wider variety of SKUs (Stock Keeping Units) available in this category, as well as its steady availability throughout the year (Fig. 1).

Expanding a product category by introducing new recipes, innovative products, or targeted promotional strategies can help strengthen market positioning and foster repeat purchases [5], [8].

Price perception and market positioning (Q11)

Most respondents mentioned that they saw the prices as medium to high, and they often compared them directly to supermarket prices. They rated this on a Likert scale, where 1 meant "very cheap" and 5 meant "very expensive." (Fig. 2). However, this impression doesn't fully reflect the reality of specialty grocery stores, or groger`s, where higher prices are normal because of the artisanal production methods and higher-quality ingredients. Right now, there is a risk that some customers might see "Băcănia LA STAN's prices as similar to those in supermarkets and not understand the added value of its products. Because of this, it would be a good idea for the store to consider raising its prices to better match those of other specialty shops. Doing so would help clearly position Băcănia LA STAN within the premium segment it belongs to and show customers that the products truly are of higher quality.

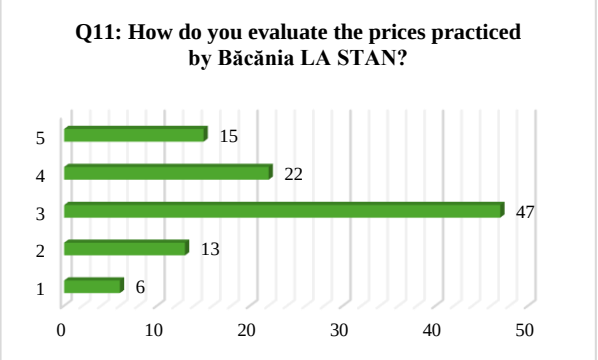


Fig. 2. Consumers perception of the prices practiced by Băcănia LA STAN.
Source: Author's own research (2025).

Raising prices in this way could help strengthen the brand's premium image and prevent possible financial problems that come from setting prices too low. It would also support fair competition in the market and make it clearer to customers why the products cost more. When prices truly reflect the specialty market, it builds trust and helps create a business model that is both transparent and sustainable [8].

In Q12, the importance of transparent packaging and clear labeling was assessed.

More than 80% of respondents considered this aspect to be very important, with 58 selecting the highest score and 26 choosing level 4. These results underline the role of packaging not just as a visual element, but as a key factor in building trust and facilitating purchase decisions.

Q13 asked what information customers value most **on a product label**. The most common responses were "product origin" and "ingredients", both selected by 26% of respondents. Other important elements included expiration date (21%) and nutritional values (17%). Only 10% mentioned information about the producer.

For Q14, we used a Likert scale to evaluate five brand attributes. The highest average score was obtained for "High product quality" (1.44), followed closely by "Authentic local origin" (1.41).

"Product variety" (1.15) and "Value for money" (1.17) received lower, though still positive, scores. The overall average across all five attributes was 1.28, indicating a generally favorable brand image in the eyes of the customers.

Discrepancies in target consumer profile (Q15–Q19)

The socio-demographic analysis of Questions 15 to 19 (Table 3) shows some clear differences between the current survey respondents and "Băcănia LA STAN's ideal target audience. Most of the participants were young adults aged 20–29 (54%), many were students (40%), and about 30% reported monthly incomes below 3,000 RON. By comparison, only 14% were in the 40–49 age group, and just 29% had incomes above 5,000 RON per month.

These results suggest that the current customer base does not fully match the typical profile of buyers interested in traditional, artisanal, or organic products, who are usually between 30 and 55 years old and have higher, more stable incomes [6].

Previous studies have shown that this group is more willing to pay premium prices for authentic and sustainably sourced products [5], [8]. Even though younger consumers are showing more interest in local and natural products, their lower incomes and student lifestyle often mean they buy these products less frequently and spend less money overall [6]. Because of this, Băcănia LA STAN might consider adjusting its marketing and targeting strategies to better connect with core customers who really value quality and can afford to pay higher prices.

In the future, promotional activities could focus more on explaining the true value of the products, highlighting their craftsmanship and health benefits, to attract older and higher-income shoppers. At the same time, the shop can keep younger customers interested by using educational content and interactive experiences, which help build a connection and keep them engaged [6], [7].

Table 3. Socio-demographic profile of respondents

Variable	Categories	Frequency (n)
Gender	Male	53
	Female	48
	Prefer not to answer	2
Age	Under 20	7
	20–29	62
	30–39	5
	40–49	16
Education	High school	43
	Post-secondary	15
	University (BA/MA)	45
Occupation	Student	46
	Employee	45
	Entrepreneur/Freelancer	7
	Unemployed	2
	Other	5
Income	< 3,000 RON	35
	3,001–5,000 RON	38
	5,001–8,000 RON	19
	> 8,000 RON	11

Source: Author's own research (2025).

Improving segmentation and adapting marketing messages could help close this gap, making sure the brand's identity is more in line with what consumers truly expect and value [6], [8].

CONCLUSIONS

This study explored how Băcănia LA STAN applies the marketing mix, focusing especially on product policy and its impact on how consumers see the brand. Overall, the survey results suggest that people have a good opinion about the quality and authenticity of the products, as shown by the higher scores in these areas.

Still, some issues came up around the assortment, especially its sufficiency, variety, and stability during off-seasons, suggesting that there is room for improvement to make the product range more diverse and reliable throughout the year.
Regarding prices, most respondents felt they were medium to high compared to supermarket prices, but still lower than what one would normally expect from specialty stores like "*băcănii"*. This shows an opportunity to gradually adjust prices to better reflect the true quality of the products and to support a premium brand image [5].
The demographic data also revealed a clear gap between the actual customer base and the ideal target group. Since many current customers are younger and have lower incomes, it would be useful for Băcănia LA STAN to adapt its communication and marketing approach to better reach older, higher-income consumers who are more willing to pay for authentic, artisanal products [1].
Based on these findings, a few practical suggestions can be made. First, expanding and stabilizing the assortment could involve introducing new seasonal and non-seasonal items, as well as working with local producers who use greenhouses to provide a steady supply throughout the year. Preserved or dried options might also help keep the selection varied, even outside harvest periods.
Another idea would be to bring prices closer to what is usually seen in other specialty markets. By doing this, the store can better highlight the value and craftsmanship behind its products, while also staying financially sustainable and making loyal customers feel they are getting truequality[8].
Additionally, improving segmentation and marketing messages could help the store better connect with higher-income, more mature customers. Focusing on stories about authenticity, health benefits, and artisanal techniques can make a strong impact. Finally, offering loyalty perks or special membership benefits might encourage customers to return and build a stronger, long-term relationship with the brand.
By putting these ideas into practice, Băcănia LA STAN can get closer to its brand goals, improve customer satisfaction, and support steady, sustainable growth in the future.

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THE EFFECTIVENESS OF CHEMICAL AND BIOLOGICAL FUNGICIDES IN COMBATING DARK BROWN SPOT OF WINTER BARLEY UNDER THE CONDITIONS OF THE WESTERN FOREST-STEPPE OF UKRAINE

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Abstract

The purpose of our research was to determine the cost-effectiveness of using biological and chemical fungicides on winter barley in the fight against the pathogen of dark brown spot in the conditions of the Western Forest-Steppe of Ukraine. To determine the features of the defeat of winter barley plants by this disease during 2021–2023, field studies were used, and to identify the pathogen of dark brown spot, laboratory studies were used. Experimental data were used to assess the reliability of the data obtained. We found that over the years of research, the most common fungal disease of winter barley was dark brown spot (pathogen – Bipolaris sorokiniana Shoem). The highest technical efficiency against this disease on winter barley crops during the years of research was noted in the variant where aviator Xpro 225 EC, k.e. (0.8 l/ha) was used and was 83.5%, and among biological preparations – when using bactofit (2.0 l/ha) + trichodermin SK (2.0 l/ha) and was 58.2%. The largest preserved yield of winter barley during the years of research was obtained in the variants where the chemical preparation aviator Xpro 225 EC, k.e. (0.8 l/ha) and biological preparations bactofit (2.0 l/ha) + trichodermin SK (2.0 l/ha) were used, while the increase in yield was 1.1–1.2 t/ha. The largest conditional net profit over the years of research was obtained in variant where crops were treated with biological preparations, in particular bactophyt (2.0 l/ha) + trichodermin SK (2.0 l/ha) and amounted to 9.9 thousand UAH with a profitability level of 50.8%.

Key words**:** *winter barley, dark brown spot, disease development, economic and technical efficiency*

INTRODUCTION

Agricultural production can be increased through measures aimed at reducing winter grain crop losses from diseases, which reach 25–30% or even more [4, 7].

As domestic and foreign experience shows, the optimal solution to the problem of plant protection from diseases is possible only within the framework of an integrated approach. Ecologically oriented measures for protecting winter cereals from diseases are the introduction of disease-resistant varieties and the use of biological means of protection [9, 17, 18].

The phytosanitary situation of various crops cultivated in the Western Forest-Steppe requires constant phytopathological monitoring [5, 6]. In the conditions of climate change, the importance of protection systems is increasing, which make it possible to prevent the development of diseases or contain them at an imperceptible level [2, 4, 12].

Winter barley grain is of important economic importance, the yield of which can reach more than 10 t/ha, in particular in the EU countries it is 7.0 t/ha, and in Ukraine it is half as low [1, 9, 11].

Like all other cereal crops, winter barley can be affected by various diseases, the most common of which are leaf spots. Yield losses with an intensity of their damage from 50 to 70% are 33-50%. Plant damage by these diseases leads to a decrease in the assimilation surface due to rapid yellowing and death of the affected leaf blades, a decrease in their productivity [1, 4].

Modern systems of chemical protection of agricultural crops from harmful organisms are

based on the repeated use of pesticides throughout the growing season, which potentially creates a certain pesticide load on the agrocenosis. Therefore, biological control agents can be widely used as alternative means of protection against pathogens. Biological preparations, by enhancing plant immunity, contribute to the realization of the potential capabilities inherent in plant varieties [3, 10, 13, 14, 17, 20].

Increasing the productivity of winter barley varieties depends on pre-sowing seed treatment and the use of biological preparations for top dressing in different periods of vegetation. In recent years, the nutrition of most plants is based on the principles of resource conservation, including the use of the best precursors or low doses of the main application of mineral fertilizers, modern biological preparations and growth regulators [3, 8].

Stability of winter barley food grain production with high quality indicators and increased yield in modern conditions is possible only with the introduction of new high-yielding varieties with wide agroecological plasticity and increased adaptive properties to adverse and extreme environmental conditions, resistant to harmful organisms [7,11] and also taking corresponding agricultural technological measures [19].

Studying the impact of biological products on pathogens of winter barley diseases and pests in order to limit their development and reduce the negative impact on the environment, which are used for seed inoculation and fertilizing at different periods of plant development, is becoming particularly relevant in the conditions of modern agricultural production.

MATERIALS AND METHODS

The research was conducted on winter barley crops of the plant protection laboratory on the Zbruch variety at the Institute of Agriculture of the Carpathian Region of the National Academy of Sciences of Ukraine. The area of the study was 100 m^2 (25 m^2 x 4 m), the experiment was repeated four times, the total number of variants was 8.The experiment was carried out on a forest silty loam soil with the following agrochemical characteristics: pHKCl - 5.62, hydrolytic acidity (according to Kappen) - 2.41 mg-eq/100 g of soil, exchangeable calcium - 7.92 mg-eq/100 g of soil, exchangeable magnesium - 0.76 mg-eq/100 g of soil, humus - 2.10%; mobile phosphorus (according to Kirsanov) and exchangeable potassium (according to Maslova) - 145.9 and 169.1 mg/kg of soil, respectively.

In the fields of the plant protection laboratory, an experiment was set up according to the following scheme: 1) control (absolute); 2) control (without seed treatment) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, IV stage + nitroTOP, VIII stage); 3) vincit 050 CS (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, IV stage + nitroTOP, VIII stage) + aviator Xpro 225 EC, k.e. (0.8 l/ha); 4) bactofit (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, IV stage + nitroTOP, VIII stage) + bactofit (2.0 l/ha); 5) trichodermin SK (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, stage IV + nitroTOP, stage VIII) + trichodermin SK (2.0 l/ha); 6) trichodermin–93 (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, stage IV + nitroTOP, stage VIII + trichodermin–93 (2.0 l/ha); 7) bactophyt (2.0 l/t) + trichodermin SK (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, stage IV + nitroTOP, stage VIII) + bactophyt (2.0 l/ha) + trichodermin SK (2.0 l/ha); 8) bactophyt (2.0 l/t) + trichodermin–93 (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+nutrimax, stage IV + nitroTOP, stage VIII) + bactophyt (2.0 l/ha) + trichodermin–93 (2.0 l/ha). Before sowing, winter barley seeds were treated with biological preparations (bactophyte (2.0 l/t), trichodermin SK (2.0 l/t), trichodermin-93 (2.0 l/t) and a chemical fungicide (vincit 050 CS (2.0 l/t)) according to the experimental scheme.The occurrence, spread and development of dark brown spot on winter barley were recorded according to generally accepted methods on the Zbruch variety [4]. Statistical processing of experimental data was carried out using Microsoft Excel programs [16]. A double spraying with the studied biological preparations (bactophyte (2.0 l/ha), trichodermin SK (2.0 l/ha), trichodermin-93 (2.0 l/ha) and chemical fungicide - aviator

Xpro 225 EC, k.e. (0.8 l/ha) was carried out in phases (I - 32 BBCH,
II - 39 BBCH). The technical efficiency of biological and chemical preparations against dark brown spot of winter barley was determined according to the method [15].
The technical effectiveness of pesticides was calculated by the formula [15]:

$$Te = 100 \frac{(Vk - Vo)}{Vk}, \quad .....(1)$$

where:
Vk – indicator of disease development in the control, %;
In – indicator of disease development on the treated variant, %.
To calculate the efficiency, the following were calculated: grain yield, t/ha according to the experimental variants, cost of sold products, thousand UAH/ha; production costs, thousand UAH/ha; conditional net income, thousand UAH/ha; cost of 1 ton of grain, thousand UAH/t; profitability level, %.
When conducting research, the authors adhere to the standards established by the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSIONS

The meteorological conditions that developed during the growing season of winter barley during 2021–2023 differed in temperature regime, amount and frequency of precipitation, which in turn was reflected in the manifestation and development of dark brown spot. The amount of precipitation exceeded the multi-year average: in September, December, January - all years of research; in January - in 2019; in February - in 2021; in March - in 2023; in April - in 2022 and 2023; in June - in 2021 and 2023; in May - in 2019 and 2020; in July - in 2023. The average monthly air temperature exceeded the multi-year average in September–July in all years of the study, except for April 2021–2022 and September 2022.
The most common disease during the growing season of winter barley in the years of research was dark brown spot (pathogen – *Bipolaris sorokiniana Shoem*).

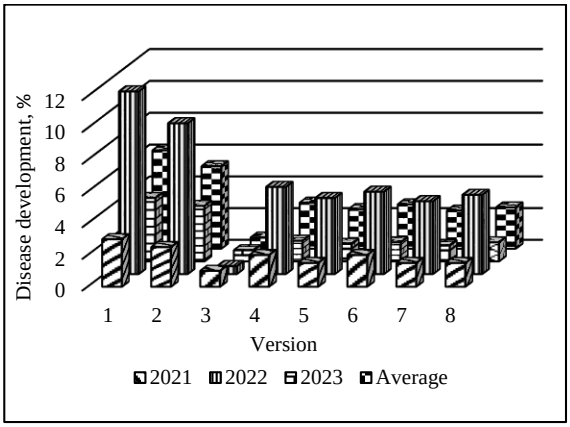


Fig. 1. The influence of biological and chemical preparations on the development of dark brown spot on winter barley, 2021–2023 (in the milky ripeness phase)
Source: Authors' own results.

Note:
experiment options – 1) control (absolute); 2) control (without seed treatment) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, IV stage + nitroTOP, VIII stage); 3) vincit 050 CS (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, IV stage + nitroTOP, VIII stage) + aviator Xpro 225 EC, k.e. (0.8 l/ha); 4) bactofit (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, IV stage + nitroTOP, VIII stage) + bactofit (2.0 l/ha); 5) trichodermin SK (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, stage IV + nitroTOP, stage VIII) + trichodermin SK (2.0 l/ha); 6) trichodermin–93 (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, stage IV + nitroTOP, stage VIII + trichodermin–93 (2.0 l/ha); 7) bactophyt (2.0 l/t) + trichodermin SK (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, stage IV + nitroTOP, stage VIII) + bactophyt (2.0 l/ha) + trichodermin SK (2.0 l/ha); 8) bactophyt (2.0 l/t) + trichodermin–93 (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+nutrimax, stage IV + nitroTOP, stage VIII) + bactophyt (2.0 l/ha) + trichodermin–93 (2.0 l/ha).

It should be noted that the development of dark brown spot in the variety of Zbruch on average over the years of research in the earing phase in the control (absolute) was on average 6.2%; and in the control (without treatment with fungicides) – 5.2%. The technical efficiency of the chemical fungicide aviator Xpro 225 EC, k.e. (0.8 l/ha) against this disease over the years of research was 88.7%, and of the biological preparations bactofit (2.0 l/ha) + trichodermin SK (2.0 l/ha) – 61.3%. In the milky ripeness phase during the years of research, the development of dark brown spot on winter barley was as follows (Fig. 1): in the control (absolute) - an average of 15.8% in the control (without fungicide treatment) - 14.7%. The highest technical efficiency against dark brown spot was obtained when using the drug aviator Xpro 225 EC, k.e. (0.8 l/ha) and was - 83.5% (Table 1).

Table 1. Technical effectiveness of the use of biological and chemical preparations against dark brown spot on winter barley, 2021–2023, (in the milky ripeness phase)

No.	Variant (product name, application rate, l/ha)	Efficiency of action, %			
		2021	2022	2023	Mean
1	control (absolute)	–	–	–	–
2	control (without seed treatment) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, IV stage + nitroTOP, VIII stage)	–	–	–	–
3	vincit 050 CS (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, IV stage + nitroTOP, VIII stage) + aviator Xpro 225 EC, k.e. (0.8 l/ha)	80.0	87.4	86.7	83.5
4	bactofit (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, IV stage + nitroTOP, VIII stage) + bactofit (2.0 l/ha)	60.0	47.4	53.3	53.2
5	trichodermin SK (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, stage IV + nitroTOP, stage VIII) + trichodermin SK (2.0 l/ha)	64.0	54.5	56.7	58.2
6	trichodermin–93 (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, stage IV + nitroTOP, stage VIII + trichodermin–93 (2.0 l/ha)	64.7	48.6	54.7	56.0
7	bactophyt (2.0 l/t) + trichodermin SK (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, stage IV + nitroTOP, stage VIII) + bactophyt (2.0 l/ha) + trichodermin SK (2.0 l/ha)	66.7	51.4	58.7	58.2
8	bactophyt (2.0 l/t) + trichodermin–93 (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+nutrimax, stage IV + nitroTOP, stage VIII) + bactophyt (2.0 l/ha) + trichodermin–93 (2.0 l/ha)	65.3	49.7	70.0	56.3

Source: Authors' own results.

Among the biological preparations used in the experimental variants, the highest technical efficiency was using bactofit (2.0 l/ha) + trichodermin SK (2.0 l/ha) and was - 58.2% (Table 2).

Table 2. Economic efficiency of the use of chemical and biological preparations, variety of Zbruch, (2021–2023)

Version	Grain yield, t/ha	Cost of sales, thousand UAH/ha	Production costs, thousand UAH/ha	Cost price, 1 ton of grains thousand UAH/t	Conditional net income, t thousand UAH/ha	Profitability level, %
1. Control (absolute)	3.0	21.0	16.5	5.5	4.5	27.3
2. Control (without seed treatment) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, IV stage + nitroTOP, VIII stage)	3.3	23.1	17.5	5.3	5.6	32.0
3. Vincit 050 CS (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, IV stage + nitroTOP, VIII stage) + aviator Xpro 225 EC, k.e. (0.8 l/ha)	4.1	28.7	20.0	4.9	8.7	43.5
4.Bactofit (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, IV stage + nitroTOP, VIII stage) + bactofit (2.0 l/ha)	3.6	25.2	19.0	5.3	6.2	32.6
5. Trichodermin SK (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+ nutrimax, stage IV + nitroTOP, stage VIII) + trichodermin SK (2.0 l/ha)	4.0	28.0	19.0	4.7	9.0	47.4
6. Trichodermin–93 (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, stage IV + nitroTOP, stage VIII + trichodermin–93 (2.0 l/ha)	3.7	25.9	19.0	5.1	6.9	36.3
7. Bactophyt (2.0 l/t) + trichodermin SK (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20} + nutrimax, stage IV + nitroTOP, stage VIII) + bactophyt (2.0 l/ha) + trichodermin SK (2.0 l/ha)	4.2	29.4	19.5	4.6	9.9	50.8
8. Bactophyt (2.0 l/t) + trichodermin–93 (2.0 l/t) + $N_{30}P_{60}K_{60}$ (autumn application) + (N_{20}+nutrimax, stage IV + nitroTOP, stage VIII) + bactophyt (2.0 l/ha) + trichodermin–93 (2.0 l/ha)	4.0	28.0	19.5	4.9	8.5	43.6

Source: Authors' own results.

The largest preserved yield of winter barley in the variety of Zbruch over the years of research was obtained on variants where the chemical fungicide aviator Xpro 225 EC, k.e. (0.8 l/ha) and biological preparations bactofit (2.0 l/ha) + trichodermin SK (2.0 l/ha) were used, while the increase in yield was 1.0-1.1 t/ha (Table 2).

Thus, the use of chemical and biological preparations against the main diseases of winter barley, provided that the appropriate technology is followed, will allow to avoid significant grain losses from diseases and preserve the harvest.

Economic efficiency makes it possible to take into account real costs and profits and, on this basis, develop the most economically advantageous technologies for growing agricultural crops.

Experimental studies have shown that the development of diseases was reduced when using chemical and biological means of protection.

It should be noted that biological preparations have a positive effect on the phytosanitary condition of crops, as well as their anti-stress and stimulating effect on cultivated plants.

Thus, with a low and medium level of disease damage, it is advisable to use biological preparations, with a strong one - it is necessary to use fungicides.

The calculations of economic indicators on the Zbruch variety (Table 2) showed that the highest economic efficiency - conditional net income, the level of profitability was obtained on the variant with the application of bactofit (2.0 l / ha) + trichodermin SK (2.0 l / ha). Conditional net income was 9.9 thousand UAH, with a profitability level of 50.8%.

The level of profitability of production of winter barley seeds of the Zbruch variety in this variant is 23.5% higher compared to the absolute control.

CONCLUSIONS

In the conditions of the Western Forest-Steppe, to protect winter barley of the Zbruch variety against dark brown spot, it is better to use the fungicide aviator Xpro (0.8 l/ha) and biological preparations bactofit (2.0 l/ha) + trichodermin SK (2.0 l/ha). The technical efficiency of biological preparations on average over the years of research against this disease in the milky ripeness phase was within 53.2-58.2%, and of the chemical preparation - 83.5%.

The largest conditional net profit over the years of research was obtained on the variant, where the crops were treated with biological preparations, and in particular bactofit (2.0 l/ha) + trichodermin SK (2.0 l/ha) and amounted to 9.9 thousand UAH. with a profitability level of 50.8%.

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ECONOMIC PERFORMANCE OF AN EIGHT-YEAR-OLD 'THORNFREE' BLACKBERRY (*RUBUS FRUTICOSUS* L.) CULTIVAR IN ARAD COUNTY, WESTERN ROMANIA

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Abstract

Blackberry (Rubus fruticosus L.) cultivation offers a sustainable solution to declining agricultural land availability and increasing demand for nutritious fruits in Romania. This study evaluates the economic performance of an 8-year-old 'Thornfree' blackberry plantation established in 2015 at Bărzani Farm, Arad County. Key agronomic practices included manual fertilization, drip irrigation, intra-row mowing, and annual soil monitoring. Results revealed progressive improvements in soil nutrient content—especially phosphorus—and organic matter, along with favorable pH and salinity conditions. Yields increased annually, reaching 10,600 kg in 2022, or 3.2 kg/plant. These outcomes support the crop's potential for small-scale farming, rural income generation, and reduced reliance on wild-harvested non-wood forest products (NWFPs). Blackberry cultivation can enhance sustainable land use and contribute to the diversification of Romania's fruit sector, particularly in marginal areas. Future efforts should focus on pest management, propagation techniques, and improving market access for rural producers.

Key words**:** *blackberry, non-wood forest products, Rubus fruticosus, economic efficiency*

INTRODUCTION

Agricultural land availability has been decreasing globally. In Romania, crop land (arable land and permanent crops) declined from 0.24 ha per capita in 2000 to 0.20 ha per capita in 2021 [27]. Simultaneously, population growth and rising consumption levels are placing increasing pressure on natural resources and food systems worldwide. Within this context, the cultivation of fruit-bearing shrubs, especially native and adaptable species such as *Rubus* spp., offers a promising solution to promote sustainable land use. Beyond contributing to biodiversity conservation and ecosystem resilience, these species offer the potential for high-value crop production, thereby supporting food security initiatives and providing economic opportunities for smallholder and farming communities.

In Romania, according to data from the 2017–2019 timeframe, a strong preference for domestic fruits was identified, particularly grapes, apples, and other orchard fruits, which account for approximately 86% of total fruit consumption [26]. This trend indicates an increasing opportunity to diversify consumer preferences by incorporating a wider range of forest fruits, such as blackberries (*Rubus fruticosus L.*), especially considering their health benefits and consumer appeal in urban areas [6], [7]. Particularly, blackberries, which are among the most important non-wood forest products (NWFPs) in several regions across Romania, play a vital role in rural development, contributing to local economies, biodiversity conservation, and food security [10], [16]. This is the case, for example, in Horezu, Vâlcea County [18] and Maramureș County, where the average annual harvests of forest fruits reached 154 tons during 2005–2013 [17].

The genus *Rubus*, within the Rosaceae family, is one of the largest plant genera globally, comprising approximately 700–750 species

[14], [15], [22]. Notable species cultivated or found in Romania include blackberry (*Rubus fruticosus* L.), raspberry (*R. idaeus* L.), European dewberry (*R. caesius* L.) and *R. candicans* Weihe. These species are valued for: nutritional content, such as vitamins, polyphenols, flavonoids, etc. [8], [20], [24], [30], medicinal properties (antioxidant, anti-inflammatory, antimicrobial, anti-diabetic) [2], [23], [32], [34], cosmetic and nutraceutical applications [31], [36], and honey potential [3], [4], [5], [29].Cultivars such as 'Thornfree' offer commercial viability, producing large, juicy, conical-shaped berries suitable for fresh consumption and processing [13]. However, cultivation faces several challenges: high post-harvest perishability (1–2 days shelf life) [35], decrease in vitamin C content during storage [25] and susceptibility to pests, notably the invasive spotted wing drosophila (*Drosophila suzukii* Matsumura), which affects fruit quality and yield [21].

Nutrient management is crucial, particularly in subtropical climates. Optimal nitrogen application rates range from 25–45 kg/ha in the first year and 45–70 kg/ha in subsequent years, with adjustments based on cultivar and soil conditions [33].

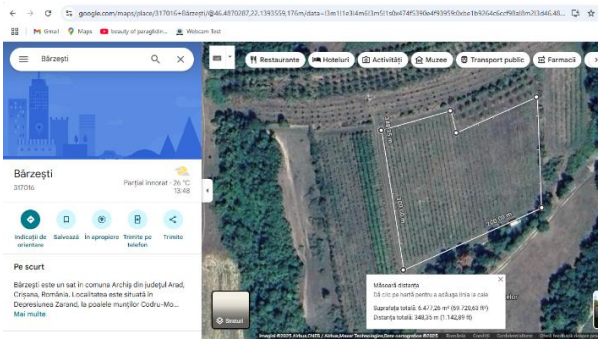
Representatives of *Rubus* genus can be propagated through both generative and vegetative ways. For example, in vitro cultivation of *Rubus* began in the 1970s, and current research shows that medium composition significantly influences shoot multiplication and growth [1], [12]. This method is important for large-scale propagation of high-value cultivars and conservation of genetic diversity.

The aim of this research was to highlight the yield and economic efficiency of an 8-year-old blackberry culture from Bărzani Farm, Arad County.

MATERIALS AND METHODS

In spring 2015, the young plants of blackberry (*Rubus fruticosus* L.) 'Thornfree' cultivar were planted in the 0.65 ha plot located in Bărzani Farm (Map 1; 46°29'14.5"N 22°08'22.9"E).

The plantation was established using a 3 × 1 m spacing configuration, corresponding to 3 meters between adjacent rows and 1 meter between individual plants within a row. Therefore, a total of 2,166 saplings were planted (Photo 1).



Map 1. The plot planted with blackberry
Source: Google Maps, Accessed 18th of July 2025 [37].

Prior to planting, soil preparation included deep plowing to a depth of 0.4 meters, followed by the application of 14.3 tons of organic manure.



Photo 1. Planting scheme
Source: Original.

The plantation underwent two distinct maintenance phases:

Phase I (2015-2016): Inter-row spaces were managed through periodic mechanical tillage conducted under a black fallow regime. However, the combination of a steep slope and intense summer rainfall resulted in significant surface runoffs and soil erosion. Additionally, this approach impeded accessibility for manual operations such as harvesting and maintenance.

Phase II (2017-2022): The maintenance strategy was revised to involve mowing the inter-row vegetation using mulching equipment, which shredded plant biomass and redistributed it as surface mulch, thereby improving soil protection and accessibility.

In both phases, intra-row weed control was achieved through regular mowing using brush cutters, as no agrotextile mulching was employed (Photo 2).



Photo 2. Intra-row weed control
Source: Original.

Starting from 2018, a series of manual fertilizer applications were performed annually until 2022, using both granular and powdered formulations.

The schedule and details of each application are as follows:

-7th of April 2018 – a complex NPK fertilizer (16-16-16) was applied at a rate of 80 kg ha^{-1} (granular form).

-5th of May 2018 – Nitrocalcar fertilizer containing 27% total N, 7% CaO, and 5% MgO was applied at a rate of 100 kg ha^{-1} (granular form).

-7th of March 2019 – Doloflor fertilizer [33% $CaMg(CO_3)_2$] was applied at a rate of 3,000 kg ha^{-1} (powdered form).

-16th of March 2019 – a second application of complex NPK fertilizer (16-16-16) was carried out at a rate of 100 kg ha^{-1} (powdered form).

-24th of March 2020 – Diammonium phosphate (DAP) fertilizer (18% N, 46% P_2O_5) was applied at a rate of 150 kg ha^{1} (powdered form).

-26th of April 2021 – Nitrocalcar fertilizer (27% total N, 7% CaO, 5% MgO) was applied again at a rate of 150 kg ha^{-1} (granular form).

-8th of April 2022 – Ammonium sulphate [$(NH_4)_2SO_4$], containing 21% N and 24% SO_4, was applied at a rate of 70 kg ha^{-1} (granular form).

All fertilizers were applied manually and uniformly distributed across the plantation area.

The same quantities were also applied for the timeframe 2018-2020 in the nearby culture with saskatoon berry (*Amelanchier alnifolia* Nutt.) [9].

The culture was irrigated. The irrigation system employed throughout the study was drip irrigation. The applied irrigation norms generally ranged around 35,000 liters per hectare per month, primarily during the critical growing period from June to August, in 2018, 2021 and 2022, respectively. One recorded exception involved a slightly reduced irrigation volume of 30,000 liters per hectare per month applied during July and August, in 2020. These irrigation rates were maintained consistently to ensure adequate soil moisture and optimal plant growth during the summer months. No irrigation was applied in 2019.

Moreover, during the 2018–2022 period, annual soil analyses were conducted at the Alchimex Laboratory. The assessments

included parameters related to primary and secondary macronutrients, soil pH (reaction), micronutrient concentrations, salinity levels, and organic matter content.
Soil samples were collected on 20th of April 2018, 24th of April 2019, 6th of March 2020, 23rd of April 2021, and 5th of April 2022, respectively.

RESULTS AND DISCUSSIONS

Fertilization for improving soil quality

The application of fertilizers resulted in an increasing trend in nitrogen availability, as indicated by the rising N index (Figure 1).

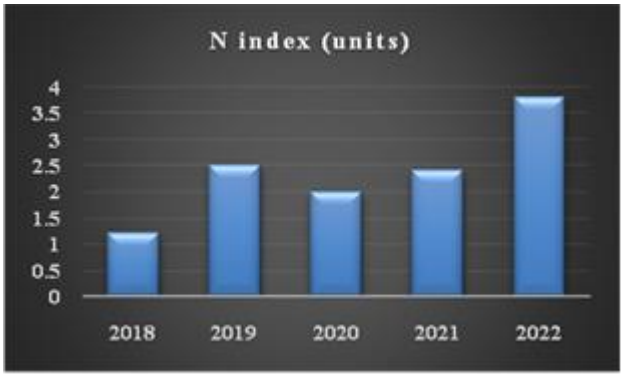


Fig. 1. N index evolution in the timeframe 2018-2022
Source: Original.

The N index is the synthetic indicator representing the soil's capacity to supply nitrogen to the crop throughout the growing season via mineralization processes. Based on the observed values, the soil exhibited a low nitrogen availability in 2018 and 2020, whereas in 2019, 2021 and 2022, nitrogen availability improved to a moderate level.
Regarding the primary macroelements assessed in the soil, their concentrations generally increased over the study period, except for 2020 (Figure 2). The most pronounced increase was observed for phosphorus [P], which rose markedly from 36.1 mg/kg in 2018 to 223.3 mg/kg in 2022.
A pronounced variable trend was observed in the case of Potassium [K], while Magnesium [Mg] and Sulfur [S] followed the same pattern as Nitrogen [N]. Particularly, Magnesium had the highest concentrations in most years, peaking in 2022 at over 200 mg/kg, indicating that it is the most abundant macroelement in the soil throughout the period.

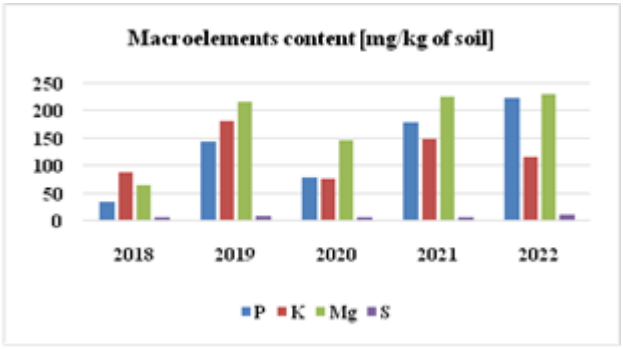


Fig. 2. Macroelements content [mg/kg of soil]
Source: Original.

The soil reaction (i.e. pH) recorded the lowest value (5.32) in 2019 and the highest one (7.38) in 2022. Thus, the soil reaction varied from moderately acid to slightly alkaline (Figure 3).

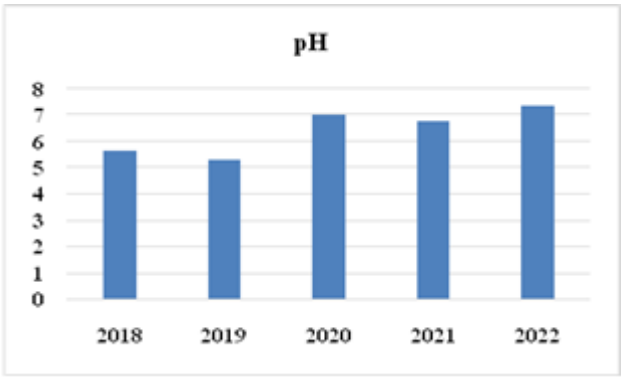


Fig. 3. pH values across the considered timeframe
Source: Original.

It is well known that the soil pH plays a fundamental role in regulating the overall nutrient dynamics within the soil, making its assessment and optimization a priority in agrochemical management. A markedly low pH typically reflects deficiencies in essential cations such as Calcium (Ca), Magnesium (Mg), and particularly Phosphorus (P). Moreover, strongly acidic conditions may be associated with an increased risk of toxicity from elements such as Aluminum, Manganese, and Iron.
As regards the content of the microelements, the soil had a good Iron [Fe] supply, ranging from 55 mg/kg of soil (in 2020) to 281.2 mg/kg of soil (in 2018).
A similar situation was recorded in the case of Magnesium [Mg] content, except for year

2020, when the supply was medium (25 mg/kg of soil) (Figure 4).

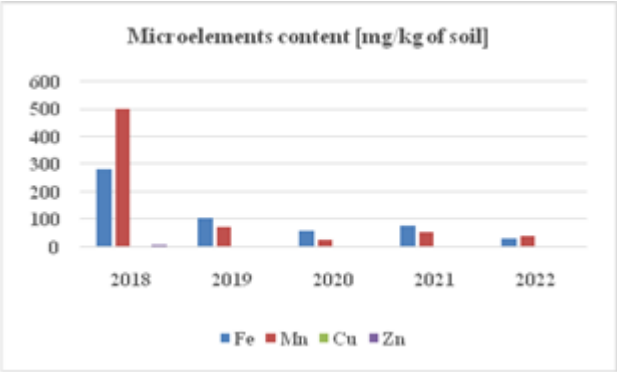


Fig. 4. Microelements content [mg/kg of soil]
Source: Original.

For the other two analyzed micronutrients—Copper (Cu) and Zinc (Zn)—lower concentrations were recorded. Copper levels ranged from 0.9 mg/kg in 2019 to 2.6 mg/kg in 2018, while Zinc levels varied between 1.21 mg/kg in 2020 and 4 mg/kg in 2018.

An increasing trend was observed in the organic matter content, reflected by the progressive rise in both organic carbon and total humus levels over the study period (Figure 5), which positively impacts soil structure, fertility, and water retention.

The increasing trend in organic matter content is a positive indicator of soil health and sustainability, supporting better nutrient cycling and soil microbial activity, which can enhance crop productivity.

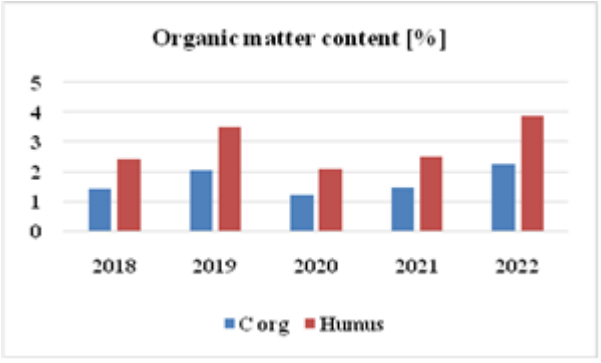


Fig. 5. Organic Carbon and total humus content
Source: Original.

Economic efficiency of the cultivation of 'thornfree' blackberry variety

Throughout the study period (2018–2022), berry harvesting took place annually in July-August.

The total harvested yields increased progressively over the years, as follows: 6,900kg (2018), 8,800 kg (2019), 9,900 kg (2020),9,800 kg (2021), and 10,600 kg (2022). This mean that in 2022, blackberry yield was by 53.62% higher than in 2018.

This yield progression corresponds to an average production of 2.07 kg per plant in 2018 (forth growing season) and 3.2 kg per plant in 2022 (eighth growing season) (Table 1; Photo 3).

Table 1. Economic efficiency of the cultivation of the "Thorn-free blackberry variety"

	2018	2019	2020	2021	2022	2022/2018 %
Total Blackberry yield (kg)	6,900	8,800	9,900	9,800	10,600	153.62
Blackberry yield (kg/plant)	2.07	2.64	2.97	2.0	3.18	153.62
Production cost (Lei/ha)	16,500	18,000	18,500	17,000	17,500	106.00
Total production cost (Lei)	10,725	11,700	12,025	11,050	11,375	124.70
Average production cost per kg blackberry (Lei/kg)	1.55	1.32	1.21	1.12	1.07	69.03
Average price at the farm gate (Lei/kg)	12	12.5	12.5	15	15	125.00
Marketed production of blackberry (kg/year)	4,400	6,600	3,800	6,300	7,200	163.63
Total Income from sales (Lei)	52,800	82,500	47,500	94,500	108,000	204.54
Profit per kg blackberry (Lei/kg)	9.56	10.72	9.33	13.24	13.42	140.37
Total profit (Lei/year)	42,065	70,800	35,475*	83,450	96,625	229,70

Source: Own results and calculations.
*The total profit at the end of the year 2020 is associated with the COVID-19 pandemic.
Note: Exchange rate 1 Euro= 5.0753 Lei on 22 September 2025, National Bank of Romania [38].



Photo 3. Blackberry specimens in the eighth year of cultivation
Source: Original.

Between 2018 and 2022, total profit from the cultivation of the "Thorn-free" blackberry variety increased markedly—from 42,065 Lei in 2018 to 96,625 Lei in 2022, reflecting a 129.7% rise. Although profitability declined in 2020 to 35,475 Lei due to the impact of the COVID-19 pandemic, it rebounded sharply in the following years, reaching record levels in 2021 and 2022.

The substantial rise in income and profit between 2018 and 2022 can be attributed primarily to the increase in marketed production and the higher farm gate price per kilogram of blackberries. Marketed production grew by 63.63%, from 4,400 kg in 2018 to 7,200 kg in 2022, while the average selling price rose from 12 Lei/kg to 15 Lei/kg over the same period. Combined, these factors contributed to a more than 200% increase in total income, which rose from 52,800 Lei to 108,000 Lei.

Between 2018 and 2022, the average production cost per kilogram of blackberries decreased significantly, from 1.55 Lei to 1.07 Lei, representing a 30.97% reduction. This notable decline indicates enhanced cost management practices and/or improved production efficiency, likely resulting from increased yields relative to input costs over the analyzed period.

The yield per plant demonstrated a significant overall improvement, increasing from 2.07 kg in 2018 to 3.18 kg in 2022, which represents a 53.62% rise. Although there was a temporary decline in 2021, when yield dropped to 2.0 kg per plant, this was followed by a strong recovery in 2022, indicating the resilience and productive potential of the crop under improved cultivation conditions.

The findings of this study support the broader potential of blackberry (*Rubus fruticosus* L.) cultivation, particularly for small-scale agricultural landowners in Romania. Given that Romania accounted for 31.8% of all agricultural holdings in the EU-27 in 2020—totaling 2,887,078 out of 9,067,300 farms [28], this crop may serve as a viable diversification strategy for fragmented and low-input farms. Moreover, the recent decline in the quantities of non-wood forest products (NWFPs) harvested from natural forests [11] further underscores the relevance of cultivating blackberries as a sustainable alternative to wild harvesting, offering both ecological and economic benefits. A notable example of successful cultivation was recently documented at HortiNova Nursery, demonstrating effective propagation techniques and promising yield performance under controlled conditions [19].

CONCLUSIONS

Based on the results obtained, it can be concluded that blackberry is a promising crop to produce high-quality and substantial berry yields, valued for their notable nutritional properties.

Blackberry holds considerable potential in multiple domains relevant to Romanian agriculture and rural development. Specifically, it can: contribute to the diversification of fruit production at the national level, support income generation in rural areas through the collection and commercialization of non-timber forest

products (NTFPs) and offer sustainable land-use alternatives, particularly in marginal or forest-adjacent areas.

To fully harness this potential, future research and targeted investment should prioritize: optimization of cultivation techniques and integrated pest management strategies, development of robust value chains for both fresh and processed berries products and facilitation of market access for local communities involved in the harvesting and cultivation of wild and domesticated berries.

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GREEN ROMANIA IN 2020–2024: CITIES EXPAND, FORESTS ENDURE, BUT ECOLOGICAL PRESSURES REMAIN

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Abstract

This study analyzes the evolution of the environment in Romania during the period 2020–2024 through an integrated approach that correlates the dynamics of urban green spaces with the overall condition of vegetation, assessed by the intensity of tree damage based on crown defoliation. The analysis relies on official statistical data provided by the National Institute of Statistics, using the indicators "Green space area by county" and "Intensity of tree damage according to crown defoliation rate", reported annually at the national level. The results highlight a heterogeneous evolution of urban green spaces, characterized by significant increases in counties with pronounced metropolitan dynamics and by stability or lower values in other regions, reflecting persistent territorial disparities. In parallel, the analysis of defoliation rates indicates that the majority of trees consistently fall within the healthy or slightly damaged category, suggesting a relatively favourable overall condition of vegetation, while also revealing the presence of a constant segment affected by ecological stress. The integration of the two indicators shows that the expansion of urban green spaces does not automatically lead to a reduction in ecological pressures, but rather represents only one component of a complex system influenced by climatic, administrative, and anthropogenic factors. The S.W.O.T. analysis and the conceptual synthesis presented in the form of an "ecological balance tree" confirm that, although cities are expanding and vegetation demonstrates a certain degree of resilience, ecological pressures remain active. The study thus provides a coherent perspective on the state of the environment in Romania and emphasizes the importance of continuous monitoring and integrated approaches in territorial analysis.

Key words**:** *urban green spaces, environment, crown defoliation, ecological pressures, territorial analysis, Romania*

INTRODUCTION

In recent decades, pressures exerted on the environment have increased significantly, driven by accelerated urbanization, the intensification of economic activities, and the increasingly frequent manifestations of climate change. The specialized literature emphasizes that these processes simultaneously affect territorial structure, environmental quality, and ecosystem functioning, generating imbalances that require integrated assessments based on relevant quantitative indicators [1]. Particular attention has been given to the relationship between the development of built-up areas and the environment's capacity to absorb and mitigate anthropogenic pressures. Recent studies show that green spaces play an essential role in regulating microclimates, reducing thermal stress, improving air quality, and maintaining biodiversity, especially in urban areas subject to demographic and functional pressures [4]. At the same time, these works highlight the existence of pronounced territorial disparities, determined by levels of investment, public policies, and local administrative capacity [2].

In parallel, the literature indicates that the overall condition of vegetation represents a sensitive indicator of environmental quality and of the impact of climatic and anthropogenic factors. Assessments based on tree crown defoliation are widely used to capture the dynamics of ecological stress and are relevant for identifying medium- and long-term trends [3]. These analyses show that even in contexts where the environment appears to maintain its functionality, vulnerable segments persist, exposed to progressive degradation [7]. At both European and national levels,

research underlines the necessity of correlating environmental indicators derived from official statistical sources with detailed territorial analyses, in order to avoid fragmented interpretations. Recent approaches insist that the separate evaluation of environmental components (urban areas, vegetation, land use) limits the capacity to fully understand the complex processes shaping contemporary geographical space [10].

In the case of Romania, the literature highlights the presence of persistent ecological pressures generated both by climate change and by historical territorial imbalances. Studies indicate that while certain regions benefit from significant natural resources and a high adaptive capacity, others face structural vulnerabilities that may amplify the effects of environmental degradation [7, 8]. These findings support the need for analyses based on official statistical data capable of capturing recent developments and providing a solid foundation for coherent interpretations.

Based on these premises, the present study aims to analyze the evolution of the environment in Romania during the period 2020–2024 by correlating two relevant indicators: green space area at the county level and the intensity of tree damage according to crown defoliation rate. By integrating these indicators, the research seeks to highlight how urban expansion and the overall condition of vegetation reflect the environment's capacity to withstand contemporary ecological pressures, while also providing a synthetic perspective on existing territorial imbalances.

The objective of this article is to examine the evolution of the environment in Romania between 2020 and 2024 by correlating the dynamics of urban green spaces at the county level with the overall condition of vegetation, assessed through the intensity of tree damage based on crown defoliation, in order to identify territorial disparities and persistent ecological pressures.

MATERIALS AND METHODS

The analysis carried out in this study relies on official statistical data, standardized data-processing tools, and the integration of information from the scientific literature and relevant institutional sources. The methodological framework is designed to ensure temporal and spatial comparability of the results, as well as transparency in all stages of the analytical process.

Data sources

The statistical data used in this study were extracted from the **Tempo Online** database of the National Institute of Statistics (INS), selecting two relevant environmental indicators for the period 2020–2024:

-**TOE1271 – Target 8 – Environment – Green space area by county**, expressed in hectares and reported annually at the county level and for the Municipality of Bucharest;

-**TMI1163 – Target 6 – Environment – Intensity of tree damage according to crown defoliation rate**, expressed in percentages and structured by defoliation classes and vegetation types.

The green space indicator includes exclusively landscaped areas located within the built-up area of localities (parks, public gardens, public squares, tree and flower plots, urban forests, cemeteries, and sports facilities), in accordance with the INS methodology. Agricultural land, greenhouses, nurseries, and water surfaces are excluded. For the Municipality of Bucharest, the data are derived from the *"Green Register,"* developed under Law no. 24/2007 [9, 10]. The crown defoliation indicator is used as a measure of the overall condition of tree vegetation and is collected annually within the European monitoring network coordinated by ICP-Forests under the auspices of CLRTAP. It reflects the dynamics of tree health status and does not have an exhaustive national coverage, being primarily oriented toward the analysis of temporal trends [8].

Data processing and analysis

Data processing was carried out using descriptive and comparative methods, focusing on:

-the analysis of the territorial distribution of urban green space area at the county level;

-the identification of annual variations and significant statistical and administrative changes;

-the assessment of the evolution of the share of trees classified within the ≤25% and >25% defoliation groups, as an indicator of ecological pressures. No direct causal relationships were assumed between the two indicators. The analysis has an exploratory and integrative character, aimed at identifying patterns and territorial disparities.

Cartographic and graphical representation

The spatial representation of green space area data was carried out through annual thematic maps using **Microsoft Office 365 – Excel**. The data were organized into structured tables, and value classification was designed to highlight territorial contrasts and the annual dynamics of the indicator. The S.W.O.T. analysis was synthesized into an original conceptual representation in the form of an *"ecological balance tree,"* created using **Microsoft Office 365 – PowerPoint**, employing graphic elements from the *Icons* section. This visual approach was chosen to facilitate the integrated interpretation of strengths, weaknesses, opportunities, and threats identified based on the statistical results.

Literature and institutional references

To contextualize the results and substantiate the interpretations, scientific articles from specialized journals, European reports, and relevant institutional documents addressing topics such as urban development, green infrastructure, climatic pressures, and environmental conditions were consulted. These sources were used exclusively to support the analytical framework and interpret the findings, without substituting the official statistical data employed in the analysis.

By combining INS data with accessible cartographic tools and an integrated analytical approach, the applied methodology enables a coherent evaluation of environmental evolution in Romania during the period 2020–2024, providing a solid basis for the interpretations presented in the following sections.

RESULTS AND DISCUSSIONS

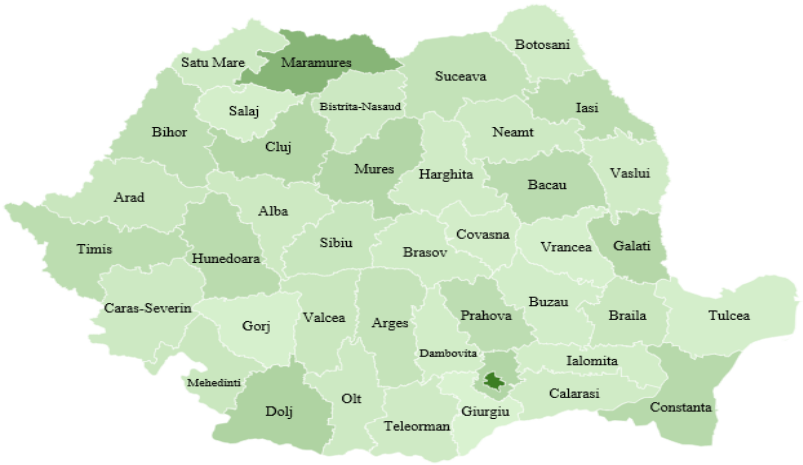
The *Results and Discussions* section analyzes the state of the environment in Romania through two complementary statistical indicators that capture both the urban dimension and the tree-based component of natural capital. The analysis is based on official statistical data provided by the National Institute of Statistics and on information derived from the European forest health monitoring network ICP-Forests, covering the period 2020–2024. Beyond their climatic role, the literature highlights the contribution of urban green spaces to reducing acoustic discomfort, as they act as natural barriers between road infrastructure and built-up areas [13].

The first indicator analyzed is the area of green spaces developed within the built-up areas of localities, expressed in hectares and reported at the county level and for the Municipality of Bucharest. According to the statistical definition, this indicator includes parks, public gardens, public squares, tree and flower plots, urban forests, cemeteries, and areas associated with sports facilities located within the buildable perimeter of localities. Agricultural land, greenhouses, nurseries, vegetable gardens, and water bodies are excluded. Urban green spaces play a crucial role in mitigating the urban heat island effect, improving the urban microclimate, reducing noise pollution, and maintaining biodiversity, while also serving as important elements of ecological connectivity between intra-urban and extra-urban areas.

The second indicator examined concerns the intensity of tree damage according to crown defoliation rate, expressed as a percentage and used as a measure of forest health. Defoliation represents the loss of leaves or needles from the crown of a tree compared to a reference tree with a complete foliar apparatus and is assessed annually through visual observation, in accordance with the methodology adopted at the European level. The data are collected within a systematic transnational network coordinated under the auspices of the Convention on Long-range Transboundary Air Pollution (CLRTAP) and ICP-Forests, with the primary objective of capturing the dynamics of forest health over time rather than providing exhaustive national coverage.

The combined analysis of the two indicators makes it possible to identify territorial and temporal patterns relevant to the assessment of ecological pressures on both the built and natural environment. The comments presented in this section focus on identifying regional disparities, extreme values, and general trends, without assuming direct causal relationships between urban green spaces and forest health status, but rather offering an integrated analytical framework for interpreting recent environmental developments in Romania.

1	Alba	419
2	Arad	528
3	Arges	622
4	Bacau	928
5	Bihor	815
6	Bistrita-Nasaud	433
7	Botosani	329
8	Brasov	352
9	Braila	502
10	Buzau	257
11	Caras-Severin	403
12	Calarasi	319
13	Cluj	1,109
14	Constanta	1,031
15	Covasna	248
16	Dambovita	276
17	Dolj	1,253
18	Galate	1,087
19	Giurgiu	70
20	Gorj	153
21	Harghita	327



22	Hunedoara	950
23	Ialomita	269
24	Iasi	913
25	Ilfov	1,178
26	Maramures	2,364
27	Mehedinti	492
28	Mures	1,123
29	Neamt	396
30	Olt	405
31	Prahova	849
32	Satu Mare	368
33	Salaj	221
34	Sibiu	533
35	Suceava	674
36	Teleorman	356
37	Timis	882
38	Tulcea	208
39	Vaslui	320
40	Valcea	496
41	Vrancea	172
42	M. Bucuresti	4,506

Fig. 1. Green space area by county in Romania, 2020 (unit of measurement: hectares)
Source: NIS, http://statistici.insse.ro [8].

In 2020, the distribution of landscaped green spaces at the county level reveals significant contrasts among Romania's regions. The highest value is recorded in the Municipality of Bucharest, with a total area of 4,506 hectares, a situation explained by the capital's special administrative status and the use of data from the *"Green Register,"* developed in accordance with the provisions of Law no. 24/2007 on the regulation and administration of green spaces within built-up areas [9].

At the county level, Maramureș clearly stands out with 2,364 hectares of green spaces, followed by Dolj (1,253 ha), Ilfov (1,178 ha), Mureș (1,123 ha), Cluj (1,109 ha), and Galați (1,087 ha). The functions of urban green spaces are not limited to their aesthetic dimension; they also contribute to microclimate regulation, water retention, and the reduction of the environmental impact of built structures [12].

The high values recorded in these counties may be associated with the presence of medium- and large-sized urban centers, as well as with the inclusion in this category of extensive urban parks, green areas associated with sports facilities, and other public amenities, in accordance with the statistical definition used by the National Institute of Statistics [8].

Ilfov County presents a particular situation, with a relatively high green space area (1,178 ha) despite its predominantly peri-urban character. This value may be linked to the expansion of new residential areas in the vicinity of the Municipality of Bucharest and to the inclusion of green spaces associated with recently developed urban complexes, a phenomenon characteristic of metropolitan development processes surrounding major cities.

An intermediate level of green space area is observed in counties such as Bacău (928 ha), Hunedoara (950 ha), Iași (913 ha), Timiș (882

ha), and Prahova (849 ha). These values suggest relatively balanced urban development, in which the development of green spaces evolved alongside the expansion of the built environment, without generating extreme variations at the county level [11].

At the opposite end of the spectrum, counties such as Giurgiu (70 ha), Gorj (153 ha), Vrancea (172 ha), Tulcea (208 ha), Sălaj (221 ha), Covasna (248 ha), and Buzău (257 ha) record the lowest landscaped green space areas. These lower values may be associated with a reduced degree of urbanization, a limited number of urban settlements, or urban structures in which landscaped green spaces do not represent a major priority in local development policies. Moreover, in counties characterized by extensive natural areas outside built-up zones, the pressure to develop urban green spaces is generally lower [5].

The uneven distribution of green spaces in 2020 highlights the decisive role of local administrative decisions and institutional capacity in shaping this indicator. The identified territorial disparities constitute an important reference point for analyzing developments in subsequent years and for assessing the effectiveness of public policies aimed at improving urban environmental quality [6].

1	Alba	421
2	Arad	540
3	Arges	622
4	Bacau	935
5	Bihor	821
6	Bistrita-Nasaud	433
7	Botosani	329
8	Brasov	357
9	Braila	502
10	Buzau	337
11	Caras-Severin	403
12	Calarasi	319
13	Cluj	1,227
14	Constanta	1,066
15	Covasna	197
16	Dambovita	277
17	Dolj	1,257
18	Galati	1,051
19	Giurgiu	70
20	Gorj	153
21	Harghita	344



22	Hunedoara	954
23	Ialomita	266
24	Iasi	1,005
25	Ilfov	2,746
26	Maramures	2,367
27	Mehedinti	506
28	Mures	1,329
29	Neamt	417
30	Olt	403
31	Prahova	849
32	Satu Mare	368
33	Salaj	221
34	Sibiu	534
35	Suceava	723
36	Teleorman	376
37	Timis	883
38	Tulcea	208
39	Vaslui	329
40	Valcea	496
41	Vrancea	172
42	M. Bucuresti	4,506

Fig. 2. Green space area by county in Romania, 2021 (unit of measurement: hectares)
Source: NIS, http://statistici.insse.ro [8].

In 2021, the distribution of landscaped green spaces at the county level generally maintains the territorial patterns observed in the previous year; however, significant increases are visible in certain counties, indicating either an intensification of urban development processes or administrative updates of statistical records. The data are reported annually and reflect the total area of landscaped green spaces within the built-up areas of localities, in accordance with the methodology of the National Institute of Statistics.

The Municipality of Bucharest maintains its constant value of 4,506 hectares, a situation explained by the continued use of the previously developed *"Green Register"* and by the absence of structural updates to the reported area during the analysed period [9]. At the county level, Maramureș remains the county with the largest green space area (2,367 ha), followed by Dolj (1,257 ha), Mureș (1,329 ha), Cluj (1,227 ha), and Galați (1,051 ha). The stability of these values suggests continuity in local policies aimed at maintaining urban green infrastructure.

The most notable change in 2021 is recorded in Ilfov County, where the green space area increases significantly from 1,178 hectares in 2020 to 2,746 hectares in 2021. This development may be associated with the accelerated expansion of urban and peri-urban areas, as well as with the inclusion in official statistics of green spaces related to newly developed residential and service complexes in the metropolitan area of the Municipality of Bucharest. The abrupt increase most likely reflects an administrative reporting update rather than a physical transformation achieved within a single year.

Moderate increases in green space area are also observed in counties such as Cluj (1,227 ha), Iași (1,005 ha), Constanța (1,066 ha), Suceava (723 ha), and Mureș (1,329 ha), developments that may be linked to ongoing urban expansion and the extension of public amenities in county-seat cities. These values reflect a trend toward the consolidation of green infrastructure in regional urban centers, without generating extreme variations at the national level.

At the opposite end, counties such as Giurgiu (70 ha), Gorj (153 ha), Vrancea (172 ha), Tulcea (208 ha), Sălaj (221 ha), and Covasna (197 ha) continue to record the lowest landscaped green space areas. The persistence of these low values suggests limited urban dynamics, as well as a possible orientation of local development policies toward other priorities, to the detriment of expanding intra-urban green spaces.

Overall, the 2021 data confirm the persistence of significant territorial disparities in the distribution of urban green spaces in Romania. Although certain counties record important punctual increases, the general structure remains uneven, highlighting the decisive role of local administrative capacity and the pace of urban development in shaping this indicator.

Alba	422
Arad	614
Arges	608
Bacau	820
Bihor	864
Bistrita-Nasaud	404
Botosani	329
Brasov	372
Braila	502
Buzau	375
Caras-Severin	420
Calarasi	319
Cluj	1,220
Constanta	1,080
Covasna	197
Dambovita	278
Dolj	1,258
Galati	1,059
Giurgiu	70
Gorj	153
Harghita	344



22	Hunedoara	954
23	Ialomita	268
24	Iasi	990
25	Ilfov	2,747
26	Maramures	2,365
27	Mehedinti	506
28	Mures	1,458
29	Neamt	417
30	Olt	403
31	Prahova	768
32	Satu Mare	368
33	Salaj	221
34	Sibiu	539
35	Suceava	828
36	Teleorman	374
37	Timis	883
38	Tulcea	208
39	Vaslui	329
40	Valcea	496
41	Vrancea	172
42	M. Bucuresti	4,506

Fig. 3. Green space area by county in Romania, 2022 (unit of measurement: hectares)
Source: NIS, http://statistici.insse.ro [8].

In 2022, the distribution of landscaped green spaces at the county level indicates a period of relative stabilization following the more pronounced adjustments observed in the previous year. The reported values suggest that, in most counties, the green space area evolved only marginally, reflecting either the consolidation of existing statistical records or a moderate pace of new urban developments, in accordance with official reporting.

At the county level, Maramureș continues to hold a dominant position with 2,365 hectares,

closely followed by Ilfov (2,747 ha), Mureș (1,458 ha), Dolj (1,258 ha), and Cluj (1,220 ha). The persistence of these high values suggests that these counties benefit from a well-established urban green infrastructure that has been maintained and strengthened over time.

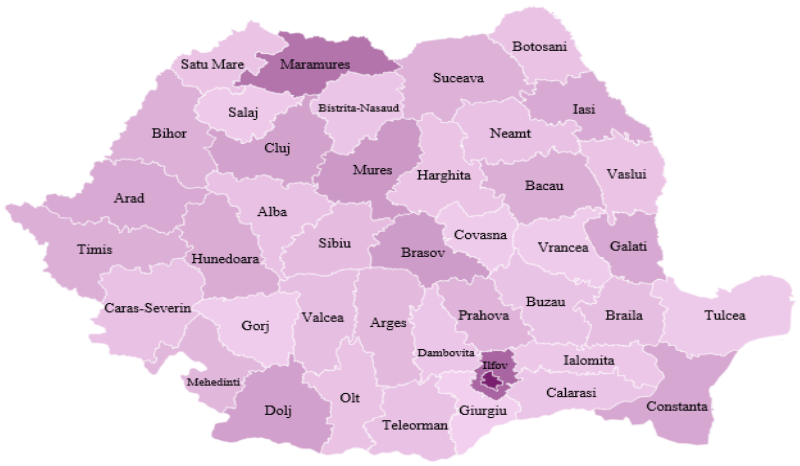
A distinctive feature of 2022 is the marked increase in green space area in Mureș County, which reaches 1,458 hectares compared to the previous year. This development indicates either the expansion of public amenities in the county's urban centers or a more detailed update of the reported areas, a phenomenon frequently observed in annual administrative statistics. A positive trend is also observed in counties such as Constanța (1,080 ha), Suceava (828 ha), Bihor (864 ha), and Arad (614 ha), where moderate increases suggest active yet controlled urban dynamics.

Counties such as Iași (990 ha), Hunedoara (954 ha), Timiș (883 ha), Prahova (768 ha), and Bacău (820 ha) fall within the intermediate value range. In these cases, variations compared to the previous year are limited, indicating a balance between the expansion of the built environment and the maintenance of existing green areas. This stability may be interpreted as a sign of the maturation of local urban planning processes.

In contrast, counties such as Giurgiu (70 ha), Gorj (153 ha), Vrancea (172 ha), Tulcea (208 ha), Sălaj (221 ha), and Covasna (197 ha) continue to record the lowest landscaped green space values. The absence of significant variations compared to previous years suggests limited urban dynamics, as well as the possible absence of local policies explicitly oriented toward the expansion of intra-urban green infrastructure.

Overall, the 2022 data highlight the consolidation of already existing territorial disparities rather than a restructuring of green space distribution at the national level.

1	Alba	425
2	Arad	1,020
3	Arges	610
4	Bacau	909
5	Bihor	863
6	Bistrita-Nasaud	322
7	Botosani	408
8	Brasov	1,365
9	Braila	502
10	Buzau	380
11	Caras-Severin	420
12	Calarasi	320
13	Cluj	1,220
14	Constanta	1,075
15	Covasna	180
16	Dambovita	286
17	Dolj	1,258
18	Galati	1,059
19	Giurgiu	70
20	Gorj	153
21	Harghita	366



22	Hunedoara	960
23	Ialomita	275
24	Iasi	1,017
25	Ilfov	2,749
26	Maramures	2,365
27	Mehedinti	690
28	Mures	1,458
29	Neamt	419
30	Olt	403
31	Prahova	768
32	Satu Mare	368
33	Salaj	216
34	Sibiu	546
35	Suceava	837
36	Teleorman	419
37	Timis	883
38	Tulcea	208
39	Vaslui	373
40	Valcea	496
41	Vrancea	183
42	M. Bucuresti	4,506

Fig. 4. Green space area by county in Romania, 2023 (unit of measurement: hectares)
Source: NIS, http://statistici.insse.ro [8].

The stabilization trend observed in most counties indicates that major developments in this indicator are closely linked to administrative decisions, methodological updates, and the general pace of urban development (factors that will continue to influence the dynamics of green spaces in the coming years).

The year 2023 marks a visible shift in the dynamics of urban green spaces, characterized by the emergence of highly pronounced punctual increases, alongside the persistence of

areas experiencing stagnation or decline. The distribution of values at the county level indicates that, unlike the previous year, certain counties record significant changes in the reported areas, suggesting either major administrative interventions or substantial expansions of urban green amenities.

The most striking development is observed in Brașov County, where the green space area increases abruptly to 1,365 hectares, compared to 372 hectares in 2022. This substantial increase represents a turning point in the analyzed time series and may be interpreted as the result of reclassification or the inclusion of extensive urban green areas, possibly following updates to local records or the integration of peri-urban zones into the built-up area. The magnitude of this variation suggests an administrative process rather than a physical transformation carried out within a single year.

A significant development is also recorded in Arad County, where the green space area reaches 1,020 hectares, nearly double the value recorded in the previous year. This increase positions the county above other traditionally recognized urban poles and indicates a rapid reconfiguration of urban green infrastructure, either through the effective expansion of landscaped areas or through the revision of local reporting criteria.

Counties with high and relatively stable values include Ilfov (2,749 ha), Maramureș (2,365 ha), Mureș (1,458 ha), Dolj (1,258 ha), and Cluj (1,220 ha). The persistence of these values confirms that these counties benefit from an urban structure in which green spaces represent a constant component of territorial development, without major year-to-year fluctuations.

An intermediate level of green space area is observed in counties such as Iași (1,017 ha), Constanța (1,075 ha), Galați (1,059 ha), Hunedoara (960 ha), Suceava (837 ha), and Sibiu (546 ha). In these cases, variations are moderate and indicate incremental evolution, typical of cities where urban planning policies are implemented gradually, without major structural interventions.

At the lower end of the distribution remain counties such as Giurgiu (70 ha), Gorj (153 ha), Vrancea (183 ha), Tulcea (208 ha), Sălaj (216 ha), and Covasna (180 ha). The persistence of these reduced values suggests ongoing administrative inertia and limited integration of landscaped green spaces into the urban structure of these counties, despite the positive developments observed in other regions.

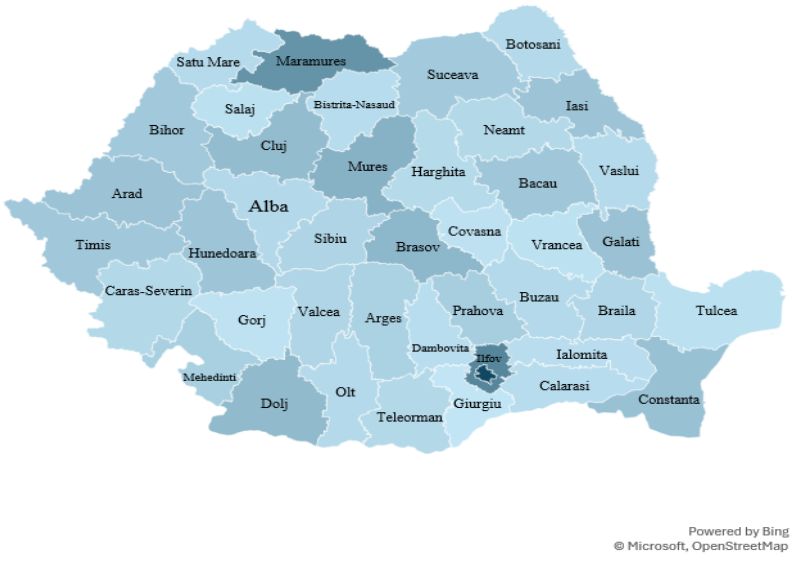
Overall, 2023 stands out through the intensification of territorial polarization in the distribution of urban green spaces. The emergence of very large increases in certain counties, alongside stagnation in others, indicates that the evolution of this indicator is decisively influenced by administrative factors, reporting capacity, and local urban development priorities, rather than by a uniform process of green infrastructure expansion at the national level.

The data for 2024 outline a picture of structural stabilization in the distribution of urban green spaces at the county level, following the significant fluctuations and adjustments observed during the 2021–2023 period. The reported values confirm that, for most counties, the area of landscaped green spaces has entered a phase of consolidation, with only marginal variations compared to the previous year, reflecting both the maturation of administrative processes and a relative plateau in urban expansion.

Counties with the highest values continue to include Ilfov (2,765 ha), Maramureș (2,365 ha), Mureș (1,524 ha), Brașov (1,365 ha), Dolj (1,262 ha), and Cluj (1,221 ha). The persistence of these values confirms that these counties have integrated green spaces as a structural component of urban development, and subsequent annual changes are more likely the result of fine adjustments rather than major interventions.

In the case of Ilfov County, the maintenance of high values consolidates the trend initiated in 2021, suggesting a lasting redefinition of green infrastructure within the metropolitan area of the Municipality of Bucharest.

1	Alba	425
2	Arad	1,020
3	Arges	610
4	Bacau	904
5	Bihor	869
6	Bistrita-Nasaud	322
7	Botosani	411
8	Brasov	1,365
9	Braila	502
10	Buzau	413
11	Caras-Severin	420
12	Calarasi	320
13	Cluj	1,221
14	Constanta	1,075
15	Covasna	177
16	Dambovita	289
17	Dolj	1,262
18	Galati	1,059
19	Giurgiu	70
20	Gorj	153
21	Harghita	365



22	Hunedoara	960
23	Ialomita	282
24	Iasi	993
25	Ilfov	2,765
26	Maramures	2,365
27	Mehedinti	663
28	Mures	1,524
29	Neamt	419
30	Olt	406
31	Prahova	725
32	Satu Mare	368
33	Salaj	217
34	Sibiu	557
35	Suceava	837
36	Teleorman	419
37	Timis	879
38	Tulcea	208
39	Vaslui	373
40	Valcea	518
41	Vrancea	183
42	M. Bucuresti	4,506

Fig. 5. Green space area by county in Romania, 2024 (unit of measurement: hectares)
Source: NIS, http://statistici.insse.ro [8].

Mureș County stands out in 2024 by reaching 1,524 hectares, confirming the sustained growth observed since 2022. This development indicates either a progressive expansion of urban amenities or a more comprehensive reporting of existing areas, placing the county in a reference position at the regional level. Similarly, Brașov maintains the high value recorded in 2023, signalling that the previous surge was not circumstantial but rather reflects a structural change in the reporting and classification of urban green spaces.

A consistent group of counties presents stable intermediate values, including Constanța (1,075 ha), Galați (1,059 ha), Iași (993 ha), Hunedoara (960 ha), Suceava (837 ha), Sibiu (557 ha), and Bihor (869 ha). In these cases, developments during the 2020–2024 period indicate a relative balance between the expansion of the built environment and the maintenance of green spaces, without abrupt variations suggesting major administrative changes.

At the lower end of the distribution, counties such as Giurgiu (70 ha), Gorj (153 ha), Vrancea (183 ha), Tulcea (208 ha), Sălaj (217 ha), and Covasna (177 ha) continue to record the smallest landscaped green space areas. The stability of these values throughout the analyzed period suggests the existence of persistent structural constraints related to the size and functionality of urban settlements, as well as to locally assumed development priorities.

Viewed as a whole, the evolution of urban green space area during the 2020–2024 period highlights a heterogeneous dynamic, marked by punctual administrative adjustments and pronounced regional differences. However, 2024 confirms the consolidation trend in territorial distribution, indicating that major changes in this indicator are more likely exceptions driven by methodological or administrative recalibrations, rather than the result of a uniform process of green space expansion at the national level. These findings provide a relevant framework for subsequent correlation with indicators concerning forest vegetation health and existing ecological pressures.

Subsequently, the analysis extends from the built environment to the general condition of vegetation through the examination of the indicator *"Intensity of tree damage according to crown defoliation rate,"* as both urban green spaces and the monitored trees reflect the environment's response to common pressures such as climate change, air pollution, and

anthropogenic stress. Their integrated assessment allows for a more coherent evaluation of environmental quality in Romania.

Table 1. Intensity of tree damage according to crown defoliation rate

Grad de defoliere a coroanei	Specii de păduri	2020	2021	2022	2023	2024
		U.M.: Procente				
Grupa de clase<=25%	Total	87.1	88	86.9	88.2	88.4
	Rășinoase	82.6	83.6	83.3	88.4	90.6
	Foioase	87.9	88.8	87.6	88.2	88
Grupa de clase>25%	Total	12.9	12	13.1	11.8	11.6
	Rășinoase	17.4	16.4	16.7	11.6	9.4
	Foioase	12.1	11.2	12.4	11.8	12

Source: NIS, http://statistici.insse.ro [8].

The indicator *Intensity of tree damage according to crown defoliation rate* provides essential information regarding the overall condition of tree vegetation and is widely used at the European level to assess the degree of biological stress affecting trees. Defoliation represents the loss of leaves or needles from the crown of a tree compared to a reference tree with a complete foliar apparatus and is considered an early signal of the impact exerted by factors such as unfavorable climatic conditions, air pollution, or other environmental stressors.

From a methodological perspective, the indicator is expressed as a percentage and is structured into two main groups:

-the ≤25% class group, which includes healthy or slightly damaged trees (defoliation classes 0 and 1),

-the >25% class group, which comprises moderately, severely damaged, or completely dry trees (defoliation classes 2–4).

Thus, high values in the ≤25% group indicate a favorable condition of vegetation, whereas an increase in the share of the >25% group signals intensifying environmental pressures.

The analysis of data for the period 2020–2024 shows that, at the national level, the majority of trees consistently fall within the ≤25% defoliation group, with values ranging between 86.9% and 88.4% of the total. This distribution suggests that, overall, the condition of tree vegetation in Romania remains within a relatively favorable range, without major large-scale deterioration during the analyzed period.

At the same time, the share of trees with defoliation greater than 25% remains limited, ranging between 11.6% and 13.1%. Although these values do not indicate a critical situation, they reflect the existence of a constant segment of vegetation affected by ecological stress, highlighting the vulnerability of certain ecosystems to external factors and the need for continuous monitoring of this indicator.

Differences between vegetation types are also relevant. In the case of broadleaved trees, values within the ≤25% group remain relatively stable throughout the period, suggesting moderate resilience to variations in environmental conditions. In contrast, for coniferous trees, a visible improvement is observed beginning in 2023, when the share of specimens classified within the ≤25% category increases significantly, while the proportion of those with high defoliation declines below 10% in 2024. This evolution indicates a reduction in stress levels affecting this type of vegetation in the final years analyzed.

Overall, the indicator shows that Romania remains in a state of relative balance regarding the condition of tree vegetation, with no signs of accelerated degradation, but also without uniform improvement at the national level. When correlated with the analysis of urban green spaces, this result suggests that environmental pressures manifest differently depending on territorial context and vegetation type, and that the integrated evaluation of these data provides a more nuanced picture of environmental quality during the 2020–2024 period.

The integrated analysis of statistical data concerning urban green space area and tree damage intensity directly explains and supports the statement formulated in the title of

the paper. On the one hand, the evolution of green spaces at the county level shows that cities are expanding, both through the increase of reported green areas and through significant administrative and urban reconfigurations, particularly visible in counties characterized by pronounced metropolitan dynamics. The punctual increases and territorial disparities reflect a process of urban adaptation in which green infrastructure is becoming an increasingly important component of local development, even though this process is not uniform nationwide.

On the other hand, the indicator regarding crown defoliation shows that the overall condition of tree vegetation remains within a relatively stable range, with a high share of healthy or slightly damaged trees throughout the 2020–2024 period. This stability suggests a certain degree of resilience of vegetation in the face of climatic variations and other stress factors, without, however, indicating a generalized improvement or a consistent reduction of existing vulnerabilities.

Nevertheless, the constant presence of a segment of trees with high defoliation, as well as the persistence of differences between vegetation types and between years, confirms that ecological pressures remain active. These pressures do not necessarily manifest through accelerated degradation or ecological collapse, but rather through chronic stress that limits regeneration capacity and amplifies ecosystem vulnerability to future extreme events.

In this context, the obtained results indicate that the expansion and reconfiguration of urban green spaces are not, in themselves, sufficient to eliminate environmental pressures. Although cities are consolidating their green infrastructure and tree vegetation demonstrates a certain degree of resilience, ecological balance remains fragile, dependent on climatic, administrative, and territorial planning factors. Thus, the title of the paper accurately synthesizes the reality highlighted by the data: urban development and the maintenance of vegetation condition coexist with persistent pressures that require continuous monitoring and coherent environmental policies.

S.W.O.T. Analysis

The S.W.O.T. analysis highlights a picture of fragile balance, in which strengths and opportunities coexist with persistent structural weaknesses.

The S.W.O.T. analysis is represented in the form of a conceptual tree, where the roots reflect the strengths of the environmental system, the trunk highlights structural vulnerabilities, the crown indicates development opportunities, and the external factors symbolize threats. This representation suggests a functional system, capable of resilience and adaptation, yet exposed to persistent ecological pressures.

The expansion of urban green spaces and the maintenance of a relatively good condition of tree vegetation constitute solid elements supporting the idea of environmental resilience during the analyzed period. These aspects confirm that, in certain regions, urban development has been accompanied by the consolidation of green infrastructure.

At the same time, the identified weaknesses highlight the lack of territorial coherence and the dependence of developments on administrative factors rather than on systematic ecological interventions. The constant share of trees with high defoliation suggests the presence of underlying environmental pressures that are not eliminated merely through the expansion of urban green spaces.

The identified opportunities reflect the potential use of the analyzed indicators as instruments for substantiating environmental policies, particularly in the context of climate change adaptation.

At the same time, the identified threats emphasize the risk that the positive developments observed may be counteracted by the intensification of ecological stress and the deepening of regional disparities.

The persistence of structural ecological pressures is also confirmed by other recent analyses, which underline that the stability of certain indicators does not exclude the existence of latent vulnerabilities [14].

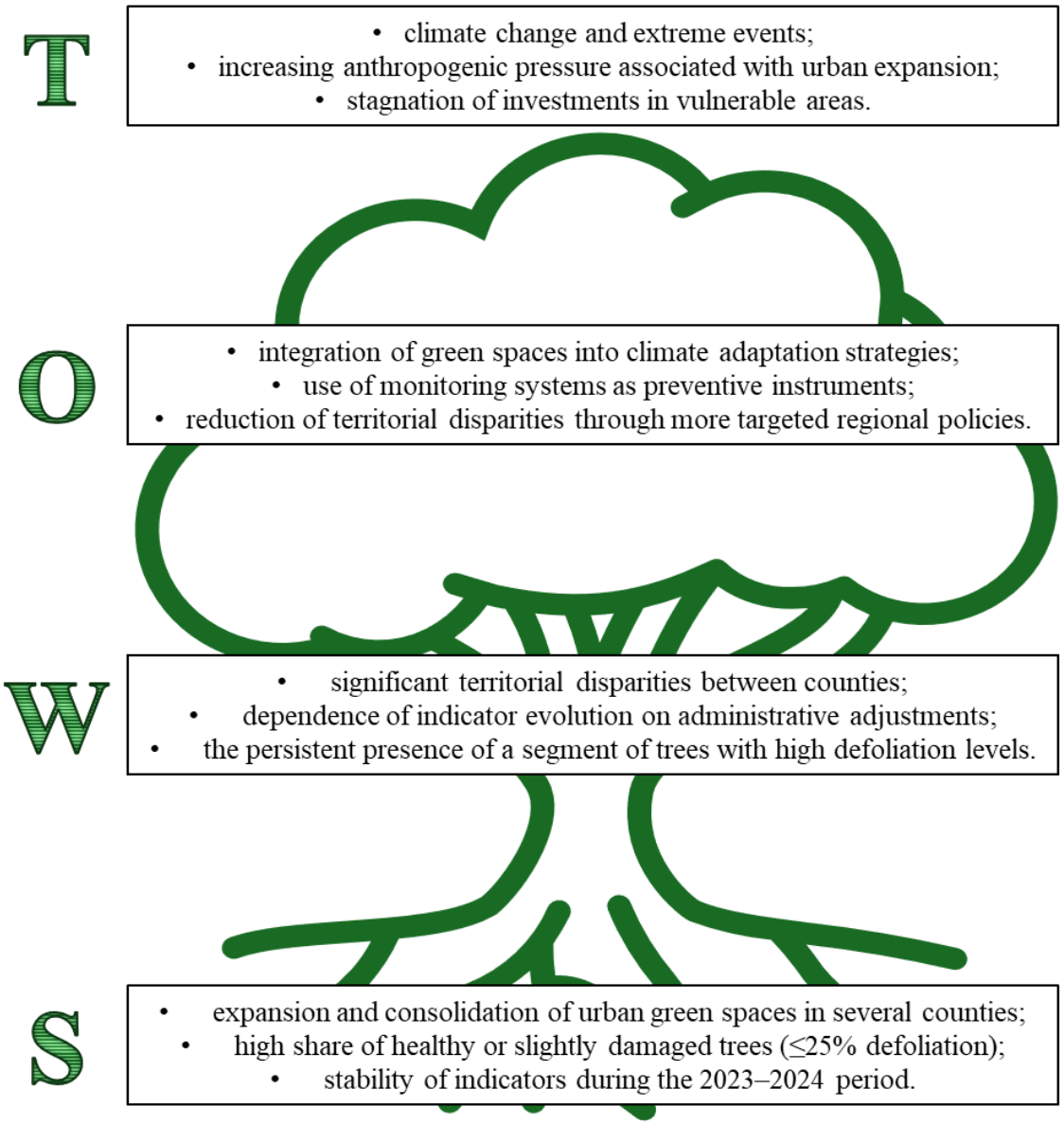


Fig. 6. "The Ecological Balance Tree": Visual interpretation of the S.W.O.T. analysis (created using Microsoft Office 365 – PowerPoint, Icons section)
Source: Own determination.

Overall, the S.W.O.T. analysis confirms the central message of the study: cities are expanding, vegetation endures, yet ecological pressures remain, and maintaining a sustainable balance depends on the capacity to transform identified opportunities into coherent policies applied in a territorially differentiated manner.

CONCLUSIONS

The analysis conducted for the period 2020–2024 highlights a complex and nuanced evolution of the environment in Romania, in which urban development, vegetation condition, and ecological pressures coexist within a fragile balance. The obtained results confirm that recent territorial transformations cannot be interpreted exclusively in terms of progress or decline, but rather require an integrated approach capable of capturing both positive dynamics and persistent vulnerabilities.

The evolution of urban green space area shows that, in several counties, cities have undergone processes of expansion and consolidation of green infrastructure, either through effective landscaping interventions or through

administrative and methodological updates. However, these developments have not been uniform at the national level, and territorial disparities remain pronounced. While certain counties have reached high and relatively stable values of urban green spaces, others continue to record low levels, suggesting significant differences in planning capacity and in the prioritization of urban environmental policies.

At the same time, the analysis of the intensity of tree damage according to crown defoliation rate indicates that the overall condition of tree vegetation remains within a relatively favorable range, with a high share of healthy or slightly damaged trees throughout the analyzed period. This stability suggests a certain degree of resilience of vegetation in the face of recent climatic and anthropogenic pressures. Nevertheless, the persistent presence of a segment of trees with high defoliation signals the existence of ongoing ecological pressures that cannot be ignored and that limit the possibility of a uniform improvement in environmental condition.

The correlation of the two sets of indicators demonstrates that the expansion of urban green spaces does not automatically translate into a reduction of ecological stress, but represents only one component of a far more complex system. Although cities are gradually consolidating their green infrastructure and vegetation demonstrates a certain resistance capacity, ecological pressures remain active, manifesting as structural and territorial vulnerabilities.

In this context, the S.W.O.T. analysis and its conceptual representation in the form of a tree accurately synthesize the results obtained: there are solid foundations supporting the current environmental condition, but also weaknesses and threats that may affect balance in the medium and long term. The findings of the study underline the importance of continuous monitoring of environmental indicators and their integration into urban and territorial planning processes, without assuming uniform or simplistic solutions.

In conclusion, the period 2020–2024 confirms the central message of the paper: cities are expanding, vegetation endures, yet ecological pressures remain. Maintaining a sustainable balance depends not only on the expansion of green spaces, but also on the capacity to understand and manage underlying environmental pressures through coherent policies adapted to territorial specificities and supported by robust statistical data.

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STUDY ON THE EVALUATION OF THE TOURIST POTENTIAL AND THE TECHNICAL AND MATERIAL BASIS OF TOURISM IN THE BAILE HERCULANE AREA, ROMANIA

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Abstract

The paper focuses on tourism in Băile Herculane, which must not only be reactivated, but must be reimagined, in a form that respects the sacred vocation of the place, that of healing. Health, not only physical, but also emotional, identity, ecological, can become the axis of its sustainable revival. This also contributes to the deep understanding of what Băile Herculane truly means, not only as a tourist destination, but as a symbol of a possible perfect harmony between man, nature and memory. Studying the area in more detail, it was observed that it possesses significant potential for the development of tourism in general and agrotourism, even if it is better known for spa and mountain tourism. Agrotourism guesthouses in the surrounding villages allow visitors to enjoy local traditions, specific gastronomy and the beauty of the rural landscape. An activity that has developed substantially in recent decades is accommodation at agrotourism guesthouses, where visitors can discover nearby picturesque villages and experience country life, enjoy traditional dishes prepared from local products and interact directly with the hosts.
Also, from the analysis of the technical and material base of tourism, it was found that there is a duality between tradition and the new transformation of the resort, which is actually the essence of the tourism problem in Băile Herculane. The city has obvious potential, supported by natural resources and infrastructure, but risks remaining trapped in an outdated model if it does not reevaluate its development strategies. The data suggest the need for intelligent repositioning, which should include diversifying the offer, digitizing services and integrating alternative tourism (ecotourism, wellness, agrotourism) in a coherent and sustainable way.

Key words*: agritourism, capital touristic, rural space, technical-material basis, tourist potential*

INTRODUCTION

From the studies and research carried out, it was concluded that Romania has a remarkable spa fund at the European level, which has not been exploited to its true potential until now. Also based on these, it was established that almost 1/3 of the thermal and mineral waters on the continent are found in our country. This value is accentuated by the complexity of natural factors, namely the finding in the same resort of the main environmental factors, along with a wide range of healing mineral substances, with beneficial multifactorial effects, which can be used in a multitude of spa treatments [2, 5, 14, 18, 20].

Hydrogeological research has shown that the Romanian subsoil contains a variety of spa resources located inside or on the surface of the earth's crust, which are complemented by existing climatic factors, due to the geographical position (solar radiation, atmospheric circulation, temperature, humidity, aeroionization, salt pan microclimate), thus offering a complete and complex balneo-climato-therapy potential, which can be used as an effective means of improving the spa tourism offer, both at national and local level [4, 19, 21, 22].

As for the tourist area under study, Băile Herculane, is characterized by its spa and historical wealth, being located in a spectacular natural setting, but which currently faces a series of constraints related to infrastructure degradation. However, it has a considerable tourist potential, based on a Roman history, the healing thermal springs and the mountain landscapes of the Domogled–Valea Cernei National Park. The main attraction of the resort is its unique thermal waters, with a high concentration of minerals such as calcium, copper, magnesium, manganese, selenium, zinc and iron. These waters are known for their anti-inflammatory and anti-allergic properties,

having been used in spa treatments since ancient times [6, 7, 11, 17, 35].

In the Herculane area, agritourism activity also emphasizes the valorization of local resources, and tourists can taste traditional Banat products, such as cheeses, cold cuts, jam and brandy, in guesthouses or directly from local producers. They can also do activities in nature, the mountainous area around Băile Herculane is ideal for hiking on marked trails, mountain biking and outdoor walks, offering a perfect complement to spa relaxation and rural experiences. At the same time, through agritourism, tourists can discover and participate in traditional activities specific to the area, traditions and crafts, such as weaving, woodworking or folk customs, thus contributing to the preservation of cultural heritage [3, 12, 13, 27, 32, 33].

In order to revive tourist activity in the area, we must take into account that looking towards Băile Herculane means stepping, at the same time, into the past, present and future. The resort is not just a point on the map, but a layered story, written in stone, water and collective memory. The thermal waters that spring ceaselessly from the depths of the mountains whisper healing stories that transcend the boundaries of the physical, while the historical buildings preserve in their structure the echoes of aristocracy, science and art [8, 9, 35, 42, 40, 46].

This work is not just a statistical analysis or a review of tourist attractions. It is an invitation to rediscover, to become aware of the fact that Băile Herculane is not only a place with unique potential, but a space that demands to be listened to, cared for and exploited responsibly. Beyond the analyses, the area reflects a spiritual geography, where nature and culture, man and mountain, legend and reality meet in perfect harmony [23, 36, 38, 42, 26].

The development of the area from a tourist and agritourism point of view must also target international demand more strongly, from the perspective of the economic effects it generates on local communities. Attracting tourists from the international market, both from neighbouring countries and from the EU, must be a priority. The economic effects generated by attracting a larger number of foreign tourists are significant, not only on the economic activity of tourist structures (which directly capitalize on thematic tourist products) but also on the overall economic development of the local community [1, 10, 25, 28, 34, 39, 41].

As is evident from other international research, in order to be attractive to these extremely demanding categories of tourists, thematic tourist products from a given area or country must be authentic, and the quality of related services must be impeccable. The main constraints in this regard are cultural and socio-political, and the poor representation of tourism in the local culture can generate discomfort for foreign visitors and alter the overall tourist experience. Political factors and decisions related to future developments in the international space must be carefully monitored, as their impact on global tourist circulation is significant [7, 15, 32, 37, 44].

The motivation for the research was also that in recent decades, through its important social and economic effects, spa tourism has become a major segment of the international tourist market, in which important material and human resources tend to be concentrated, by providing modern and high-quality tourist and medical services, which fully satisfy the essential requirements of the modern tourist. The motivation also came from the observation that after 1989, with the democratization of political and economic life, spa tourism in Romania, despite the high value of both quantitative and qualitative natural healing factors, entered a deep crisis, and the technical and material base underwent a process of continuous degradation [15, 18, 24, 29, 30].

MATERIALS AND METHODS

The process of carrying out the work involved the use of several investigation methods, namely: observation; analysis; explanation; comparison. For the statistical analysis, the data used were taken from the Tempo Online Database of the National Institute of Statistics [29].

During this research, we discovered a living world, vulnerable and at the same time full of

latent strength. The potential is there, both in the unique natural resources and in the human endowment, in the stories of villages suspended between sky and stone, in the echoes of Roman baths or in the modernity of wellness centers. There is no shortage of limitations, they often relate to infrastructure, the lack of coherent vision or the continuous degradation of the heritage, but even these can become starting points towards a sustainable regeneration [16, 35].

The true future of the Băile Herculane resort will not be built only by restoring buildings or rehabilitating roads, but by rediscovering its soul. By reconnecting to the essence that gave birth to it, that meeting between the sacred and the therapeutic, between legend and science. Tourism in the area, even if it remains anchored in treatments and infrastructure, is not just a simple industry, but a form of culture, of healing and of restoring the relationship between the individual and the space in which he lives.

This work thus becomes not just research, but a testimony. A silent but firm appeal to all those who can still look with sincere eyes at a resort that has not died, but is just waiting to be rediscovered.

Therefore, the Băile Herculane area does not need a "reinvention", but only a reminder. And this reminder begins with every work, every voice and every step taken towards tourist development. What was once the "Pearl of Central Europe" can shine again, not through gold and marble, but through authenticity, coherence and the love of those who choose to say it, feel it, support it.

RESULTS AND DISCUSSIONS

1.Evaluation of natural and anthropogenic resources of tourist interest

The tourist area of Băile Herculane represents a harmonious combination of historical heritage and natural therapeutic potential. The architectural heritage (period buildings, spa pavilions and historical monuments) organically blends with the mountain landscape, offering not only the possibility of health care, leisure, sports and entertainment, but also a complex experience of recovery and regeneration, both physical and spiritual. This fine balance between nature and culture, between resource and emotion, gives the area a uniqueness that is difficult to match in the Romanian and even European tourist landscape [2, 5, 21, 23, 37, 46].

The Băile Herculane resort offers a perfect combination of nature and culture, between resources and emotion, which ensures a unique tourist offer that is completely different from other Romanian and even European offers, while also being a reference offer in the spa tourism landscape. Accessibility in the area is supported by road, rail, air and river infrastructure, which significantly contributes to the development and diversification of domestic and foreign tourist circulation.

1.1. Natural tourist capital

The climate is temperate continental with a slight Mediterranean and mountainous nuance, determined by the geographical position and the structure of the relief and creating favorable conditions for the development of tourism and spa treatment, as well as the emergence and development of a very rich fauna and flora, which can be exploited as important assets in attracting tourists. In terms of the landscape, it is particularly picturesque, with a sculptural appearance carved by the karst relief, thermal springs, but also with endemic forests.

The natural resources of the area are essential resources for attracting visitors and balneology, giving the resorts an original and valuable tourist identity. An essential role in the valorization of the area is also given by the negative ionization of the air, with proven therapeutic effects, being considered a true support for the shaping of an exceptional natural tourist potential [2, 5, 21, 23, 37, 46].

Mineral waters (rich in sulfur, sodium, calcium and other trace elements) are spa resources with an essential role in healing primarily the body but also with a special role in improving the mental and emotional state, and thermal springs are water sources with properties considered almost miraculous with a role in improving health, regeneration and relaxation. Legends say that the goddess Hera gave it to people through Hercules, but the scientific

explanation for the healing effect is currently given by geology, because these meteoric waters penetrate the deep layers of the earth's crust, where, heated by the high internal temperature of the earth, they make their way through rock layers rich in minerals, reaching the surface with high concentrations of sulfur, calcium, magnesium, sodium and other trace elements, with undeniable therapeutic effects [2, 5, 21, 23, 35, 46].

The Băile Herculane resort benefits from over fifteen active mineral and thermal springs, used both in external procedures (baths, wraps, inhalations) and in internal cures. Among the most famous are the Hercules Spring, the Neptun Spring, the Diana Spring and the Domogled Spring. Each of these springs has its own story and a specific therapeutic value, which allows for the personalization of treatments and the diversification of the typologies of ailments addressed.

The Neptun, Domogled and Diana springs occupy a central place in the resort's spa landscape, being natural healing sources that, over time, have significantly contributed to the therapeutic prestige of Băile Herculane. These springs not only complete the hydromineral heritage of the area, but also offer a diverse range of uses, being adapted to both internal and external treatments. The chemical composition rich in sulphur, calcium, sodium, magnesium and other trace elements gives them remarkable therapeutic effects, validated by both traditional balneological medicine and modern research [2, 5, 21, 23, 35, 46].

The waters of these springs are captured and integrated into modern balneological circuits, which comply with European standards of hygiene and efficiency. Within the treatment bases they are used for general or individual baths, hot packs, underwater showers and inhalations. In particular, they are indicated in digestive, hepato-biliary, metabolic, respiratory diseases, but also in the treatment of degenerative rheumatism, arthrosis and dermatological diseases.

A special aspect of these springs is their variable temperature, ranging between 37 and 60°C, a characteristic that allows them to be used in thermal therapies without additional interventions. The natural heat of the water acts directly on the muscles and joints, relaxing, stimulating circulation and enhancing the absorption of active principles through the skin. The integration of these resources into modern treatment facilities has not diminished the sacred and deeply regenerative character of the water, but on the contrary, has allowed a more refined and personalized valorisation of each spring [2, 5, 21, 23, 35, 46].

The Hercules Spring concentrates in itself the entire essence of the resort, the regenerative power, the nobility of nature and the sacred communion of man and earth. Springing from the depths of the Hercules Cave, it stands out not only for its symbolism, but also for its geochemical characteristics. It has the highest flow rate of all the resort's springs, reaching 94.8 litres per second, an impressive flow that suggests abundance, strength and permanence. The mineralization of the water varies significantly, between 0.29 and 2.51 g/l, and its chemical composition oscillates between the bicarbonate-calcium and chlorosodic-calcium types. This diversity transforms the spring into an adaptable element in balneal therapy, being used for a wide range of conditions, from rheumatic and orthopedic ones, to digestive and metabolic disorders.

Its complex architecture, with caldarium, tepidarium and frigidarium rooms, reflects the refinement of imperial Rome, a culture that understood that health was an integral part of the harmony of being. Truly remarkable remains the functional continuity of the place, being used throughout the centuries, rediscovered and reinterpreted in each era. From the sacred baths of the Roman legions, they later became the inspiration for the thermal constructions of the Habsburg and Austro-Hungarian periods, and today, even in ruins, they continue to exert their attractive force.

Visitors who walk among the ruins do not just discover stone and mortar, but a special vibration, an inner call to simplicity, balance and ancestral wisdom [2, 5, 21, 23, 35, 46].

Domogled – Valea Cernei National Park is a sanctuary of biodiversity and deep peace. The mountain trails that cross the Feregari Gorges

or climb to Domogled Peak (1,105 m) can become true initiatory journeys. The Banat black pine forests raise their silhouette like silent sentinels, while the depths of the mountain hide caves with bat colonies and karst springs.

Hidden in the steep cliffs of the Cernei Mountains, *the Steam Cave* is a small fossil cave, approximately 14 meters long, accessible through a single narrow entrance. Local oral tradition attributes it to over two millennia and claims that Burebista himself knew this sacred place.

The cave's peculiarity lies in the constant emanations of thermal steam that rise from the depths through a crack in the rock, fed by a geothermal spring. The steam reaches temperatures between 52 and 56°C, and the humidity inside the cave reaches an impressive 100%, creating a unique microclimate with recognized therapeutic potential.

This atmosphere saturated with mineral vapour's generates the formation of gelatinous, fragile and translucent stalactites, several centimetres thick, sculpted by the interaction of hot water with the cold air from outside. On the damp walls of the cave grows an extremely rare endemic moss (Philonotis schliephackei) identified only here, which confirms the exceptional nature of the ecosystem. Also, the presence of sulfur in high concentrations contributes not only to the biological specificity, but also to the reputation of the place as beneficial for respiratory and rheumatic diseases. Under these conditions, visiting the cave can become a multisensory experience [2, 5, 21, 23, 35, 46].

The Great Soronişte Cave (Gaura din Soroniste, Gaura Dracului, Pestera Tatarczi, Pestera din Domogled) is located in the Domogled massif at an altitude of approximately 630 meters and represents one of the most spectacular underground structures in the area of the Domogled – Valea Cernei National Park. The cave houses stalactite formations, wall leaks and its own, relatively stable microclimate, which supports the life of rare troglobite species. In the past, it was associated with popular legends, for example the name *"Gaura Dracului"* reflects beliefs related to unseen telluric forces, to which the locals attributed the power to shape the underground and to hide treasures or spirits. It is not developed for tourist purposes. [2, 5, 21, 23, 35, 46].

The Outlaws' Cave (Grota haiducilor), located at a modest altitude, offers a wide-ranging view of the resort, being one of the most picturesque and mysterious karst formations in the area. It is also known by the popular names of the Thieves' Caveor the Thieves' Hole.

Access to the cave is easy, on a pedestrian trail that starts near the Roman Hotel, climbing gently through the deciduous forest to the entrance to the cavity. With a length of approximately 14 meters and a wide opening towards the valley, the Outlaws' Cave does not necessarily impress with its size, but with its legendary and cultural content. In past centuries, the cave would have been a refuge for outlaws (oral tradition mentioning hidden treasures), and was also a silent witness to the oaths and betrayals that occurred during the Ottoman expansion [2, 5, 21, 23, 35, 46].

The cave is now frequented by tourists who are passionate about light hiking and photography, being the ideal place for contemplation and reconnection.

The Vânturătoarea Waterfall is one of the most spectacular waterfalls in southwestern Romania, located just a few kilometres from the Băile Herculane resort, in the heart of the Cerna Mountains. Its waters fall from a height of approximately 40 meters, in a dramatic landscape, among steep slopes, bare rocks and lush vegetation.

Access to the waterfall involves a hike of medium difficulty, but the reward is visual and emotional. The route follows the Râmnuța valley and offers viewpoints towards the wild Cerna gorge, and at the end, the sound and visual spectacle of the "windy" water (named after the way the water is scattered in the air) creates a sensation of purification and amazement. During periods of high flow, the water curtain transforms into a veritable vapor screen, reflecting light and forming ephemeral rainbows [2, 5, 21, 23, 35, 46].

The Prisaca Dam and Lake, located approximately 6 kilometres downstream from

Băile Herculane, was built for hydropower purposes and to regulate the river flow, but later became a tourist attraction and viewpoint, due to its unique landscape. Also, in addition to it, spectacular tourist routes and a road that accompanies the valley have been created on the slopes, from which unique karst phenomena and biodiversity of the area can be observed, this harmoniously completing the ecological route of the Cerna Valley, also representing a living example of the harmonious integration of an energy objective in the surrounding natural environment [2, 5, 21, 23, 35, 46].

1.2. Anthropogenic tourist capital

Heritage buildings require extensive rehabilitation interventions, but in order to preserve the remarkable architectural appearance unaltered, these must be done with maximum responsibility and in close collaboration with specialists, so that through careful and responsible reconfiguration and remodelling, the resort can be reoriented towards a destination where wellness and cultural tourism is practiced at a maximum quality level. Their restoration and valorization could reconfigure the identity of the resort, bringing it back to the public's attention as a destination of excellence in wellness and cultural tourism.

The historic center of the Băile Herculane resort constitutes a living synthesis of history, architecture and the European spa spirit. Mentioned since antiquity under the name Ad Aquas Herculi Sacras, its true affirmation as an elite resort occurred in the 18th century, especially in the 19th century under the administration of the Austro-Hungarian Empire, when Băile Herculane was integrated into a vast program of modernization and imperial representation.

The historic center preserves impressive architectural masterpieces even today, in an urban ensemble of particular stylistic coherence. The buildings built during the Belle Époque period—marked by Baroque, Neoclassical, and Eclectic elements—reflect a period in which aesthetics, functionality, and imperial symbolism were in perfect harmony. The ornate facades, massive columns, pediments with mythological motifs, and arched wrought-iron walkways create an urban landscape of great historical and artistic value [2, 5, 21, 23, 35, 46].

The Casino, built in an eclectic style with obvious Neoclassical influences, was a veritable hub of European social and intellectual life in the 19th century. Balls, concerts, and gatherings of the Viennese elite were held here, in a sumptuous setting, complete with Viennese-inspired interior decor and refined furniture. The building remains one of the most telling symbols of its former grandeur, despite its current state, which requires urgent restoration.

The Imperial Pavilions (including the Central Pavilion and Pavilion 6) are true architectural jewels, built specifically to provide hospitality to dignitaries, members of the imperial family and high-ranking visitors. They have preserved the refined sobriety of neoclassical architecture and the intimate atmosphere of the elitist treatment of the past. The wide arches, vaulted corridors, carved columns and decorated stained glass windows are details that highlight the care for comfort, aesthetics and uniqueness. Beyond their aesthetic value, these buildings are carriers of cultural and identity memory, reflecting the moment when Băile Herculane was positioned among the top spa resorts in Europe. They illustrate not only an era, but also a model of sustainable tourism development, in which health care, culture and refinement coexisted harmoniously.

The Decebal Hotel, one of the most emblematic buildings in Băile Herculane, embodies the imperial spirit of the resort during its heyday in the 19th century. Built in the Viennese Baroque style, the building impresses with its monumental proportions, richly ornamented pediments, massive columns and fine architectural details, which evoke the aristocratic elegance specific to the Habsburg era [2, 5, 21, 23, 35, 46].

Originally intended to accommodate the nobility and high-ranking officials, the hotel was an integral part of the imperial spa complex, offering not only accommodation, but a sophisticated experience, in a refined environment, complemented by the proximity to the thermal springs. Every element of its

construction, from its privileged location near the Central Pavilion, to the interior decorations and the symmetry of the facades, was designed to evoke the prestige and therapeutic value of a unique thermal resort.

The statue of Hercules, made in the Viennese workshops of the famous sculptor Dominik Fernkorn (1847), watches over the Hercules Spring (located nearby) with unreal solemnity and dignity, thus deepening the connection between myth and reality, between past and present.

Beyond the aesthetic force of the artistic composition, the work has a special symbolic value, Hercules (in Greco-Roman mythology), the hero subjected to great trials, acquired the strength to overcome obstacles, just as by analogy, thermal waters have the inner power to heal the body and strengthen the spirit [2, 5, 21, 23, 35, 46].

The statue, with a height of almost 4 meters, witnessed the times of imperial glory, the post-war decline and the contemporary tourist revival, being also a landmark and contemplation point for locals and visitors.

Hotel Diana, is located in the middle of a wonderful landscape and natural environment and very close to the valuable thermal springs, benefiting from the strongly ionized air, is the tourist reception structure with a representative offer within the resort. It was recently renovated by the Bacolux Hotels Romania brand and reclassified to three stars, with a new spa center certified for thermal mineral water therapies, physiotherapy procedures, electrotherapy, therapeutic massage, mud packs and galvanic baths.

Hotel Afrodita is located in a privileged location very close to the forest and the main thermal springs, is considered one of the most refined tourist structures in Herculane and health care based on thermo-mineral waters. It was completely renovated and remodelled according to the most demanding modern international standards, offering high-quality tourist services, with personalized spa and medical recovery programs [2, 5, 21, 23, 35, 46].

Sara's Sons Hotel represents a bridge between traditional Romanian hospitality and the demands of current wellness and treatment tourism. Located in a secluded and quiet area of the city and in the vicinity of thermal springs, the hotel stands out for its intimate atmosphere, personalized services and a therapeutic offer well adapted to the needs of tourists. It promotes a holistic approach to well-being, encouraging not only physical healing but also emotional relaxation and inner balance. The treatments offered target a wide range of rheumatic, post-traumatic or mild neurological conditions, and are supervised by medically trained specialists.

Due to its smaller size compared to large resorts, Sara's Sons cultivates a direct relationship with guests, which makes it a frequent choice for tourists looking for not just a place to stay, but a complete experience. In this way, the hotel contributes to the diversification and enrichment of the local tourist landscape, offering an elegant and accessible alternative, strongly anchored in the spa spirit of the place [2, 5, 21, 23, 35, 46].

1.3. Traditional villages

In contrast to the hustle and bustle of the Băile Herculane resort and the modernity of the spa complexes, the traditional villages of the Cerna Valley are preserved as islands of time, where the rhythm of life is still dictated by the seasons, by the work of the fields and by the rules inherited from generations.

Set on the slopes or along the Cerna River, these villages, such as Prisăcina, Dobraia, Ineleț, Scărișoara or Godeanu, are not just simple rural settlements, but true landmarks of ethnographic identity.

The difficult access, often achieved only by steep paths or wooden stairs fixed in the rock (the famous "stairs to heaven" at Ineleț), contributed to the isolation and authentic preservation of these communities.

Here, wooden houses with shingle roofs, home-made fabrics, brightly coloured folk costumes and a language with archaic inflections outline a distinct universe, where tradition is not an act of museumification, but a natural way of life [2, 5, 21, 23, 31, 35, 46].

The hospitality of the locals, the stories told around the stove and the sacred simplicity of everyday life, attract more and more tourists in

search of authentic experiences. At the same time, these villages represent an opportunity to develop sustainable rural tourism, through ecotourism initiatives, accommodation in traditional households, local gastronomy and craft workshops. From a heritage perspective, they constitute a living testimony of Romanian ethnogenesis and a cultural resource that should be more actively included in responsible tourism strategies. The surrounding landscape, dominated by forests, alpine meadows and cliffs, amplifies the value of these villages, transforming them into unique destinations, where adventure tourism blends with spiritual or contemplative tourism. Valorizing the traditional villages of the Cerna Valley means not only promoting the beauty of this area, but also respecting the spirit of a world that endures through simplicity, community and a deep connection with nature [2, 5, 21, 23, 31, 35, 46].

2.Evaluation of the technical and material base for tourism

2.1. Accommodation units

During the period 2022–2024, the dynamics of tourist accommodation structures in Băile Herculane reveal a complex reality, tense between apparent stability and the need to adapt to a changing tourist landscape.

Table 1. Accommodation units (number) in Băile Herculane (2022-2024)

Types of tourist reception structures		2022		2023		2024	
		No.	%	No.	%	No.	%
Total	Caraș-Severin, of which:	334	100	337	100	353	100
	Băile Herculane	91	27.25	93	27.60	94	26.63
Hotels	Caraș-Severin, of which:	35	10.48	35	10.39	34	9.63
	Băile Herculane	16	4.79	16	4.75	15	4.25
Hostels	Caraș-Severin, of which:	10	2.99	9	2.67	11	3.12
	Băile Herculane	3	0.90	3	0.89	4	1.13
Apartments and rooms for rent	Caraș-Severin, of which:	67	20.06	69	20.47	89	25.21
	Băile Herculane	18	5.39	18	5.34	21	5.95
Apartment hotels	Caraș-Severin, of which:	:	0.00	:	0.00	1	0.28
	Băile Herculane	:	0.00	:	0.00	1	0.28
Motels	Caraș-Severin, of which:	4	1.20	5	1.48	5	1.42
	Băile Herculane	1	0.30	1	0.30	1	0.28
Tourist villas	Caraș-Severin, of which:	3	0.90	4	1.19	5	1.42
	Băile Herculane	1	0.30	1	0.30	1	0.28
Tourist cabins	Caraș-Severin, of which:	19	5.69	20	5.93	19	5.38
	Băile Herculane	1	0.30	1	0.30	1	0.28
Bungalows	Caraș-Severin, of which:	3	0.90	4	1.19	4	1.13
	Băile Herculane	1	0.30	2	0.59	2	0.57
Camping sites	Caraș-Severin, of which:	4	1.20	4	1.19	5	1.42
	Băile Herculane	:	0.00	:	0.00	1	0.28
Tourist rest stops	Caraș-Severin, of which:	5	1.50	4	1.19	3	0.85
	Băile Herculane	3	0.90	3	0.89	3	0.85
Tourist cottages	Caraș-Severin, of which:	6	1.80	7	2.08	7	1.98
	Băile Herculane	1	0.30	1	0.30	1	0.28
Tourist guesthouses	Caraș-Severin, of which:	71	21.26	71	21.07	68	19.26
	Băile Herculane	44	13.17	45	13.35	40	11.33
Agritourism guesthouses	Caraș-Severin, of which:	105	31.44	103	30.56	100	28.33
	Băile Herculane	2	0.60	2	0.59	3	0.85

Source: processing based on own data and from NIS [29], :Missing data.

Although the city continues to be a dominant pole within Caraș-Severin County, concentrating almost half of the total accommodation capacity, the analyzed figures indicate a series of subtle but persistent imbalances between what exists, what works and what is really used.

The analysis of the data in Table 1 attests to the following:

• tourist guesthouses dominate the local market, constituting the main form of

accommodation and even if their number has registered a slight decrease (from 48% in 2022, to 43% in 2024), they hold a consistently high share;

• the increase in the number of apartments and rooms for rent from 19.8% (2022) to 22.3% (2024), indicates a diversification of the offer influenced by the demand for private, independent spaces (like AirBnB);

• hotels have a slightly downward trend, explainable by high costs and changes in tourist preferences from 17.6% in 2022 to 16.0% in 2024;

• hostels and agrotourism guesthouses have recorded slight percentage increases, small but significant, with alternative segments constantly consolidating their position;

• motels, tourist villas, cabins, campsites, tourist cottages and tourist stops are the structures with a small share (shares below 2%), but stable, remaining constant in the offer.

If we analyze the number of tourist reception structures (Table 1), in the period 2022-2024, at the level of Caraș-Severin County, it is found that the total number of tourist structures increased from 334 (in 2022) to 353 (in 2024), with an increase of 5.69%.

The most significant percentage increases were in tourist villas +66.67%; bungalows +33.33%; apartments and rooms for rent +32.84%; motels and campsites +25%. Decreases were recorded in: tourist stops (-40%); tourist guesthouses (-4.23%); agritourism guesthouses – (4.76%); hotels (-2.86).

During the analyzed period, apartments and rooms for rent were the most popular form of accommodation, registering an increase of almost 33%.

Apartment hotels were non-existent until 2024, when only one such unit appeared. Tourist and agritourism guesthouses, although remaining important forms of accommodation in the county, their number decreased relatively slightly, the probable cause being the conversion or closure of some units (Table 2).

2.2. Accommodation capacity

Overall, the existing accommodation capacity in the city of Băile Herculane remained almost constant (5,090 places in 2022; 5,131 in 2023; 5,050 in 2024).

The city's share at the county level decreased slightly, from 48.15% (2022) to 46.56% (2024), which otherwise indicates local stagnation (Table 3).

In terms of tourist structures, hotels dominate the existing structure, but their share decreases, from 33.04% (in 2023) to 31.32% (in 2024), from 3,504 places in 2023 to 3,398 places in 2024, due to the reduction in the capacity of some large hotels or the lack of renewal of operating permits.

Hostels show a significant increase in 2024 (from 1.00% to 2.93%), which indicates the orientation towards low-cost structures, attractive to young people and groups.

The accommodation capacity in apartments and rooms for rent had a slow upward trend from 2.19% (2022), 2.17% (2023), to 2.19% (2024), which signals a greater involvement of the private sector. The accommodation capacity in campsites and bungalows has been increasing slightly, (Table 3) which suggests an increase in interest in alternative, more intimate or nature-based forms.

Regarding the operating accommodation capacity (Table 4), the constant dominance of hotels is noticeable, over 50% at the county level and over 40% in the case of the city of Băile Herculane, with a slight decrease in 2024 in both cases. The decrease may be due to the closure of some hotels or the decrease in demand for this type of accommodation, in favor of more flexible alternatives.

The decrease in the share of operating accommodation capacity from 9.20% (2022) to 8.388% (2024) in tourist guesthouses is particularly noticeable, which indicates a reduction in functional capacity or the withdrawal of some operators from the market. The decrease may also be associated with the increase in operating costs or the migration of tourists to other, more accessible forms of accommodation. Apartments and rooms for rent show a decrease in 2024 compared to 2022 and 2023, a sign that the private sector is quickly adapting to market demands. Tourist villas and cabins have seen decreases and even stagnation.

Table 2. Accommodation units (number) in Caraș-Severin County (2022-2024)

Types of tourist reception structures		2022		2023		2024	
		No.	%	No.	%	No.	%
Total	Total country, of which:	12,201	100	12,697	100	13,538	100
	Caraș-Severin	334	2.74	337	2.65	353	2.61
Hotels	Total country, of which:	1,602	13.13	1,601	12.61	1,608	11.88
	Caraș-Severin	35	0.29	35	0.28	34	0.25
Hostels	Total country, of which:	313	2.57	316	2.49	329	2.43
	Caraș-Severin	10	0.08	9	0.07	11	0.08
Apartments and rooms for rent	Total country, of which:	3,081	25.25	3,591	28.28	4,411	32.58
	Caraș-Severin	67	0.55	69	0.54	89	0.66
Apartment hotels	Total country, of which:	27	0.22	27	0.21	30	0.22
	Caraș-Severin	:	0.00	:	0.00	1	0.01
Motels	Total country, of which:	207	1.70	198	1.56	194	1.43
	Caraș-Severin	4	0.03	5	0.04	5	0.04
Tourist villas	Total country, of which:	758	6.21	756	5.95	703	5.19
	Caraș-Severin	3	0.02	4	0.03	5	0.04
Tourist cabins	Total country, of which:	220	1.80	223	1.76	218	1.61
	Caraș-Severin	19	0.16	20	0.16	19	0.14
Bungalows	Total country, of which:	493	4.04	475	3.74	460	3.40
	Caraș-Severin	3	0.02	4	0.03	4	0.03
Camping sites	Total country, of which:	71	0.58	84	0.66	107	0.79
	Caraș-Severin	4	0.03	4	0.03	5	0.04
Tourist rest stops	Total country, of which:	39	0.32	41	0.32	38	0.28
	Caraș-Severin	5	0.04	4	0.03	3	0.02
Tourist cottages	Total country, of which:	127	1.04	155	1.22	201	1.48
	Caraș-Severin	6	0.05	7	0.06	7	0.05
Camps for students and preschoolers	Total country, of which:	47	0.39	46	0.36	42	0.31
	Caraș-Severin	2	0.02	2	0.02	2	0.01
Tourist guesthouses	Total country, of which:	1,696	13.90	1,642	12.93	1,574	11.63
	Caraș-Severin	71	0.58	71	0.56	68	0.50
Agritourism guesthouses	Total country, of which:	3,484	28.56	3,498	27.55	3,578	26.43
	Caraș-Severin	105	0.86	103	0.81	100	0.74

Source: processing based on own data and from NIS [29], :Missing data

Tourist villas reappear in 2024 with a reduced share (0.19%), and chalets register decreases, suggesting a lack of investment or low interest in this type of structure.

The operating accommodation capacity for campsites and bungalows has recorded minor but significant fluctuations, as follows: campsites reappear in 2024 (0.24%), possibly due to the reopening of seasonal locations or the development of adventure tourism; in bungalows it decreases in 2023 and partially recovers in 2024, a sign of a renewed interest in simple and cheap accommodation.

In hostels, the operating accommodation capacity has been steadily increasing, a clear signal that low-cost tourism and young travellers are growing in the area.

The operating accommodation capacity has doubled in agritourism guesthouses, this change may signal the increased interest in authentic experiences and nature.

At the city level of Băile Herculane, the operating accommodation capacity decreased from 1,237,442 place-days in 2023 to 1,205,707 place-days in 2024.

This state of affairs confirms the closure or partial operation of some units.

During the analyzed period, the most affected appear to be tourist guesthouses, hotels and tourist villas, suggesting economic or maintenance difficulties.

The reappearance of campsites and the increase in interest in agrotourism indicate a change in tourist preferences and in the area's business model.

Table 3. Existing accommodation capacity (no. of places) by type of structure in Băile Herculane (2022-2024)

Types of tourist reception structures		2022		2023		2024	
		Places	%	Places	%	Places	%
Total	Caraș-Severin, of which:	10,572	100	10,604	100	10,846	100
	Băile Herculane	5,090	48.15	5,131	48.39	5,050	46.56
Hotels	Caraș-Severin, of which:	4,713	44.58	4,757	44.86	4,651	42.88
	Băile Herculane	3,460	32.73	3,504	33.04	3,398	31.32
Hostels	Caraș-Severin, of which:	270	2.55	242	2.28	329	3.03
	Băile Herculane	106	1.00	106	1.00	148	2.93
Apartments and rooms for rent	Caraș-Severin, of which:	982	9.29	1,035	9.76	1,299	11.97
	Băile Herculane	232	2.19	230	2.17	248	2.28
Apartment hotels	Caraș-Severin, of which:	:	0.00	:	0.00	16	0.14
	Băile Herculane	:	0.00	:	0.00	16	0.14
Motels	Caraș-Severin, of which:	135	1.28	147	1.39	147	1.35
	Băile Herculane	30	0.28	30	0.28	30	0.27
Tourist villas	Caraș-Severin, of which:	70	0.66	92	0.87	105	0.96
	Băile Herculane	32	0.30	32	0.30	32	0.29
Tourist cabins	Caraș-Severin, of which:	427	4.04	441	4.16	431	3.96
	Băile Herculane	14	0.13	14	0.13	14	0.12
Bungalows	Caraș-Severin, of which:	64	0.61	80	0.75	76	0.70
	Băile Herculane	12	0.11	28	0.26	24	0.22
Camping sites	Caraș-Severin, of which:	182	1.72	166	1.57	206	1.89
	Băile Herculane	:	0.00	:	0.00	40	0.36
Tourist rest stops	Caraș-Severin, of which:	325	3.07	290	2.73	208	1.91
	Băile Herculane	208	1.97	208	1.96	208	1.91
Tourist cottages	Caraș-Severin, of which:	92	0.87	100	0.94	108	0.99
	Băile Herculane	12	0.11	12	0.11	12	0.11
Tourist guesthouses	Caraș-Severin, of which:	1,470	13.90	1,435	13.53	1,372	12.64
	Băile Herculane	948	8.97	937	8.84	834	7.68
Agritourism guesthouses	Caraș-Severin, of which:	1,691	16.00	1,668	15.73	1,747	16.10
	Băile Herculane	36	0.34	30	0.28	46	0.42

Source: processing based on own data and from NIS [29], : Missing data

DISCUSSIONS

It is known that in Romania and including the Herculane area after 1990, the traditional model of spa tourism, focused on long-term cures (14–21 days) entered a period of decline because it could not adapt to the new market requirements, which were more oriented towards wellness and prevention. Currently, this classic model depends largely on treatment tickets through the social insurance system. Spa resorts are believed to be intended exclusively for the elderly (+60 years) or those with chronic conditions. Tourists also prefer short vacations (city breaks) or dynamic, personalized online packages, which include mental health services, mindfulness, recovery from burnout and modern therapies: cryotherapy, mofeta. At the Herculane resort level, the tourist offer can be considerably improved and personalized by capitalizing on biodiversity, the very rich rural and cultural heritage, essential aspects for the development and relaunch of agrotourism, ecotourism and wellness tourism. Studies conducted in the area consider that climate change also has an impact on the reorientation of tourism activity towards sustainable, authentic experiences and in connection with nature. The reorientation involves practicing agritourism by involving tourists in traditional agricultural activities, local culinary experiences and accommodation in rural households. Practicing ecotourism, which is responsible tourism, based on observing fauna and flora, hiking and cycling, promoting and preserving the environment. At the same time, wellness tourism must be developed in the area, because the spa resources, mineral waters and therapeutic climate offer high potential for spa centers, natural treatments and relaxation programs, with an emphasis on health.

Table 4. Operating accommodation capacity (places-days) by type of structure in Băile Herculane (2022-2024)

Types of tourist reception structures		2022		2023		2024	
		places-days	%	places-days	%	places-days	%
Total	Caraș-Severin, of which:	2,126,193	100	2,107,691	100	2,068,717	100
	Băile Herculane	1,223,179	57.53	1,237,442	58.71	1,205,707	58.28
Hotels	Caraș-Severin, of which:	1,162,682	54.68	1,176,893	55.84	1,134,785	54.85
	Băile Herculane	908,623	42.73	915,038	43.41	894,362	43.23
Hostels	Caraș-Severin, of which:	37,580	1.77	49,938	2.37	58,281	2.82
	Băile Herculane	16,340	0.77	23,870	1.13	25,896	1.25
Apartments and rooms for rent	Caraș-Severin, of which:	194,863	9.16	171,932	8.16	205,106	9.91
	Băile Herculane	47,077	2.21	34,474	1.64	36,122	1.75
Tourist villas	Caraș-Severin, of which:	17,326	0.81	16,334	0.77	16,356	0.79
	Băile Herculane	4,896	0.23	:	0.00	3,936	0.19
Tourist cabins	Caraș-Severin, of which:	69,473	3.27	53,471	2.54	51,619	2.50
	Băile Herculane	5,082	0.24	5,096	0.24	3,850	0.19
Bungalows	Caraș-Severin, of which:	8,984	0.42	8,000	0.38	4,220	0.20
	Băile Herculane	2,580	0.12	1,836	0.09	2,196	0.11
Camping sites	Caraș-Severin, of which:	14,990	0.71	13,480	0.64	13,355	0.65
	Băile Herculane	:	0.00	:	0.00	5,035	0.24
Tourist rest stops	Caraș-Severin, of which:	37,068	1.74	42,092	2.00	45,630	2.21
	Băile Herculane	37,068	1.74	42,092	2.00	45,630	2.21
Tourist cottages	Caraș-Severin, of which:	10,188	0.48	9,804	0.47	10,268	0.50
	Băile Herculane	1,356	0.06	3,572	0.17	3,144	0.15
Tourist guesthouses	Caraș-Severin, of which:	294,641	13.86	301,072	14.28	277,857	13.43
	Băile Herculane	195625	9.20	206454	9.80	173416	8.38
Agritourism guesthouses	Caraș-Severin, of which:	249,710	11.74	240,179	11.40	225,674	10.91
	Băile Herculane	4,532	0.21	5,010	0.24	12,120	0.59

Source: processing based on own data and from NIS [29].

An important component that can contribute to the revitalization of the Herculane area and that can be practiced by all reception structures is alternative tourism, which includes cultural, religious (monasteries), adventure or culinary tourism, offering unique and authentic experiences, while also contributing to diversifying and completing the spa tourism offer. Diversifying tourism into these forms not only reduces the impact on the environment, but also stimulates regional economic development, especially in the context in which domestic tourism represents a major component of the economic sector. Tourism in the Herculane resort faces major structural imbalances, even in recent years, generated by a mixture of poor infrastructure, changes in consumer behavior and ineffective promotion.

The major problems identified both at national level and at the Herculane area level are: the mix between tradition and modernity: there is a visible discrepancy between accommodation units that have invested in international standards and those that have remained at the level of past decades. Low occupancy rate and seasonality: generated by the decrease in Romanians' vacation budgets and the non-granting of vacation vouchers. Lack of visibility and identity: the lack of a coherent country brand and a promotion strategy that would attract foreign tourists. The lack of qualified and specialized personnel for various types of treatment, combined with a low salary level, leads to the migration of employees from the sector.

The valorization of the identity of Băile Herculane for sustainable development can be achieved by restoring the historical heritage (e.g. the Casino, the Imperial Baths) for tourism purposes, promoting modern balneology based on natural resources (thermal waters, microclimate) and developing ecotourism in the Domogled-Valea Cernei National Park. Integrating Roman and Austrian history into unique cultural experiences and attracting green investments can transform the resort into a sustainable destination throughout the year. By practicing new forms of tourism

based on the ecological principles of preserving and protecting the environment and cultural and historical values and by applying support measures at both local and central levels, Băile Herculane can regain its status as a renowned European resort, while protecting its resources for future generations.

The transformation of tourism demand is the result of an interdependence between the diversification of accommodation units and the new priorities of modern travelers. The modern tourist is much more informed and oriented towards specific values such as: authenticity they often avoid standardized hotels in favor of spaces that reflect local tradition; permanent connectivity has become a fundamental need; increasing awareness of the principles of sustainability which leads to a growing demand for tourism with low environmental impact. As a result of reaching this higher level of awareness, demand is no longer dictated solely by price, but by experiential value. There are many tourists who choose rural accommodations where they tend to get more involved in outdoor activities, while others prefer to participate in a wider spectrum of urban activities.

In order to reposition the Băile Herculane resort as a top European destination, first of all the authorities must act to recover and restore the imperial heritage, return as much as possible of the historical buildings to the public heritage, all 19 symbolic buildings of the resort, including the Apollo Complex and the Old Casino to be recovered, subsequently they must initiate a coherent and integrated restoration plan, to restore the splendor of the "Imperial Center". At the same time, action must be taken to modernize the Spa Tourism infrastructure - massive investments in specific infrastructure that will lead to the transformation of the resort into a modern wellness and treatment center, the rehabilitation of thermal water networks and adjacent public spaces. Urban regeneration and green spaces must also be carried out - specific revitalization projects that will improve the tourists' experience outside the treatment facilities. Social and cultural revitalization by creating a calendar of events that will attract new segments of visitors (young people, active tourists), which will ultimately lead to the transformation of the image of an "outdated" resort into a vibrant and cultural one. Another important objective is the creation of a modern urban framework by implementing a new General Urban Plan (PUG), which will regulate new constructions and ensure sustainable development that does not affect the unique historical and natural character of the resort.

CONCLUSIONS

Strategically positioned in a contact area between the Romanian and Balkan areas, in a place endowed with exceptional tourist potential, the Băile Herculane resort has evolved over time. The thermal waters, with temperatures ranging between 38°C and 60°C, rich in minerals such as sulfur, sodium, calcium and magnesium, are recognized for their beneficial effects in treating rheumatic, neurological and dermatological conditions.

By preserving its historical and natural values, Băile Herculane continues to be a reference space in the tourism landscape, offering a remarkable continuity of tradition, medical science and reconnection with nature.

Among the tourist reception structures, the dominant structure remains the hotel, with a consistent share, both in functional capacity and in the number of overnight stays, supporting the idea that classic spa tourism, with treatment facilities, long-term stays and medical tourism, still dictates trends in the area.

This tourism model attracts a loyal clientele, which favors comfort and predictability, but leaves little room for innovation or diversification.

On the other hand, alternative accommodation structures (hostels, tourist villas, chalets, campsites and family-type spaces) although present in the landscape, remain marginal in terms of actual use. Occupancy rates for these units rarely exceed 20%, and some, such as inns or school camps, are dangerously close to the threshold of economic irrelevance.

This discrepancy seems to betray not a lack of infrastructure, but rather a crisis of visibility, identity and adaptability.

Interestingly, although total capacity remains relatively constant, functional capacity registers a slight decrease in 2024. This subtle gap signals either temporary closures of some units or a strategic decision to reduce expenses by not fully utilizing available spaces.

At the same time, the net occupancy rate, although slowly increasing, does not exceed 30 % overall, which indicates a modest occupancy rate, contradicting the perception of mass tourism associated with the resort.

It should also be noted that new or more flexible structures, such as apartments and rooms for rent in a hotel system, have an increasingly visible presence. Although they fail to rival hotels in terms of volume, they reflect a subtle transformation of tourist demand (younger, more mobile tourists, interested in autonomy, price and authentic local experience).

In essence, the Băile Herculane tourist area seems to be at a crossroads, between the glory of a consecrated spa past and the opportunities of a plurivalent tourist future. The choice of direction depends less on current figures and more on the courage with which the local community and the authorities will know how to transform these data into policies, vision and action.

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STUDY ON THE EVOLUTION AND DEVELOPMENT OF SUSTAINABLE RURAL TOURISM IN BRAȘOV COUNTY, ROMANIA

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Abstract

The paper aims to evaluate and analyze sustainable rural tourism in the Brașov area, which is based on picturesque villages, medieval fortresses, the promotion of crafts and local entrepreneurs, while also addressing sustainable development by increasing their quality and visibility, correlated with the harmonious and responsible development of the Brașov metropolitan area. In the first part, picturesque relief areas are researched and presented, with traditional villages, where rural tourism has begun to develop in a sustained but not very responsible way. The medieval fortresses that add cultural value to the area are also targeted. The analysis of tourism indicators regarding the rural tourism offer attests to a considerable existing potential in the area. In particular, the expansion of the number of tourist and agritourism guesthouses is noteworthy, representing almost half of the total number of tourist reception structures existing in Brașov County. At national level, the representativeness of agritourism guesthouses existing in Brașov is around 10%. In the last part, it was insisted on determining the importance of sustainable development of rural tourism which by design represents the harmonious combination between tourist activity, protection of the natural environment, preservation of cultural traditions and sustainable development. From this study, it was observed that in the Brașov area, investments are made in local entrepreneurs, in order to improve the quality and visibility of rural tourism and that it is necessary to raise the awareness of the population to reduce pollution, a crucial aspect in the long-term development strategy.

Key words: *quantitative analysis, rural tourism, agritourism, durable tourism, rural space, tourist potential*

INTRODUCTION

Today, no one can deny the importance of rural tourism. For over 200 years, rural areas around the world have attracted and continue to attract an increasing number of tourists, being the most popular form of tourism. Agritourism is fully integrated into rural tourism, both activities complement and support each other, constituting a field that must be specifically organized taking into account the role it must play in the development of rural space. Rural accommodation is a hospitality service on a smaller scale, combining human and cultural authenticity, gastronomy and traditions, within the limits of resource conservation [11, 20, 37, 39].

A territory and its resources are highlighted through equipment and planning, so that an area, sub-area or village becomes a tourist destination. When a tourism planning and development strategy is created, the territorial realities of the country and areas, as well as quantitative and qualitative determinations, must be taken into account [25, 29, 38, 40].

In the last three decades, we have all witnessed an accelerated expansion of tourist activities in Romanian rural areas. Satisfying tourist demand implicitly implies the possibility of its assimilation by the environment. Therefore, tourist activity exerts pressure on natural resources, anthropogenic resources and to the same extent on the population in those areas. The negative pressure of tourist activity is distinguished by visual and auditory pollution, the expansion of constructions to the detriment of the landscape, waste, water, soil, air and environmental pollution, environmental risk, degradation/devaluation of historical and cultural objectives and monuments [2, 8, 12, 15, 28, 31].

Under these conditions, the evaluation and monitoring of the dynamics and intensity of the impact of tourist activities in Romanian rural areas is more than necessary. The attractiveness of rural areas in Brașov County

is based on the unmodified environment, authentic rurality, without irreversible imbalances. Such areas can be declared "unique" under the conditions of preserving the current balance [14, 25, 27, 32].

Due to the rich tourism potential that Romania has, the "Tourism" sector could contribute more to the socio-economic development of the country. The direct contribution of the tourism sector to the national GDP was, in 2024, 2.5%, and the total contribution of 5.6%, among the lowest in Europe. The main objective of any tourism activity is to generate a source of income, in which the private sector plays an essential role. The development of tourism also contributes to the development of the state sector, mainly through the revenues generated to the budget from the payment of taxes and duties for the activities carried out and by generating jobs [3, 4, 7, 13]. In addition, adapting the infrastructure, renovating buildings, improving the natural environment, improving the image of the area, etc. will have an immediate effect on improving the standard of living of residents and will influence visitors' decision to choose Brașov County as a tourist destination. Therefore, the effort that must be made by the local administration to boost tourism must be understood as a long-term investment due to the economic and social benefits generated, but also in the short term with immediate benefits for citizens and society [5, 18, 19, 33].

In recent decades, Brașov County has grown and developed as a tourist destination, Brașov tourism has adapted and developed at a rapid pace to respond to market opportunities. However, Brașov County is characterized by a common situation that is found throughout the country: the development potential in the field of tourism is high and could contribute more to the development of the local economy if more investment were made in this sector. The main destination for tourists continues to be the municipality of Brașov, which has attracted over 50% of the tourists who visited the county in recent years. The other localities that attract over 10,000 tourists annually are: Predeal, Moieciu, Bran, Săcele, Fundata, Zărnești, Râșnov, Rupea, Sâmbăta de Sus [1, 6, 24].

In order to increase the number of tourists, but especially the income from tourism, there must be a more concerted marketing effort, since, although attractive, most of the tourist packages of the tourism units were designed to serve mainly Romanian tourists. At the county level, the official tourist promotion/marketing activity is not carried out centrally, by an entity with legal personality that would outline the general development direction and marketing for tourism, which is reflected in the way in which the tourist activity is carried out in the county and in the quality of the tourist services offered. However, although numerous cultural and sporting events take place annually in Brașov County, which are mainly aimed at local communities, but also attract Romanian and foreign tourists, they are not known to most interested parties because there is no common database of events and tourist services offered at the county level, which is made available to the general public through an online platform [16, 17].

Tourism in Brașov County benefits from an important potential, represented by the special natural setting and its cultural objectives of certain value. The investments made in recent years and those expected to be made in the future, in order to modernize and expand the tourist reception units and the facilities offered for practicing winter sports, will increase the attractiveness of the 2 tourist resorts. Combining rustic charm with natural attractions, agritourism is one of the forms of tourism that has experienced remarkable development in recent years, being well represented in the Bran Moeciu area. Located between the Piatra Craiului Mountains and the Bucegi Mountains, in the northern part of the Rucăr-Bran corridor, the Bran-Moeciu area is the area with the most developed rural tourism in Romania. The enchanting natural landscape, the picturesque localities located up to altitudes of over 1,000 meters, the well-preserved pastoral and culinary traditions have constituted the premises for the emergence and development of tourism in this rural area. Cultural tourism has experienced significant development in recent years. The main attraction is the city of Brașov, but smaller

localities of tourist interest include Făgăraș (medieval fortress), Bran (with the well-known medieval castle), Râșnov, Rupea, Feldioara (peasant fortresses), Viscri, Prejmer, Hărman (fortified churches, the first two of which are included in the UNESCO heritage), Sâmbăta de Sus (an important Orthodox monastery), as well as numerous other cultural sites located in all areas of the county, not yet included in the tourist circuits [16, 34, 36, 41, 42].

MATERIALS AND METHODS

In the evaluation of the potential for sustainable development of rural tourism, quantitative and qualitative methods were used, as they allow for the outline of a general picture and the identification of factors with a negative impact on rural tourism [9].

All of these represented the main objectives of the work, constituted in a logical sequence in three distinct components very well analyzed and researched, which allowed the formulation of pertinent and thoroughly scientifically justified conclusions at the end of the work.

Methodologically, a series of reports and studies were analyzed in the documentation phase, followed by the study and processing of data, analysis and interpretation of the results. The data used were taken from official statistics belonging to the National Institute of Statistics (NIS) [10].

Also, the research methodology of tourism activity involved a complex approach, from identifying and inventorying resources (natural, cultural, anthropogenic) to analyzing the potential, evaluating their value, mapping and, finally, proposing development and marketing strategies, using quantitative and qualitative methods, to understand their impact and tourism exploitation.

The method itself involved going through several stages such as: [7, 9, 10, 15, 22, 37].

1. Preliminary and documentation stage;
2. Resource identification and inventory stage;
3. Potential evaluation and analysis;
4. Analysis of reception capacity and impact;
5. Synthesis and proposals for sustainable exploitation of resources through the practice of rural tourism.

Assessing the dynamics and intensity of tourism activity at county and local levels can highlight problems between tourism and the environment. This requires analysis indicators and a phased research process to establish the necessary action measures, according to national and European legislation and standards in the field.

RESULTS AND DISCUSSIONS

1. Evaluation of the relief and natural tourist attractions

With a privileged geographical position, Brașov County is an integral part of the Central Region. The main feature of the region's relief is its diversity, from large mountain and hilly areas with the most picturesque landscapes, to fertile meadow and plateau areas favorable to agriculture. The territory of Brașov County has three major relief stages, regarding their morphology, namely:

• The stage of high mountains, which exceeds the altitude of 1700 m altitude, found in Făgăraș, Piatra Craiului, Bucegi, Bârsei and Ciucaș;

• The stage of low mountains, with a height between 800 m and 1,700 m altitude, found in Dârselor, Codlei and Perșani. The group of low mountains also includes the Tâmpa and Poiana Brașovului mountains;

• The stage of depressions and plateau hills, with a height between 450 m and 700 m altitude. This group includes: the Bârsei Plain with the Zărnești – Tohan depressional bays, Vlădeni and the Măieruș corridor, then the Făgăraș Plain. In this stage are also located the Brașov, Homoroadelor, Făgărașuluri Depressions and the Târnavelor Hills, the Hârtibaci Plateau [6, 16, 34, 36, 41, 43].

Among the main natural tourist attractions are: Tampa, the Bear Reserve in Zarnești, the Bison Reserve in Vama Buzăului, the Bogății Forest, the Citadel and Sânpetru Hills, the fossil site in Vama Strunga, Piatra Craiului, Măgura Codlei Peak, the extinct volcano in Racoș, the Ice Cave in the Piatra Mare Massif, the Bat Cave in Moieciu commune, Solomon's Stones, the Postăvarul Massif, the Perșanilor Mountains in the Rupea area, the Emerald Lake in Racoș, the

Homoroadelor Hills, the Zarneștilor Gorges, the Dopca Gorges, the Tamina Waterfall, the 7 Stairs Canyon, the Old Man of the Carpathians [6, 16, 33, 34, 41, 43].

Protected areas

Established in 1990, *Piatra Craiului National Park* covers an area of 15,000 hectares, of which 40% are strictly protected areas, where only tourism and research activities are allowed.

The uniqueness of this area lies in the fact that representative ecosystems are preserved in their natural state, while creating conditions for visiting, education and recreation.

The park is home to 1,189 plant species, large areas of beech forests and mixtures of beech and coniferous trees. Piatra Craiului carnation, edelweiss, yellow poppy, yellow achene, lady's slipper are the most well-known plants [6, 16, 33, 35, 36, 38, 43].

The park also hosts over 40% of the mammal species found in our country (the ibex, bear, wolf and lynx being the most widespread), 100 species of birds, 200 species of butterflies and 200 species of bats.

Among the natural tourist attractions are: Zărnești Ravines, Creasta Piatra Craiului (the longest limestone ridge in our country), Grohotișurile, Cerdacul Stanciului, Zaplazul, Cheile Brusturetului, Cheile Dâmbovicioarai, Peștera Stanciului, Peștera Liliecilor, Peștera Uluce, Peștera etc [6, 16, 34, 36, 41, 43].

Bucegi National Park, known as a protected area in the country and abroad, is composed of a series of natural reserves such as: Bucșoiu-Mălăiești-Gaura Scarp, Lăptici Peatland, Plaiul Hoților Fossiliferous Site, Răteiului Cave, Barber's Fangs Mountains, Bucegi Prahova Scarp. On the 32,633 hectares, there are alpine forests, caves, acidophilous forests and siliceous screes, as well as a varied floristic and faunal composition (the blood of the mighty, the cornflower, the yellow gintura, the white ivy, the stinkhorn, the juniper, the bison, the yew, the deer, the wolf, the lynx, the bear, the capercaillie, the Carpathian newt, the pond vole). The park also includes the highest peak in Romania, Omu Peak (2505 m) [6, 16, 34, 36, 41, 43]. The Sphinx and Babele, conglomerate rocks carved by wind erosion, continue to attract the interest of Romanian and foreign tourists alike, regardless of age or profession. These are joined by tourist attractions such as: Ialomița Cave, Tatar Gorges, Heroes' Cross, Bolboci Lake. There are also 40 tourist trails in the park with varying degrees of difficulty.

2. Quantitative evaluation of rural tourism in relation to classic tourism at the level of Brașov County

Sustainable tourism, attractive to both tourists and local communities, is one of the strategic directions for the development of Brașov County. The county's tourism potential is exceptional, offering the possibility of practicing a wide range of tourist activities, from practicing winter sports to recreation in a unique, picturesque mountain or hilly natural setting.

For over a decade, Brașov County has continued to be among the most preferred destinations in Romania, being ranked second in terms of Romanian and foreign tourist arrivals (868,792 international tourist arrivals in Bucharest, 164,062 international tourist arrivals in Brașov County, in 2023), but despite this, the turnover in the tourism sector accounts for less than 3% of the total turnover of Brașov County, according to NIS data.

Tourist structures with small accommodation functions (tourist guesthouses, agritourism guesthouses) represent approximately 50% of the total tourist reception structures existing at the county level. The agritourism guesthouses existing at the county level account for almost 10% of the total agritourism guesthouses existing at the national level (Table 1, Figure 1 and 2).

In the dynamics of the three years (2022, 2023, 2024), a slight decrease in the number of tourist guesthouses in Brașov County is noted, thus, a number of 230 tourist guesthouses are recorded in 2022, respectively 217 tourist guesthouses in 2023 and 213 tourist guesthouses in 2024.

Regarding agritourism guesthouses in Brașov County (Figure 2.) the evolution of their number shows a slightly downward trend (380 agritourism guesthouses in 2022 and 377 agritourism guesthouses in 2024).

Table 1. Tourist reception structures in Brașov County

Types of tourist reception structures		Year/Number		
		2022	2023	2024
Hotels, hostels, apartment hotels, motels, inns, tourist villas, tourist chalets, bungalows, holiday villages, etc.	Total country, of which:	12,201	12,697	13,538
	Brașov	1,229	1,253	1,332
Tourist guesthouses	Total country, of which:	1,696	1,642	1,574
	Brașov	230	217	213
Agritourism guesthouses	Total country, of which:	3,484	3,498	3,578
	Brașov	380	372	377

Source: [30].

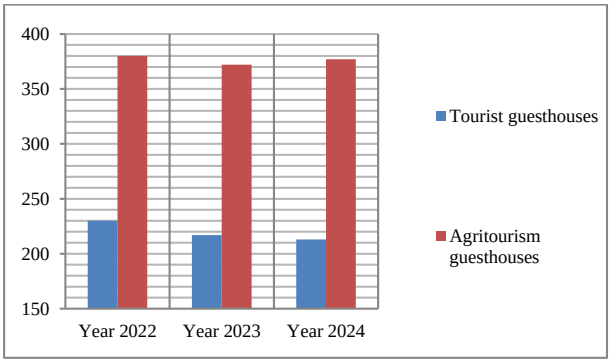


Fig. 1. Evolution of reception structures with rural tourism function in Brașov County (number)
Source: [30].

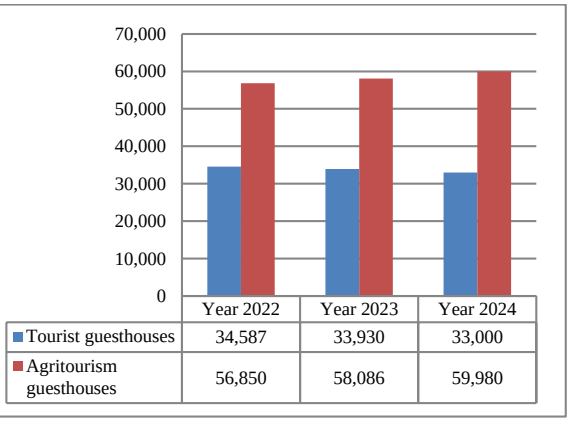


Fig. 2. Trends in existing tourist accommodation capacity at national level (number of beds)
Source: [30].

In the case of agritourism guesthouses in Brașov County, the increases in existing accommodation capacity are +33 number of beds (Figure 3 and 4). The tourist accommodation capacity in use reflects similar trends for agritourism guesthouses (+23,976 number of beds-days). At national level, the tourist accommodation capacity in use of agritourism guesthouses in Brașov County represents 14.6% (Figure 4 and 5).

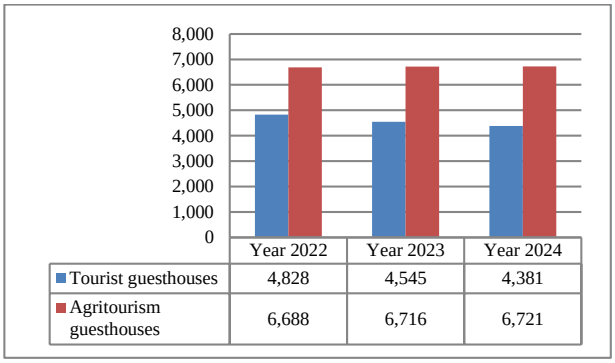


Fig. 3. Evolution of existing tourist accommodation capacity at Brașov County level (number of beds)
Source: [30].

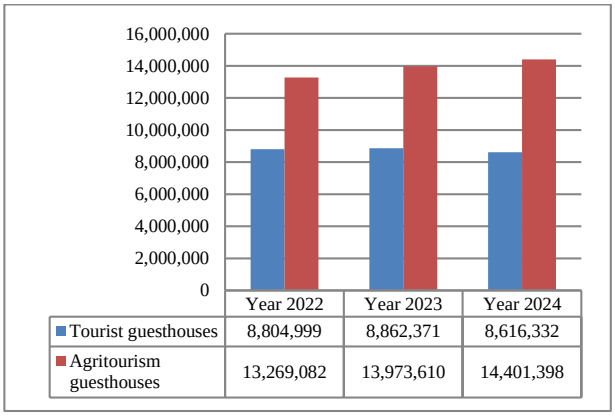


Fig. 4. Tourist accommodation capacity in use at national level (number of beds-days)
Source: [30].

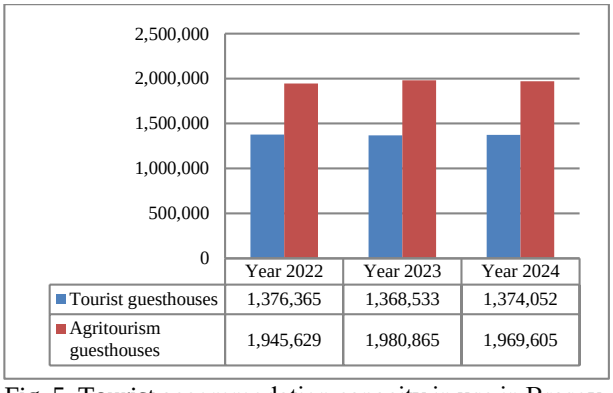


Fig. 5. Tourist accommodation capacity in use in Brașov County (number of beds-days)
Source: [30].

Evolution of tourist circulation indicators

In recent years, Brașov County has experienced a significant increase in tourism development, ranking among the top destinations preferred by Romanian and foreign tourists. Brașov County ranks first as a preferred tourist destination in Romania in terms of tourist arrivals. Tourist arrivals in tourist accommodation structures in Brașov County, recorded in 2022, amounted to 1,405,004 people, 1,556,679 in 2023, and 1,562,294 in 2024 (Table 2, Figures 6 and 7).

Table 2 shows a significant annual increase in the number of tourist arrivals.

The data in Figure 6 attests to the following: arrivals in tourist guesthouses register a significant growth in the year 2023 (170,742 tourists); the interest of foreign tourists has progressively increased, but the structure of arrivals indicates an overwhelming share of domestic tourists (over 90% of total arrivals in tourist guesthouses).

The highest number of tourist arrivals accommodated in agritourism guesthouses in Brașov County was recorded in 2023 (191,651 tourists), of which 185,495 were Romanian tourists (96%) and 6,156 were foreign tourists (4%).

Even though the number of foreign tourists increased (by 1,802 tourists in 2023 compared to 2022 and by 1,531 tourists in 2024 compared to the same year 2022), agritourism guesthouses in Brașov County represent the majority option of local tourists (Table 2, Figure 7).

Table 2. Arrivals in Brașov County

Types of tourist reception structures	Year/Number of tourists			
		2022	2023	2024
Hotels, hostels, apartment hotels, motels, inns, tourist villas, tourist chalets, bungalows, holiday villages, etc.	Total country of which:	12,588,333	13,910,956	14,569,794
	Romanian	10,914,023	11,790,888	12,156,984
	Foreigners	1,674,310	2,120,068	2,412,810
	Brașov	1,405,004	1,556,679	1,562,294
	Romanian	1,297,409	1,390,052	1,374,207
	Foreigners	107,595	166,627	188,087
Tourist guesthouses	Total country of which:	977,694	1,037,475	1,012,361
	Romanian	917,722	961,547	935,369
	Foreigners	59,972	75,928	76,992
	Brașov	155,122	170,742	161,374
	Romanian	143,977	156,001	146,010
	Foreigners	11,145	14,741	15,364
Agritourism guesthouses	Total country of which:	1,181,699	1,306,683	1,323,848
	Romanian	1139724	1245163	1259667
	Foreigners	41975	61520	64181
	Brașov	184897	191651	170451
	Romanian	180543	185495	164566
	Foreigners	4354	6156	5885

Source [30].

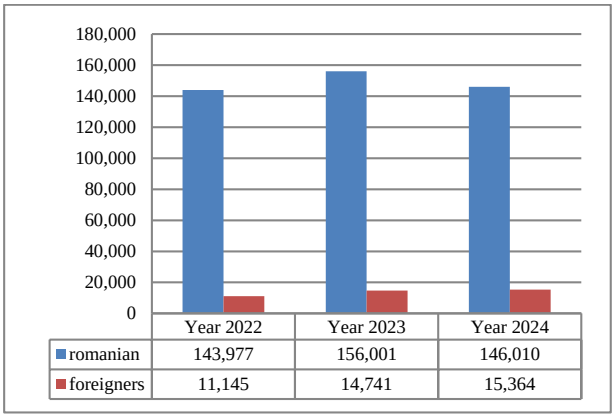


Fig. 6. Tourists' arrivals in tourist guesthouses from Brașov County
Source: [30].

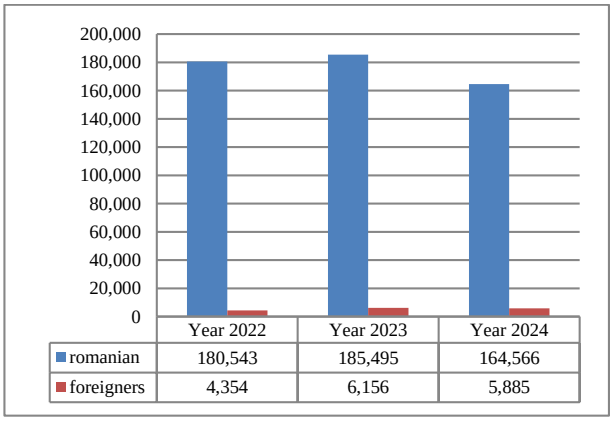


Fig. 7. Tourists' arrivals in agritourism guesthouses from Brașov County
Source: [30].

Table 3. Overnight stays in tourist accommodation facilities in Brașov County

Types of tourist reception structures		Year/ Overnight stays		
		2022	2023	2024
Hotels, hostels, apartment hotels, motels, inns, tourist villas, tourist chalets, bungalows, holiday villages, etc.	Total country of which:	27,044,372	29,691,592	30,837,328
	Romanian	23,377,839	25,186,916	25,843,937
	Foreigners	3,666,533	4,504,676	4,993,391
	Brașov	2,616,872	2,932,423	2,936,342
	Romanian	2,407,697	2,615,651	2,570,813
	Foreigners	209,175	316,772	365,529
Tourist guesthouses	Total country of which:	1,754,388	1,837,049	1,777,419
	Romanian	1,638,934	1,689,717	1,636,827
	Foreigners	115,454	147,332	140,592
	Brașov	295,401	318,738	302,981
	Romanian	274,788	289,828	274,237
	Foreigners	20,613	28,910	28,744
Agritourism guesthouses	Total country of which:	2,265,633	2,529,052	2,559,867
	Romanian	2,183,949	2,403,698	2,431,206
	Foreigners	81,684	125,354	128,661
	Brașov	363,693	385,958	347,797
	Romanian	354,704	372,765	335,479
	Foreigners	8,989	13,193	12,318

Source: [30].

During the analyzed period, tourist overnight stays in tourist reception structures in Romania and Brașov County increased from one year to the next, over the entire period the percentage increase being 14% for the total at national level and 12.2% for Brașov County (Table 3). For overnight stays (Table 3,

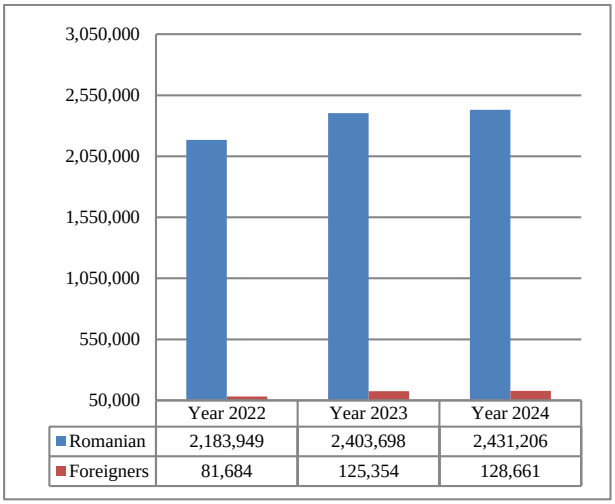


Fig. 8. Tourist overnight stays in agritourism guesthouses in Romania
Source: [30].

Figure 8, Figure 9) it may be determined that: at national level as well as at the level of Brașov County, the highest number of overnight stays in tourist guesthouses was recorded in 2023 (1,837,049 overnight stays at national level and 318,738 overnight stays at Brașov county level); a significant growth of overnight stays in agritourist guesthouses was noticed in same year (2023); Romanian tourists' overnight stays are predominant.

Functionality of tourist structures

The degree of effective use of the accommodation capacity in operation can be expressed synthetically by the net use index of the accommodation capacity.

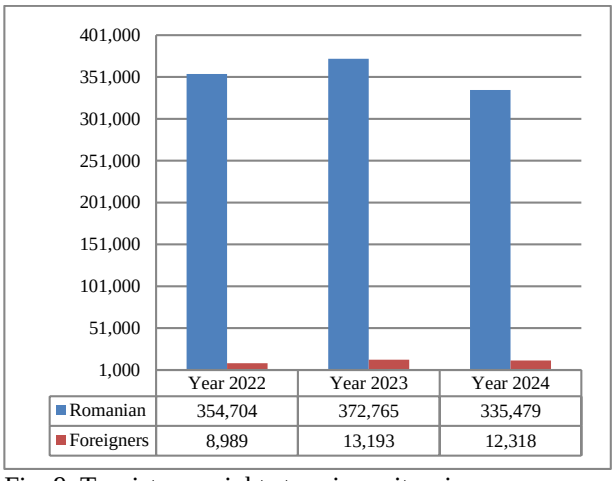


Fig. 9. Tourist overnight stays in agritourism guesthouses in Brașov County
Source: [30].

The net use index of accommodation places on the total of tourist accommodation structures in Brașov County had lower values compared to the values recorded at national level (Figure10).

The comparative analysis of the degree of effective utilization of the operating accommodation capacity in tourist and agritourism guesthouses shows higher values for Brașov County, except for 2024, only in the case of agritourism guesthouses (Figure 11 and 12.)

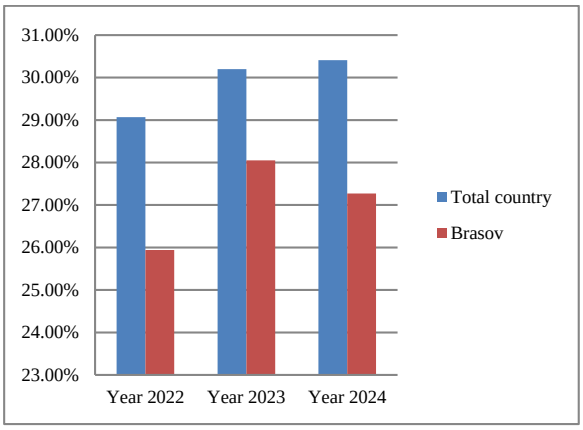


Fig. 10. The net use index of accommodation places per total tourist accommodation structures (%)
Source: [30].

The higher values of the net utilization index of the operating tourist accommodation capacity for Brașov County can be explained by the average length of stay being 1.8-1.9 days longer.

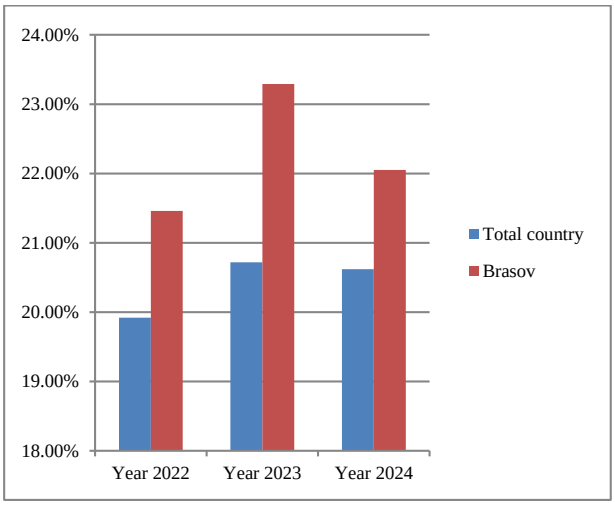


Fig. 11. Net occupancy rate of accommodation places in tourist guesthouses (%)
Source: [30].

3.Determining the importance of sustainable development of rural tourism

By design, rural tourism represents the harmonious combination of tourist activity, protection of the natural environment, preservation of cultural traditions and sustainable development.

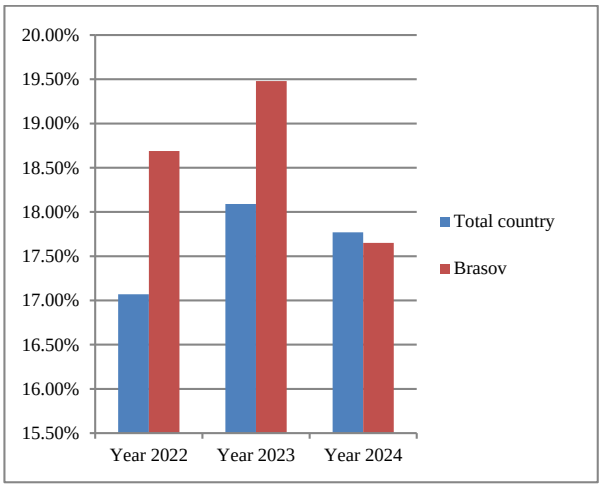


Fig. 12. Net occupancy rate of accommodation places in agritourism guesthouses (%)
Source: [30].

Tourist activity in rural areas of Brașov is carried out in full accordance with the particularities of the environment (relief, waters, soils, climate).

Tourism sustainability has been a major objective in the development strategies of Brașov County, implemented or in progress, such as: "Brașov County Sustainable Development Strategy 2021-2030", which includes objectives regarding the consolidation of the tourism infrastructure, increasing the level of sustainability and attractiveness of tourism, efficient use of qualified human capital in the field of tourism [16]; The project "Increasing the capacity for sustainable management of the Brașov tourist destination at the county level"; The "Casa Noastră Viscri" project consolidates the cultural identity of the area and supports sustainable tourism; The annual actions of the "Let's Do It, Romania!" Association to combat pollution; The "Unforgettable Cultural Experiences in the Heart of Transylvania" project [16, 34].

Legislatively, environmental protection is regulated by a series of orders, conventions, directives, protocols, regulations, ordinances

and decisions. The guidelines for action for environmental protection are specified in Emergency Ordinance no. 195/2005 on environmental protection, approved by Law 265/2006 on environmental protection [20, 26]. The specific measures, administrative responsibilities and directions of action for preserving the authenticity and integrity of exceptional cultural values are established by Government Decision no. 1268/2010 on the approval of the Program for the protection and management of historical monuments inscribed on the UNESCO World Heritage List [21].

The most intense economic effect of rural tourism lies in the generation of jobs and financial income, a true small-scale industry for local entrepreneurs, along with the intense valorization of tourism resources and a more uniform distribution of income, a better preservation of the cultural-historical treasure, as well as a wider spectrum of possibilities for recreation/leisure time. At the environmental level, noise pollution and slight land degradation are noted.

In order to assess the impact of tourist activity and identify options for sustainable development of rural tourism, two representative villages were selected: Șirnea and Viscri.

Known and appreciated by Romanian and foreign tourists, the village of *Viscri* belongs to the commune of Bunești, being listed as a UNESCO World Heritage Site. Historical documents attest to the first mention of the village of Viscri, in 1400, as the White Church. Viscri is mainly distinguished by the special architectural style of the buildings, traditions, crafts and specific customs, local culture and atmosphere, and a country lifestyle specific to the Brașov village. The main crafts practiced are crocheting wool products and blacksmithing.

Those who visit the village or want to spend a stay can benefit from the comfort and services offered by the guesthouses and restaurants with local specialties.

Surrounded by very high walls, the fortified church, also called the defensive fortress, is a well-known tourist attraction. The church dates back to the 13th century, and during the wars it became a refuge for the villagers. The interior of the fortification is to be admired by the large number of towers and bastions.

Inside the fortress there is also a museum that displays the activities and customs specific to the Saxons, tools and pieces of furniture, traditional costumes, looms, wooden chests, hand-painted objects.

Șirnea belongs to the Fundata commune and was declared among the first tourist villages in Romania. Due to its special geographical position, on the Rucăr-Bran corridor at the foot of the Piatra Craiului Mountains, Șirnea offers some of the most picturesque landscapes. The main economic activity of the villagers is shepherding. Olympic Days, Sânzienele, Măsura Laptelui, Răvășitul Oilor, Christmas Caroling are specific celebrations and events mainly related to the pastoral calendar.

Located in the center of the village, the "Nicolae Frunteș Ethnographic Museum" exhibits ethnographic values specific to the area (objects/tools used in the agro-pastoral household, pieces of furniture, folk costumes), contemporary art and an Olympic sports section (old skis made of wood).

The village is equipped with agritourism guesthouses, restaurants, gastronomic points, as well as leisure centers, where you can practice horse riding, carriage or sleigh rides in winter, visits to sheepfolds or archery games.

Local entrepreneurs involved in tourism activity in Șirnea consider that sustainable rural tourism is at the "beginner" stage. In addition, very few guesthouses encourage the practice of activities based on the principle of sustainability.

Both in Viscri and in Șirnea, there is a complete lack of personnel specialized in the field of sustainability.

Even though, in both villages, sustainable tourism is practiced spontaneously and at an empirical level, tourism investments made by entrepreneurs or administration have not harmed the landscape (the case of Șirnea) or the local architectural style (the case of Viscri).

Good practices identified in Viscri and Șirnea include local integration and quality experiences (calm locals present the history of

the village and its specific customs, rustic decor, well-preserved specific architecture, impeccable accommodation, bike rides in nature, on hills and mountain trails, blacksmith or weaving workshops), local supply (sweets, jams, honey, hearth-baked bread, matured telemea cheese, rustic cured meat products, wild berries, palinca, wines, pies), involvement of the entire local community in tourism (milk, meat, fruit, vegetable producers, handicraft products, local guides), ecological wastewater treatment (the Viscri station has three discharge lakes, uses gravity, maintenance costs are minimal), participation of locals in trade courses.

These practices can be replicated in the case of small communities and appropriate associative structures.



Fig. 13. Principles of sustainable tourism development
Source: Own conception.

Sustainable development of tourism in the Romanian village involves minimizing the pressures and conflicts caused by the complex interaction between tourism activity, tourists, the environment and host communities. This approach has a specific relevance in rural areas where the interdependence between tourism and the environment is very pronounced. In other words, sustainable development takes into account governance, good management and equity (Figure 13).

Continuity of tourism activity in rural areas

In order to achieve an integrated, balanced and long-term development of tourism activity in Viscri and Șirnea, it is necessary to:

1. Popularize the principles of sustainable development;
2. Involvement of tourists in supporting local identity;
3. Return to their origins of those who emigrated or their descendants (Viscri village);
4. Improving the standard of living of the local population;
5. Rehabilitation and preservation of historical and cultural objectives;
6. Close collaboration between all "actors" directly/indirectly involved in tourism activity - tourists, population, authorities, entrepreneurs (Șirnea);
7. Involvement of the local population in promoting local products/services;
8. Strengthening the image of unique villages;
9. Directing investments towards protecting nature and the landscape (Șirnea), better capitalizing on natural resources and traditions, organizing events/ demonstrations with an impact on tourism activity.

The sustainable development strategy for rural tourism in Brașov County should be oriented towards reducing air and noise pollution, certifying destinations that adopt sustainable practices, providing professional training in the field of sustainable development, promoting a distinctive tourism image, and consulting and involving rural communities.

CONCLUSIONS

Brașov County is distinguished by mountainous and hilly areas with picturesque

landscapes, plateau areas favorable for practicing agriculture, representative ecosystems preserved in their natural state, the diversity of cultural-historical values, multiethnic and cultural fusion.

The attractiveness of rural areas in Brașov County is based on the unmodified environment, authentic rurality, without irreversible imbalances. Such areas can be declared "unique" under the conditions of preserving the current balance. Tourist activity in rural areas exerts pressure on natural resources, anthropogenic resources and rural communities. Under these conditions, the evaluation and monitoring of tourist activity become a major desideratum.

Brașov County tends towards the status of an already established destination, being ranked second in terms of arrivals of Romanian and foreign tourists. Tourist and agritourism pensions represent approximately 50% of the total tourist reception structures existing in the county. The existing agritourism guesthouses in Brașov County account for almost 10% of the total agritourism guesthouses in Romania.

The existing accommodation capacity of agritourism guesthouses in Brașov County during 2022-2024 recorded an increase of +33 accommodation places. During 2022-2024, the tourist accommodation capacity in use recorded an upward trend for agritourism guesthouses (+23,976 number of beds-days), representing over 14% of the total accommodation capacity used of agrotourism guesthouses in Romania.

Tourists arriving in tourism guest houses in Brașov Country reached a maximum number in 2024, with Romanian tourists being the overwhelming majority.

The maximum number of overnight stays was recorded in 2023 in the case of tourist guesthouses, while in agritourism guesthouses the maximum was reached in 2024. In both cases the Romanian tourists' overnight stays are predominant.

The comparative analysis of the net utilization index of the accommodation capacity in operation in tourist and agritourism guesthouses attests higher values for Brașov County, compared to the national level. A possible increase in accommodation capacity could determine a decrease in the values for this index.

Synthetic, the tourist offer in Brașov County is in line with the trend of domestic demand, with the existence of development potential by attracting foreign tourists being noted.

In the context of Romanian rural areas, tourist structures with small accommodation functions (tourist/agritourism guesthouses) are the most efficient way to harmonize tourists' requirements with the rigors of sustainable development of rural tourism.

The development of rural tourism should be approached in a balanced, longer-term and above all integrated manner – ecologically, economically, socially.

The sustainability of rural tourism can be ensured by involving and working together with local entrepreneurs, authorities and the local population in achieving a common goal - a better environment. Only in this case, can tourism become a long-term resource, not a pressure on the village (communities and tourism resources).

The involvement of entrepreneurs includes their association at a local level to create integrated tourist services, adoption of sustainable practices, joint online promotion of the village and not just the guesthouse, capitalizing on authentic traditions.

At the local authority level, in addition to investments in basic infrastructure, procedures can be simplified for small entrepreneurs and community involvement in tourism decisions can be achieved.

The contribution of the local population can be materialized through accommodation with locals, traditional meals, rural life experiences, customs transmitted by those who live them, education in sustainability, initiatives.

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DOES FARMERS' ASSOCIATION IMPACT SMALL-SCALE VEGETABLE PRODUCTION? AN ORDINAL LOGISTIC MODELING

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Abstract

This article aims to elucidate the impact of the Farmers' Association (FA) on small-scale vegetable production in Silago, Southern Leyte, Philippines. The study employed purposive sampling to survey 88 farmers and collected primary data from them using a developed research questionnaire. Descriptive measures were employed to describe the collected data such as counts, percentages, mean average, standard deviation, and maximum and minimum values. In addition, an ordered logistic regression was used to predict the factors on the impact of FA on small-scale vegetable production. All statistical calculations were presented in tabular forms and bar graphs. Results depicted that, on average, vegetable small-scale farmers were satisfied (M=3.88; SD=0.73) with the project management of FA which indicates that they are aided in their production activities to improve their economic yield. In addition, 46.59% of small-scale vegetable farmers said that FA has more help in their production, 47.73% of them said that FA has less help, and 5.68% of them said that FA has no help at all. The ordered logistic regression model revealed that the profile of farmers does not influence the impact of FA on their vegetable production. Moreover, it is depicted by the regression model that project implementation (p-value<0.05) and monitoring and evaluation (p-value<0.01) are the predictors of the impact of FA on vegetable production. Hence, it is concluded that the government must support the FA by allocating funding for project implementation and investing in extension agents that help FA officials and farmer members enhance vegetable production in the country.

Key words**:** *Farmers' association, vegetable production, small-scale farmers, ordered logistic regression*

INTRODUCTION

Vegetable production in the Philippines is a vital industry in the agricultural sector since it serves as a helpful food supply for every Filipino and it has a great impact on the economy. Moreover, vegetable production has provided a livelihood for many Filipinos, provided an opportunity for economic well-being and profitability, and sustained their household activities. In [3] and [25], it is mentioned that there are challenges and limitations that the agricultural sector is facing including a lack of provisions in the Philippine government, a lack of programs for enhancement, and insufficient training activities and technologies, among others. However, the development of vegetable production can be attained through the help of organizations that aim for sustainability and economic progress [25]. In that case, the Farmers' Association (FA) was initiated to foster collaboration and efficiency in improving agricultural production, solving economic problems, and obtaining an optimal decision-making process [4], [10].

FA has an important role in vegetable production which provides several benefits that include enhancing access to resources, providing farming techniques, and improving market strategies, among others [14], [20]. In addition, FA can facilitate every member in the adoption of new innovative technologies that enhance their efficiency in their production process through training and seminars as well as promoting sustainability [17], [19], [21]. Accordingly, in [26], it is stated that to increase productivity in farming and attain

sustainability, innovative agricultural practices must be introduced to the group of farmers or to the FA to integrate into their production activities. Apparently, farmer members of an FA often share new knowledge, resources, and techniques that could be adopted in improving their vegetable production processes [9]. Currently, in the Philippines, there are problems and limitations in the vegetable production industry that need to be addressed including climate change, high agricultural inputs, low price of vegetable products, increasing competition with imported products, pests and diseases, and lack of knowledge among farmers, among others [7], [13]. Hence, it is necessary to enhance the knowledge and practices of the members of the farmers' association to address the problems and challenges they are facing. In that case, useful information through scientific research must be provided to improve the current agricultural policy and enhance the impact of farmers' associations on vegetable production in the Philippines.

The concept of FA is well investigated, however, elucidating the impact of FA on the small-scale vegetable farmers in the Philippines is scarce. In fact, a study on the influence of FA on small-scale vegetable farmers using a regression analysis that investigates the influencing factors has never been conducted. Hence, this research article is realized. Generally speaking, this study provides an explanation of the influence of FA on small-scale vegetable production and determines its significant factors. Specifically speaking, this research paper sought the following objectives: (1) to summarize the profile of vegetable small-scale farmers; (2) to measure the farmers' perception of FA's program management; (3) to proportionate the percentage of farmers who are positively influenced with FA; (4) to construct a regression model that predicts the influencing factors of the impact of FA to the vegetable production.

The significance of this study is to explain the role of FA in the production of vegetables and its impact on economic profitability and well-being. The results of this study may provide useful information that aids the FAs in improving their management skills and administration in doing their responsibilities in improving the production of vegetable farmers in the Philippines. Moreover, the findings of this research paper hope to supply vital knowledge that leads to the optimal decision-making of farmer members and officials of the FA.

MATERIALS AND METHODS

Research Design

This article involved describing the profile of farmers, their perception of the FA's program management, and the impact of FA on vegetable production. In addition, the study dealt with capturing the influencing factors of the impact of FA on vegetable production. In that case, the study used a descriptive-correlational research design to answer the desired objectives. The goal of the said research design is to describe the relationship of the dependent variable with respect to the independent variable. Hence, the study employed standard descriptive metrics and used statistical modeling as inferential analysis for drawing conclusions.

Research Participants, Sampling Technique, and Ethical Procedure

The farmers' association in Silago, Southern Leyte seeks to enhance production activities and economic prosperity by advocating for sustainable agricultural practices, particularly in vegetable production. Nonetheless, based on the initial formal interview with the vegetable small-scale farmers, the FA is encountering issues and obstacles with the project implementation, particularly in the promotion of innovative agricultural techniques and sustainable agricultural inputs. This study aims to assess the project implementation of the association to develop sustainable solutions and policies that would improve vegetable production.

The participants in this study are all vegetable producers who are current members of the FA in the municipality of Silago, Southern, Leyte. There were 121 vegetable farmers registered in the association. This study only considers

small-scale farmers where their farm size is at most 2.5 hectares.

Due to the challenging geographical locations of respondents in the 14 Barangays of Silago, Southern Leyte, and their availability during the survey, convenience sampling was utilized. The total number of respondents that participated in the survey was 88 small-scale farmers.

The researchers coordinated with the Municipal Mayor of Silago and partnered with the Municipal Agriculture Office to facilitate finding the locations of farmers' association members involved in vegetable production.

A letter requesting permission to conduct the study was disseminated to all Barangay Captains and voluntary consent forms were provided to the participants, affirming their intention to participate in the study. The signed consent form specifies that their involvement as informants in the study was voluntary, and any information collected may be incorporated into the researchers' report, contingent upon the non-disclosure of their personal information in any report or publication without their prior consent and authorization.

The consent form stipulates that participants may decline, withdraw, or terminate their participation at any time if they encounter questions that are offensive, discriminatory, or derogatory during the interview, without facing any prejudice, penalty, or detriment to the subject matter under investigation. Moreover, respondents will receive no financial remuneration; nevertheless, they may be given supplementary relevant information following the outcome of their participation when deemed suitable.

Research Questionnaire and Data Collection

This study employed primary data collection via survey method. This research employed a developed semi-structured questionnaire as the instrument for data collection.

The questionnaire has three (3) parts profile of small-scale farmers, project management perception of farmers, and the impact of FA on vegetable production based on the proportion of farmers.

Under the profile, the vegetable farmers were asked about the following: (i) sex, (ii) actual age in years, (iii) educational attainment, (iv) civil status, (v) household size, (vi) vegetable farm size (in hectares), (vii) years as a member of FA, (viii) other source of income, (ix) monthly income for vegetable farming (in Philippine peso (PHP)).

As for the project management questions, this study utilized the USAID-NUPITA Organizational Capacity Assessment (OCA) as its research instrument [24].

The Organizational Capacity Assessment (OCA) tool assesses an organization's capability to efficiently manage its association [5].

The assessment evaluates competency in six critical domains: governance, administration, financial documentation, operational management, communication strategy, and program management. This study only analyzes the program management domain of farmers' associations and identifies possible predictors that enhance vegetable production.

The program management of farmers' organizations was evaluated using the USAID-NUPITA Organizational Capacity Assessment (OCA) tool, focusing on three sub-domains, namely: community involvement (3-item question), project implementation (3-item question) and monitoring and evaluation (5-item question). The evaluation of a farmers' organization's program management is conducted to gauge if it assists the farmers association in attaining their goals, enhancing their effectiveness, and guaranteeing the enduring sustainability of their operations.

Through good program management, farmers' associations may enhance member service, augment their incomes, and facilitate the advancement of the wider agricultural sector. These question statements are formed based on the USAID-NUPITA OCA tool, and the respondents of the study may agree or disagree with the statements (Likert scale) indicating how satisfied or dissatisfied they are based on the range of perception scores as shown in Table 1.

Table 1. Perception scores and their verbal interpretation

Perception scores	Interpretation
1.00-1.80	Very dissatisfied
1.81-2.60	Dissatisfied
2.60-3.40	Neutral
3.41-4.20	Satisfied
4.21-5.00	Very satisfied

Source: Authors' construction (2025).

As for the last part of the questionnaire, the farmers were asked about the impact of FA on their vegetable production with the following choices: 0-Not at all, 1-less, 2-more. The research questionnaire was checked and evaluated by professors (at least a Master's degree in agricultural extension) for substantiation and validation. Fortunately, they found the questionnaire as valid and consistent which captures and measures the the well-being of vegetable farmers and the effectiveness of FA. Moreover, a reliability test was also done to make sure that the instrument was reliable and accurate. In that case, it is found that the program management instrument (Community involvement: α=0.98; Project implementation: α=0.98; Monitoring and evaluation: α=0.97) is reliable as shown in Table 2.

Table 2. Reliability test for the farmers' association's program management.

Questionnaire	No. of items	Reliability scale
Community involvement[a]	3	0.98
Project implementation[a]	3	0.98
Monitoring and evaluation[a]	5	0.97

Note: a - Scale of 1 to 5.
Source: Authors' calculation (2025).

The research instrument given to the respondents was initially prepared in English and thereafter translated into their native dialect. Eighty-eight (88) vegetable farmers from fourteen Barangays in Silago, Southern Leyte, received the survey questionnaires. Additionally, a personal interview was undertaken to assist older farmers facing difficulties in reading and understanding the questionnaire.

Data Management and Analysis

The gathered data were encoded in Microsoft Excel and coded to convert the qualitative to quantitative data. In addition, the respondents with missing data and outliers were removed to avoid bias. The data were then formatted to the STATA version 14 environment for statistical computations. Descriptive metrics were employed in describing the collected data to give interpretations such as percentages, mean average (M), standard deviation (SD), and maximum and minimum values. Descriptive calculations were presented in statistical tables and bar graphs for easy statistical visualization and interpretation. In addition, the Spearman rho correlation was used to determine the relationship between the ordinal variables (perception scores). Moreover, to capture the influencing factors of the impact of FA on vegetable production, ordered logistic regression was employed since the dependent variable (0-Not at all, 1-Less, 2-More) is ordinal. Hence, the empirical ordered logistic regression models are given as follows:

$$FAimpact_j = a_0 + a_1 Male_j + a_2 Age_j + +a_3 Education_j + a_4 Married_j + a_5 HHsize_j + a_6 Oincome_j + \varepsilon_j \quad (1)$$

and

$$FAimpact_j = b_0 + b_1 FSize_j + b_2 Membership_j + +b_3 Mincome_j + b_4 ComInvolve_j + b_5 ProjectIm_j + b_6 MandE_j + e_j \quad (2)$$

where $FAimpact_j$ refers to the impact of FA on the vegetable production as a regressand variable (0-Not at all, 1-Less, 2-More), j refers to the j^{th}small-scale vegetable farmer ($j \in \{1, 2, \ldots, 88\}$), a_i and b_i ($i \in \{1, 2, \ldots, 6\}$)refers to the parameters of the models 1 and 2, respectively, which is subject to approximation and interpretation, and $\varepsilon_j$and $e_j$refers to the remaining random errors of the ordered logistic regression models ((1) and (2)). As for the regressor variables, $Male_j$ refers to a dummy (indicator) variable that captures a male small-scale farmer (0-female,

1-male), Age_j refers to the farmer's age in years, $Education_j$ refers to the educational attainment (1-elementary level, 2-elementary graduate, 3-high school level, 4-high school graduate, 5-college level, 6-college graduate) of small-scale vegetable farmer, $Married_j$ refers to a dummy (indicator) variable that captures a married small-scale farmer (0-not married, 1-married), $HHsize_j$ refers to the number of household members (count) of a farmer, $FSize_j$ refers to the farm size (in hectares) manage by vegetable farmers, $Membership_j$ refers to the farmer's number of years as a member in FA under vegetable production, $Mincome_j$ refers to the income (in Philippine Peso (PHP)) of vegetable farmers within a month, $ComInvolve_j$ refers to the perception of vegetable farmers in regard to the community involvement (Scale of 1 to 5) of the FA, $ProjectIm_j$ refers to the perception of farmers in regard to the project implementation (Scale of 1 to 5) of the FA, and $MandE_j$ refers to the perception of farmers in regard to the monitoring and evaluation (Scale of 1 to 5) of the FA. To ensure statistically sound results, post-estimation techniques were employed. Furthermore, all statistical computations were tested for their significance at an appropriate level, and necessary conclusions were drawn.

RESULTS AND DISCUSSIONS

Profile of Small-Scale Vegetable Farmers

Table 3 presents the socio-demographic and farm profile of small-scale vegetable farmers. It is shown that there are 38% male farmers and 62% are female farmers. In [1], it is mentioned that women's participation in vegetable farming is becoming substantial, contributing to food production in rural areas and improving economies. The mean average age of a farmer is close to 54.39 (SD=13.14) years old with a youngest of 22 years old and an oldest of 81 years old. This result is consistent with the findings in [8] that most of the farmers are relatively old and traditional since the younger generations are looking for a decent and high-paying job as opposed to farming. The mean years of education of the vegetable farmers is close to 2.92 (SD=1.42) which indicates, on average, the farmer's educational attainment is a high school level. The lowest educational attainment is elementary level (min=1) and the highest is college degree (max=6). This finding is consistent with [8] that most of the farmers do not finish a bachelor's degree. Most (89%) of the vegetable farmers are married and only 11% of them are non-married. In addition, the mean average household size is close to 4 (SD=1.87), the lowest is 1 (single as the civil status of a farmer), and the highest is 11 members. The mean average farm size cultivated for vegetable farming is close to 0.33 hectares (SD=0.47). The smallest farm size is 0.01 hectares and the biggest is 2.5 hectares. About 45% of the farmers have other income aside from vegetable production and 55% of the farmers totally depend on their vegetable income. The mean average monthly income for vegetable farming is close to 1,753.41 PHP, the lowest income is 200.00 PHP, and the highest income is 10,000.00 PHP.

Table 3. Profile of small-scale vegetable farmer-members of farmers' association.

Profile	Mean	SD	min	Max
Male[a]	0.38	0.49	0	1
Age (actual years)	54.39	13.14	22	81
Education[b]	2.92	1.42	1	6
Married[a]	0.89	0.30	0	1
Household size (actual count)	4.18	1.87	1	11
Farm size (in hectares)	0.33	0.47	0.01	2.5
Years as a member (actual years)	8.70	11.13	0.1	50
Another source of income[a]	0.45	0.50	0	1
Monthly income in vegetable farming[c]	1,753.41	2,052.53	200	10,000

Note: a - dummy (indicator) variable; b - (1-elementary level, 2- 2-elementary graduate, 3-high school level, 4-high school graduate, 5-college level, 6-college graduate); c - Philippine Peso (PHP).
Source: Authors' calculation (2025).

Table 4 presents the findings of organization members' responses to eleven item statements representing their satisfaction with their farmer organizations' program management. Based on the findings, farmer members agreed with all the statements and were satisfied in all three sub-domains being assessed, with mean perception scores ranging from 3.87 to 3.89.

This implies that the respondents agreed that their farmer's associations have been involved in projects that also benefit the community (M=3.89; SD=0.75). This is consistent with the opinion in [15] that the community which participates in the program must be a member of farmers' groups and the requirements for the farmer's participation in the program's agricultural development is the farmers who are members of a farmers group, to attract the surrounding community. The findings in Table 4 also show that farmers perceived their association implemented agricultural projects with adherence to established criteria (M=3.88; SD=0.74) and the FA offers a chance to verify that project activities are in accordance with sanctioned work plans, and that monitoring and evaluation mechanisms are functional to assess performance against established standards and indicators (M=3.87; SD=0.71)implying satisfaction of farmer-members in their associations' project management. This aligns with [16] and [23] wherein the evaluation program is the final indicator for observing farmers' perceptions of the implementation of agricultural development programs and the evaluation result has an impact on the positive activity and addition of farmer group members.

Table 4. Characteristics of farmers' association's program management

Program management	**Mean**	**SD**	**Interpretation[b]**
Community involvement[a]	3.89	0.75	Satisfied
Project implementation[a]	3.88	0.74	Satisfied
Monitoring and evaluation[a]	3.87	0.71	Satisfied
Total	**3.88**	**0.73**	**Satisfied**

Note: a - Scale of 1 to 5; b - See Table 1.
Source: Authors' calculation (2025).

Overall, farmers are satisfied (M=3.88; SD=0.73) with the program management of the FA which positively impacts their vegetable production activities.

Results shown in Table 5 are the correlation of three subdomains of the farmers association's program management. Findings show that community involvement, project implementation, and monitoring and evaluation are highly and positively correlated with each other. As argued in [6] for farmer organizations to succeed farmers must be able to manage their organizations autonomously, with minimal external interference, farmers and members must participate actively in cooperative activities that are beneficial or profitable to the members and the whole community. It can be understood that successful project management of a farmers' organization is directly linked to community involvement emphasizing benefits not only for the members but to the whole community as well [6]. In addition, in [22], it is portrayed that farmer members of an organization are empowered because of the Participatory Monitoring and Evaluation (MP&E) because they were able to demand that everyone, including their leaders, be accountable and transparent for their actions within the group and this empowerment is an outcome of good program management, thus project implementation is directly related to project monitoring and evaluation. An efficient project monitoring and evaluation (M&E) system is essential for the successful implementation of agricultural projects [12]. An effectively structured M&E system ensures project adherence, facilitates early problem identification, and provides evidence for decision-making, ultimately resulting in improved project outcomes.

Table 5. Spearman correlation matrix between the characteristics of program management.

Program management	**Community involvement[a]**	**Project implementation[a]**	**Monitoring and evaluation[a]**
Community involvement[a]	1	-	-
Project implementation[a]	0.624* (<0.001)	1	-
Monitoring and evaluation[a]	0.579* (<0.001)	0.727* (<0.001)	1

Note: a - Scale of 1 to 5; b - See Table 1; *p<1%.
Source: Authors' calculation (2025).

Impact of Farmers' Association on Vegetable Production

In Figure 1, it is shown that there are 5.68% of vegetable farmers that does not experience the impact of being a member of FA on their production activities. This proportion of farmers has not benefited from the opportunities given by the FA, especially in

their project management and implementations. The reason for this is that some farmers are living in challenging geographical locations and it is difficult to reach by the FA project implementations. In [11], rural small-scale farmers are living in remote areas, thus, they rarely have access to agricultural resources and training which is a challenge for farmers' organizations and agricultural extension agents. About 47.73% of the small-scale farmers said that the FA has less impact on their vegetable production. This implies that they partially benefited and less experienced the benefits of being a member of the FA such as access to resources, training and workshops, and guidance from the experts. In [7], [9], and [15], it is portrayed that vegetable farmers who acquired membership in a farmer's organization have somehow learned new technologies and adopted practices that improve their production activities and enhance their economic well-being.

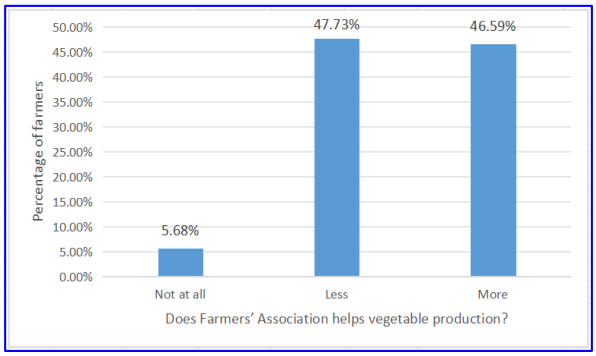


Fig. 1. Percentage of vegetable farmers being helped by farmers' association
Source: Authors' construction (2025).

Moreover, Fig. 1 revealed that 46.59% of the vegetable farmers said that the impact of being a member of the FA is vital and more beneficial. In this case, farmers are being well-assisted and managed by the officials and staff of the FA in regard to their vegetable production needs, knowledge and skills, and decision-making process for economic growth and sustainability. Also, farmers are well-benefited with the project management of the FA for improving the vegetable production. In [4] and [25], it is mentioned that FA is successful in their endeavor if they have a strong leadership that motivates the farmer-member to engage, access resources, implement training in new technologies, and adapt to changing economic conditions and climate change which allows the farmers improve their production processes to obtain the desired goals.

Regression Modeling

Tables 6 and 7 show that ordinal regression models (I and II) were the dependent variable is the impact of FA on the farmers' vegetable production. In model I, the mean-variance inflation factor (VIF) of independent variables is 1.12 which is less than 10. This indicates that the regression model I does not have a multicollinearity problem which leads to stable and reliable results for the parameters [2]. Table 6 reveals that Model I is not significant (X^2=2.54; *p*-value=0.865) and suggests a very low coefficient of determination (R^2=0.017). This indicates that the model does not imply a good model fit in regard to the impact of FA on the vegetable production and socio-demographic profile of farmers.

Table 6. Ordinal regression model with socio-demographic profile as independent variables.

Predictors	Ordinal Regression Model I		
	Coefficient	Std Error	p-value
Male[a]	0.426[ns]	0.441	0.333
Age (actual years)	0.011[ns]	0.018	0.552
Education[b]	0.079[ns]	0.169	0.640
Married[a]	0.158[ns]	0.721	0.826
Household size (actual count)	0.104[ns]	0.121	0.389
Another source of income[a]	-0.069[ns]	0.427	0.870
Observation	88		
Chi-square test	2.540[ns]		
p-value	0.865		
R-squared	0.017		
Log-Likelihood	-75.452		

Note: a - dummy (indicator) variable; b - (1-elementary level, 2- 2-elementary graduate, 3-high school level, 4-high school graduate, 5-college level, 6-college graduate);ns - not significant.
Source: Authors' calculation (2025).

In particular, the following predictors in the model I are not significant: sex (*p*-value=0.333), age (*p*-value=0.552), educational attainment (*p*-value=0.640), civil status (*p*-value=0.826), household size (*p*-value=0.389), and other source of income (*p*-value=0.870). This implies that the socio-demographic profile of vegetable farmers does not influence the impact of FA on their

vegetable production. This result is inconsistent with the findings in [18], which indicates that the farmer's productivity is correlated to their socio-demographic profile.

The second model (II) possesses a mean-variance inflation factor (VIF) of 1.63 with respect to the independent variables and it is less than 10. This implies that the regression model II does not possess a multicollinearity problem and this indicates that results may lead to stability and reliability [2]. Model II (*p*-value=0.089) is significant at a 10% level and indicates a model fit of R^2=0.072 (Table 7). This implies that the model has predicted some significant factors that influence the impact of FA on the farmers' vegetable production. Table 7 reveals that farm size (*p*-value=0.935), years a member of FA (*p*-value=0.484), monthly income in vegetable farming (*p*-value=0.961), and community involvement (*p*-value=0.352) are insignificant predictors of the impact of FA to the farmers' vegetable production. On the other hand, project implementation (*p*-value=0.029) is a statistically significant factor affecting the impact of FA on the farmers' vegetable production at a 5% level. This implies that the project implementation of FA has improved the farmers' productivity and enhanced livelihood through strategic planning, allocation of resources, and fostering collaboration with the various stakeholders. In [9] and [20], project implementations have supported vegetable farmers' needs and have improved their knowledge, practices, and economic profitability. Moreover, Model II depicts that monitoring and evaluation (M&E) has an inverse influence (*p*-value=0.005) on the impact of FA on the farmers' vegetable production and it is significant at a 1% level. This implies that even if the FA does not initiate an M&E to the activities of the farmers, their production process is still working well as long as they are supported by the project implementations of the organization. This result is not parallel to the findings in [10], [16], [21], [22], and [25] that M&E is necessary to assess the improvement of agricultural production and economic sustainability.

Table 7. Ordinal regression model with farm profile as independent variables

Predictors	Ordinal Regression Model II		
	Coefficient	Std Error	p-value
Farm size (in hectares)	-0.038^{ns}	0.462	0.935
Years as a member (actual years)	-0.014^{ns}	0.019	0.484
Monthly income in vegetable farming[a]	5.17e-6^{ns}	0.0001	0.961
Community involvement[b]	0.362^{ns}	0.390	0.354
Project implementation[b]	1.034**	0.473	0.029
Monitoring and evaluation[b]	-1.415***	0.501	0.005
Observation	88		
Chi-square test	10.89*		
p-value	0.089		
R-squared	0.072		
Log-Likelihood	-71.223		

Note: a - Philippine Peso (PHP); b - Scale of 1 to 5; ns - not significant; *p<10%; **p<5%; ***p<1%.
Source: Authors' calculation (2025).

CONCLUSIONS

The main target of this research article is to evaluate the impact of FA on vegetable production and determine the possible significant influencing factors. It is concluded that there are 46.59% of them said that FA has more help in their production, 47.73% of them said that FA has less help, and 5.68% of them said that FA has no impact on their agricultural activities. Moreover, it is revealed that, on average, small-scale farmers were satisfied with the project management of FA which indicates that they are aided in their vegetable production activities to improve their livelihood and economic sustainability. The regression model revealed that the socio-demographic and farming profile of farmers does not influence the impact of FA on their vegetable production. Moreover, it is depicted by the regression model that project implementation has directly influenced the impact of FA on the farmers' vegetable production. This implies that project implementation has enhanced the farmers' agricultural practices and economic profitability. In addition, it is revealed by the ordinal regression model that monitoring and evaluation have an inverse effect on the impact of FA on the farmers' vegetable production. This indicates that even though the FA has lacked assessing progress in production and

does not identify problems, still farmers can improve their agricultural activities with the aid of the FA's project implementation. Conclusively, FA must improve its administration in regard to methodologies and frameworks to further enhance vegetable production and ensure an efficient allocation and utilization of agricultural resources. The study recommends that farmer members and officials of FA must undergo seminars and training in regard to the new innovative technologies to improve their management skills and practices that are useful in developing their vegetable production and enhancing their economic well-being. As for further studies, one must evaluate the governance and administration processes of FA to enhance the current findings.

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VULNERABILITIES AND ADAPTIVE CAPACITY IN REPUBLIC OF MOLDOVA'S PIG SECTOR IN THE CONTEXT OF ENSURING ITS RESILIENCE

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Abstract

The paper aims to carry out an analysis of the standing vulnerabilities and adaptive capacities in the Republic of Moldova's pig sector, in the context of enhancing its resilience under the emerging risks related to biological, economic, and climatic hazards. Using the historical time-series data on the pig populations, production volumes, self-sufficiency rates, and pork prices, the paper quantifies the structural shifts from the Soviet-era to declines observed during the post-independence period, as well as the most recent recovery of enterprises. Total production costs for the year of 2025 have been calculated two categories of enterprises: large and medium-sized ones, following three daily weight gain scenarios. The SWOT analysis aims to synthesize internal and external determinants, while a reflection of adaptive measures points on the importance of subsidies, biosecurity protocols, training, and cooperation under the provisions of the National Strategy for Agricultural and Rural Development 2023–2030. The results of the carried-out research underscore the opportunities to boost self-sufficiency level through modernization and reduced import dependency, while disease control and farm consolidation are prioritized for increasing the resilience of the pig sector.

Key words**:** *pig sector, value chain, adaptiveness, Republic of Moldova, resilience, African Swine Fever*

INTRODUCTION

The world pig sector represents an important pillar of food security in both, developed [11] and developing countries, with a strong contribution to meat and protein supply [9] provision of employment, and a significant role in foreign trade. In the next years, forecasts for pork consumption presume a growth trend especially for regions that already have high indices of consumption, while pig meat will be in the top 3 of the largest contributions to the general increase of meat consumption [13].

However, as other sectors, the pig sector faces a series of disruptions, starting with provision with inputs, being followed by primary production, processing, distribution, and consumption. The existing vulnerabilities of the sector take the shape of various forms, like occurrence of diseases such as African Swine Fever [6], asymmetries in supply chain, growing prices for inputs, meat price fluctuations [8] and trade barriers.

The importance of the pig sector for the country's economy is manifested through various forms, starting from an important share in economic output, with a positive influence on GDP and stabilization of the agri-food economy. Moreover, it creates employment opportunities during the entire year, avoiding the seasonality aspects from the agri-food sector. It is also a source of economic and financial stability in the short and medium term for the population from rural areas, ensuring the families with one of the most important staple products.

At the same time, it is an important source of raw material necessary for the food industry of the Republic of Moldova, mainly the processing one, as there is produced an extensive range of goods, such as meat, sausages, various culinary preparations and canned products. This does not only satisfy the nutritional needs of the population, but also stimulates the development of other related branches of the economy.

Last but not least, the pig sector contributes to the diversification and enrichment of the assortment of gastronomic products available on the local market. Through this economic branch, consumers in the Republic of Moldova have access to a wide range of quality food products, starting from raw products to processed ones [3], which satisfy their varied tastes and preferences.

The most recent occurrence of African Swine Fever outbreaks from 2025 which had a major impact on the decline in the number of heads, exposed the existing vulnerabilities of the pig sector at the level of production, having as negative consequences shortages in supply, volatility of prices and even a stronger reliance on import. Generally, these types of negative phenomena underscore the interconnection among biological hazards, climate pressures, and socio-economic drivers in determining the resilience of the sector.

The scholarly inquiry into sectoral analysis, in particular the pig one, has focused on the challenges of vulnerability and adaptation. The early works on this topic emphasized the failures in the domestic production after the collapse of Soviet Union [2], as well as the lack of integrated agro-complexes with complete cycle of production and processing [1].

At the same time, research underscores the sector's great exposure to epidemiological risks, geopolitical context and risks related to climate change. In Moldova, the import dependency of the pork value chain has been aggravated by the external shocks, such as Russian trade embargoes from 2013 – 2014 that banned Moldovan pork exports, while, recently, outbreaks of African Swine Fever had devastating impacts on pig herds at the regional levels, affecting Moldova, Romania, Poland and Ukraine [14; 10], both in terms of number of heads, as well as the diminishes in production volumes and surge in prices.

Nevertheless, gaps in the literature on the complex analysis of the pork-specific sector in Moldova are still present, as most of the research is being focused on the general agri-food resilience, or the one connected to plant sector, leaving behind the livestock sector that suffers from disease and climate co-risks.

Therefore, the paper aims to analyze the vulnerabilities inherent to the pig sector in the Republic of Moldova and present adaptive capacities to enhance the resilient development of the key actors across the sector.

MATERIALS AND METHODS

The paper includes a mixed-methods approach that combines the quantitative analysis of secondary data with qualitative synthesis through the SWOT framework, in order to assess the current vulnerabilities, as well as adaptive capacities in Moldova's pig sector.

The used data sources include various databases concerning production indicators, number of heads, etc. retrieved from the National Bureau of Statistics of the Republic of Moldova [12]; trade volumes and values, as well the main foreign trade partners from the UN Comtrade database [16]; as well as personal observations and in-depth interviews with pork producers and associations for the determination of the structure of production costs.

The calculation of costs of production was performed correspondingly with the cost grouping rules, separately for large and medium-sized households. The presented items intend to ensure the inclusion of costs supported by the economic agents engaged in pig growing. Therefore, the standardized structures of costs have been calculated for live pig meat production for the year 2025, divided by large and medium-sized enterprises across three average daily weight gain levels (500 g, 650 g, 800 g). Costs are disaggregated into variable (feed, weaning piglets, veterinary services, mechanized/manual operations, mortality, other), constant direct (depreciation, other fixed), and indirect components, expressed in Moldovan Lei (MDL) per head.

The quantitative methods used are represented by descriptive statistics and trend analysis for the evolution of pig heads, production, and self-sufficiency rates.

The cost structure analysis was calculated based on the following formula:

TC = $VC + CDC + IC$, where:

TC - Total costs

VC - Variable costs

CDC - Constant direct costs
IC - Indirect costs.
The qualitative methods include the SWOT analysis, represented by the structured evaluation of internal and external factors, as well as review of policy interventions, including subsidies via the Agency for Intervention and Payments in Agriculture, biosecurity measures by the National Food Safety Agency, training programs, and cooperative promotion.

RESULTS AND DISCUSSIONS

The pig sector has been highly valued since the Soviet period, especially in agricultural enterprises, where the number of livestock reached a peak of over 2 mil. heads, but usually stood at around 1.9 mil. heads.
At the same time, households had in their ownership for about 200 thousand heads, with annual fluctuations (Fig. 1).
After gaining independence of the country, this area faced numerous difficulties, which led to a significant decline.
In agricultural enterprises, between 1990 and 2000, the livestock population of pigs decreased by more than 12 times.
Households tried to compensate for this decrease, and only in 10 years, the number of heads in auxiliary households increased over 1.6 times, becoming the main providers of pig meat, especially for family consumption and informal economy [15], holding this position for an entire decade.
In the post-independence period, this is the specifically time interval when the lowest number of pigs was recorded in the history of agricultural enterprises.
However, starting with 2009-2010, the number of pigs in enterprises began to gradually increase, while a decrease was noted in households and in 2019, for the first time in a long period of time, agricultural enterprises surpassed households in terms of pig population, with this trend increasing continuously until 2024.

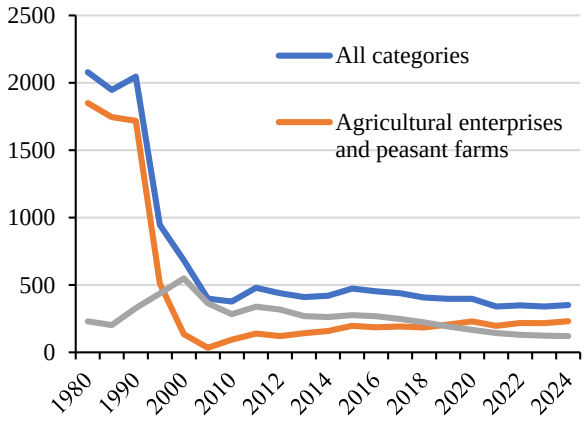


Fig. 1. Number of pigs by types of producers in the Rep. of Moldova, 1980 – 2024 (thousand heads)
Source: developed by author based on National Bureau of Statistics, 2025 [12].

In the last ten years, pork production in Moldova has reached the amount of around 64 thousand tons.

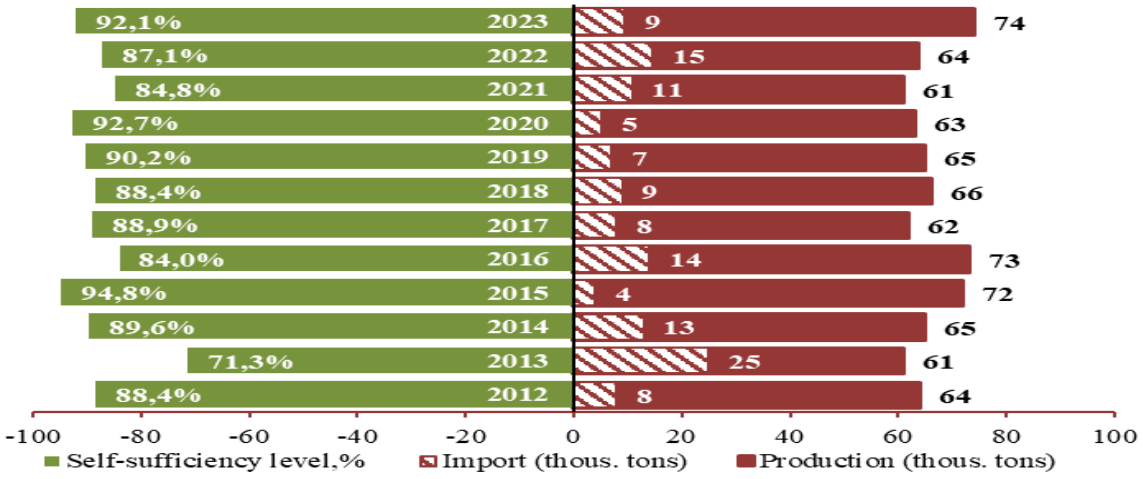


Fig. 2. Production and import volumes and self-sufficiency level with pork, 2012 – 2023
Source: developed by author based on National Bureau of Statistics, 2025 [12].

Of course, there are also exceptional years such as 2015, 2016 and 2023 where these figures have increased to about 73 thousand tons of pork.

However, this production volume is not enough to cover the needs of the domestic market, these being covered by imports that vary in quantities from year to year. Thus, there is a deficient level of self-supply with pig meat, which over the last ten years has been around 88% (Fig. 2). This fact must be viewed positively by local producers who, being already familiar with the standards and requirements of the local market, may have the opportunity to increase their production volume by 7 - 10%, especially as a result of engagement in competitive economic models of livestock farms [4; 5].

Decline in the number of heads and fluctuations in production are largely determined inclusively by the high costs of production of pig meat. Thus, based on the most recent collected data for 2025, there was calculated the standard cost for the production of live pig meat, expressed in MDL, structured by two categories of enterprises – large and medium-sized – and by three levels of average daily weight gain (500g, 650g and 800g). The data are aggregated at the level of costs per animal, distinguishing between variable, constant direct and indirect consumption.

Therefore, the total costs for meat production varies significantly depending on the size of the enterprise and the growth rate, with minimum values of 8,668 MDL per head (large enterprises, 500g/day) and maximum values of 12,098 MDL per head (medium enterprises, 800g/day), highlighting a higher efficiency of large units at high growth rates (Table 1).

Table 1. Standard cost for live pig meat production, MDL (year 2025)

	Large enterprises			Medium-sized enterprises		
	Average daily weight gain, g			Average daily weight gain, g		
	500	650	800	500	650	800
1. Variable costs - total	8,095.7	8,966.5	9,196.7	9,869.1	10,774.7	11,147.2
cost of youth at weaning	1,463.0	1,322.0	1,228.0	1,813.0	1,638.0	1,519.0
feed	5,622.8	6,265.4	6,426.0	6,872.3	7,657.7	7,854.0
veterinary services and preparations	150.0	150.0	150.0	200.0	200.0	200.0
mechanized operations	161.3	209.7	258.0	181.4	235.9	290.3
manual operations	241.9	412.1	387.1	272.2	353.8	435.5
cost of animal mortality	194.3	266.2	327.6	215.3	279.8	344.4
other variable costs	262.5	341.3	420.0	315.0	409.5	504.0
2. Constant direct costs - total	416.6	505.8	580.7	479.4	574.4	648.4
depreciation of fixed assets	126.0	170.6	218.4	126.0	167.9	210.0
other constant direct costs	290,6	335.2	362.3	353.4	406.5	438.4
3. Direct costs - total	8,512.3	9,472.4	9,777.4	10,348,5	11,349,0	11,795.6
4. Indirect costs	155.4	204.8	260.4	178.5	238.9	302.4
5. Total costs for meat production	8,667.7	9,677.1	10,037.8	10,527.0	11,587.9	12,098.0

Source: Own calculation.

With respect to the structure of variable costs, which represents the dominant component of direct costs, feed accounts for the largest share (between 61.6% and 70.5% of total variable

costs), followed by the cost of young animals at weaning (14.5%–18.3%). Other categories, such as veterinary services, mechanized and manual operations, mortality and other variable consumption, contribute marginally, but with notable variations between the presented scenarios. For example, the cost of mortality increases from 194.3 lei/animal (500g/day) to 327.6 MDL per head (800g/day) in large enterprises, thus pointing on the risks associated with intensification of production.

The constant direct and indirect costs have a relatively low contribution to the total costs (4.8%–6.7%). Depreciation of fixed assets and other direct constant costs are influenced by the degree of mechanization, being higher in large enterprises. Indirect costs, although modest (155.4–302.4 MDL per head), increases proportionally with production intensity, indicating a greater allocation of administrative and support resources in high-performance systems.

As a result of low production capacities, and aiming at ensuring the local market with the necessary quantities of pig meat, the import of meat in the last 5 years has an oscillatory character. Although the import of pork is made from several European countries, the main import partners account for Spain, Poland and Germany, that have only intensified their presence on the market of the Republic of Moldova. In 2024, only these three countries reached the uppermost presence on our market with a common share of 90.6% of the total import of pork (Table 2).

Table 2. Imports of pork, 2020 – 2024 (tons)

	2020	2021	2022	2023	2024
Total import (tons)	3,448.3	8,373.9	11,680.8	6,645.0	6,416.9
Spain	751.2	1,448.5	2,628.9	1,859.4	3,019.6
Poland	326.7	1,497.0	3,088.7	2,606.0	2,056.4
Germany	596.9	1,684.1	2,489.0	868.2	739.2
Top 3 of total import partners %	48.6	55.3	70.3	80.3	90.6

Source: developed by author based on UN Comtrade, 2025 [16].

At the same time, the export volume of pork is too small to be taken into account.

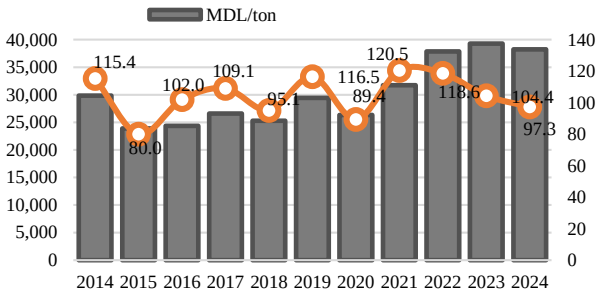


Fig. 3. Average prices and average selling price indices of pork, 2014 – 2024

Note: Average exchange rate 1 EUR=20.21289 MDL

Source: developed by author based on National Bureau of Statistics, 2025.

On the local market, although the price of pork in the last ten years has increased by approximately 28%, one cannot mention that its increase is a forecasted factor. Pork prices are rather unstable and are subject to significant variations from year to year, such as the significant reduction by 20% in 2015 compared to 2014 or significant increases in 2019 and 2021, which recorded growth by 16.5% and 20.5% respectively (Fig. 3).

Such volatility of prices from year to year is characterized rather not by the market or by the way buyers are prepared for these prices, but rather by the dependence on production factors (feed, energy, other production factors) and the risks accompanying this sector (various diseases, climatic influences, trade policies).

As for **vulnerabilities**, the Moldovan pig sector encounters a series of key challenges and difficulties, which have a generally negative influence on its economic performance, as well as hinders the enhancement of the competitiveness and sustainability of the national agri-food sector.

One of the most serious and persistent problems is the spread of various diseases,

among which African swine fever stands out. In recent years, outbreaks of this disease have caused massive economic losses for both large-scale farmers and medium- and small-scale farmers who did not have the resources necessary to implement effective biosecurity measures. Preventive slaughter, transport bans, trade restrictions and livestock losses have led to a sharp imbalance in the production and supply chain.

In addition to the sanitary and veterinary risk, the pig sector in the Republic of Moldova suffers from excessive fragmentation of agricultural holdings. In many cases, households come with a small size, outdated technical means and a limited capacity to adapt to modern market demands. Generally, such a structure of agricultural holdings will possess a number of limitations for increasing the sector's productivity, among which can be mentioned:

- Obtaining high yields in productivity and optimizing technical processes;
- Unsuccessful location and lack of necessary infrastructure will lead to abandoning the physical growth of the holding and switching to more advanced modern technologies;
- Lack of equity will reduce access to investments or new sources of financing;
- The large number of small producers and weak cooperation between them leads to limited possibilities in price negotiation, losing their positions on the shelves and the inability to adapt to market changes.

Also, an important aspect is the lack of qualified labor in the livestock field. This result is a consequence of the massive migration of the young population from rural areas to urban areas or abroad. Such a situation also creates difficulties in the ability of farms to operate efficiently, to maintain a high level of professionalism in animal management, nutrition, reproduction and veterinary health.

The developed SWOT analysis (Table 3) will focus on a wider range of vulnerabilities of the sector, as well present some opportunities for increasing its resilience.

Although pig farming in the Republic of Moldova is an important segment of agriculture, at the moment, its potential is still insufficiently exploited.

Table 3. SWOT analysis of the pig sector in the Republic of Moldova

Strengths
-Pork is among the most consumed types of meat in Moldova, having a strong position in the domestic diet; -Availability of feed and other biological resources; -Stable and sufficient domestic market demand, both from people and industry; -Incentives from the state as subsidies; -Emerging modern farms/investments: some commercial farms are adopting better genetics, breeding, and modernization (per sector strategy); -Low labor costs.
Weaknesses
-Disease risk and veterinary control issues; -Limited economies of scale - operation on small scale for a large part of the household farms, with obsolete technology and management; -Low productivity due to weaker genetics (in households); -Fragmentation of production and high production costs; -Dependence on imported breeds, piglets or genetic material; -Structural issues and lack of stable partnerships between producers and processors; -Insufficient logistics and infrastructure.
Opportunities
-Prospects for EU integration; -Increasing domestic demand and consumption of raw and processed products; -Focus on high-value processed products; -Potential for increasing public support; -Development of the organic / niche pork sector.
Threats
-Disease outbreaks such as African Swine Fever; -Volatility of prices for feed and final product; -Increased competition from de side of imports; -High tightening and EU standards; -Climate-change threats; -Decrease and aging phenomenon among the rural population.

Source: developed by author.

As **adaptive capacities**, the central authorities, having as their objective's food security, import reduction and rural economic development, are inclined to make efforts and support key actors in this field. The support given is visible both, through financial support in the shape of subsidies and through the necessary structural policies and reforms.

Among the most highlighted can be mentioned the following:

Subsidies. Financial support from central authorities is provided through the public institution called the Agency for Intervention and Payments in Agriculture, which is responsible for managing the resources of the National Fund for the Development of Agriculture and the Rural Environment. In recent years, this institution has had complex mechanisms to support the livestock sector, among which the pig sector is certainly included. The main directions of financial support have been represented by post-investment subsidies for farm adaptation/modernization and complementary payments and advance payments for various facilities. It is worth mentioning that the pig sector does not fall under the grant of direct payments per head of livestock or per kg of product. But compensations were granted to those actors who suffered from African swine fever, based on an assessment carried out by veterinary services. Although these payments do not fully cover the actual losses, they represent a form of support, especially for the affected small farmers.

At the same time, for fighting the vulnerabilities related to African Swine Fever, *disease prevention and biosecurity measures* have been taken, including restrictions on animal movement, disinfection of means of transport, fences and buffer zones around farms and prohibition of feeding with food scraps. Moreover, the Ministry of Agriculture and Food Industry, in collaboration with the National Food Safety Agency, periodically organizes inspections and training to raise the level of compliance of farms.

The central authorities also recognize the lack of a sufficient modern knowledge base among farmers. Thus, they have developed *policies to stimulate professional training and consultancy in the field*. These policies have been developed in collaboration with international institutions, and, therefore, short courses, seminars and study visits to other countries have been organized. A special role is played by the Agricultural and Rural Advisory Centers, which provide guidance for the development of business plans, accessing subsidies, breed selection, nutrition management and veterinary treatments.

Providing support for small producers in associations and their integration into the value chain. An aspect that creates vulnerabilities especially within peasant households is their excessive fragmentation. This phenomenon leads to a weak economic integration. To combat such a situation, the state through its policies encourages the creation of cooperatives or producer groups; joint storage and sale of animals; creation of partnerships between farmers and processors; stimulating local slaughtering and processing projects with the aim of internally capitalizing on the meat produced, reducing additional expenses and maintaining added value in the local economy.

Future-oriented strategic directions. Within the National Strategy for Agricultural and Rural Development 2023–2030 [7], a more coherent framework for animal husbandry is proposed, with a focus on adapting sanitary and veterinary legislation to EU standards, promoting organic farming and traditional products, digitizing traceability and reporting processes on farms, facilitating access to credit through state guarantees or guarantee funds. At the same time, central bodies are involved in complicated negotiation processes aimed at improving improve access on foreign markets, mainly through trade negotiations, enhancement of quality of production and obtaining export certifications.

CONCLUSIONS

The pig sector of the Republic of Moldova has gone through difficult times that were marked by notable reductions in livestock number of heads, as well as sanitary-veterinary challenges. Nevertheless, it has stood out due to its capacity for adaptation to the existing challenges and resilience.

The large quantities of pig production that were made during the Soviet period demonstrate to us approximately what potential can be achieved and what are the possible production limits.

Although in recent times a positive trend of consolidation of farms has been highlighted, the excessive fragmentation of agricultural holdings still persists, which in correlation with the lack of specialized labor force and price instability creates obstacles to increasing production and overcoming the self-supply deficit and reducing dependence on imports. On the other hand, this situation can also offer real opportunities for local producers, who can benefit from the constant demand of the domestic market and the support offered by public policies.

The efforts carried out by the authorities related to stimulation of investments, modernization of the livestock infrastructure and promotion of cooperation and association among producers are essential for overcoming the existing vulnerabilities in the sector.

If the current support measures are to be maintained and consolidated, together with the continuous implementation of strategic policies, the pig sector has viable chances to become not only resilient, but also sustainable and competitive over time. In such a way, it will contribute to the revival of national agriculture, intensification of its resilience and boost of the economic growth of the Republic of Moldova.

ACKNOWLEDGMENTS

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COMPARATIVE ANALYSIS OF THE ECONOMIC RISK IN MILK PRODUCTION BY SPECIES IN ROMANIA

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Abstract

This study evaluates the economic efficiency and risk associated with milk production across different livestock species in Romania, focus on cows, sheep and goat production systems. The research aims to identify the main determinants of economic vulnerability by conducting a comparative analysis of profitability and risk indicators based on income and expenditure budgets and technical-economic parameters. The methodology relies on the calculation of production value, cost structure, unit production cost, profitability indicators, operating risk rate, and security index using 2024 average production levels and market price data. The analysis has considered two productivity levels for dairy cows and average production levels for sheep and goats, allowing for an assessment of economic performance under different technological conditions. The results highlighted significant differences in economic viability between species. Cow milk production is economically sustainable only at high levels of productivity, while low levels of production generate losses and high operational risk, with a strong dependence on subsidies. Sheep milk production presented minimal profitability and high vulnerability to cost and price fluctuations, remaining economically fragile in the absence of public support. Goat milk production highlighted relatively higher economic stability, characterized by positive profitability and a more favorable balance between costs and revenues, although sensitivity to market variations persists. The results indicated that economic risk in milk production is mainly determined by technical efficiency, cost structure and productivity level. Improving the efficiency of input use, optimizing feed costs and increasing productive performance are essential to reduce economic vulnerability and ensure the financial sustainability of livestock farms.

Key words**:** *dairy production, economic risk, profitability, production costs*

INTRODUCTION

An economic activity can only develop under conditions of efficiency, both technically and economically, which allows it to achieve its objectives. Depending on the context of its development, any activity is subject to a certain degree of economic risk. Over the past forty years, both milk production and consumption have spread around the world, and trade in dairy products has increased [14]. The multiple challenges in the recent period in the dairy sector influence the level of farm efficiency and their profitability [2].

Milk production is influenced by a large sort of factors such as: species and breed, genetic inheritance, feeding, reproduction, health, farm size etc [3, 4].

Sustainable milk production is essential [6] for ensuring human nutrition and health [13], but it faces economic risks generated by price volatility, increasing costs, as well as climate change. Through the efficient use of inputs, the farms can increase their economic efficiency [5]. Farmers who decide to intensify their production systems may have a higher profit but must afford higher investments and deal with profit variability depending on the selling price or even climate risk [1]. The most important risks that farmers perceive are market, political and production risks, therefore they must selectively apply risk management strategies [12].

The significance of this research paper lies in the importance that the economic risk assessment in milk production in different species has for farmers, both for those who already carry out a production activity, and for those who aim to establish a dairy farm. The originality is ensured by the comparative calculations of technical-economic and risk indicators, with recent data, which the authors have carried out, as a necessity in relation to the existing literature in the field. Therefore,

this study brings new knowledge to the domain, providing a starting point for other economic studies and research. The research hypotheses on which this study started were the followings:

H1: Costs in milk production are high, relative to market prices;

H2: Milk production in Romania has poor levels of economic efficiency;

H3: Economic risk levels are very high in milk production.

The main purpose of this study was to determine the recent levels of economic risk associated with milk production activities on dairy cow, sheep and goat farms in Romania. The objectives of the research were to determine the income and expenditure budgets for cow, sheep and goat milk production in Romania, as average values per country, for the most recent data from the year 2024, and comparative analysis of technical-economic and risk indicators for milk from the three species.

MATERIALS AND METHODS

The calculations were made for the milk production in Romania, for average levels of the milk, usually obtained in farms, on species. Thus, for cow's milk, there were considered two levels – 3,500 liters/head, as national average level, and 6,000 liters/head, as average commercial farms level. For sheep, the average level was 60 liters/head, and for sheep, 270 liters/head, usually obtained as national level, which are considered in different technical-economic documents, when income and expenditures estimates are required. Calculations are based on the specific allocations of technological factors for milk production, provided in the specialized literature and average used in farms, as well as data and information on the prices of inputs on the free market, at the level of the year 2024. The income and expenditure budget was prepared, including the components of variable expenses and fixed expenses. This model is a replicable one for any milk production farm, thus the expenditures categories and economic formulas used are the same applicable. Variable expenses include expenses for feed, biological material, energy, medicines, other material expenses, supply quota, and fixed expenses include labor expenses, general expenses, interest, depreciation.

Variable expenditures are costs that change depending on the volume of production (number of animals, amount of milk produced etc.). Feed costs include those for hay, green fodder, silage, protein and energy concentrates, mineral and vitamin supplements etc., purchased from outside or produced on the farm. Biological material costs express the value of animals introduced into the base herd for milk production, which replace animals that have been culled. Energy costs are for electricity consumption for milking, lighting, ventilation, as well as fuels for machinery, feed transport, heating (where applicable). Medicines costs refer to mandatory and necessary or preventive treatments that are applied to animals on the farm. Other material costs are those for hygiene materials for milking and shelter, consumables (gloves, disinfectant solutions), spare parts for machinery. The supply quota is for the supply of feed, materials, and services. Fixed costs remain relatively constant, regardless of production variations, and refer to labor costs, overheads, payments for contracted loans, annual wear and tear on buildings, machinery, equipment, which reflects the decrease in the value of machinery and infrastructure over time.

The budget also includes the component of income level indicators: production value, main production value, taxable income, net income, profit rates. The value of production refers to the income obtained from the sale of milk, as the main product, and of secondary products (calves/lambs/kids, manure). Taxable income represents the value of the gross profit obtained after the sale of production and covering expenses, and net income is the profit remaining after paying tax. Calculations are made according to the following formulas:

$$TE = VE+FE \quad (1)$$

where:

TE – total expenditures, VE – variable expenditures, FE – fixed expenditures.

VP = VM + VS.....(2)

where:
VP – value of production, VM – value of main production, VS – value of secondary production.

TI = VP - TE.....(3)

where:

TI – income subject to tax.
NI = TI - t, where NI – net income, t – tax.

TIR = TI/EM.....(4)

where:
TIR – rate of taxable income, EM – expenditures for main production.
For the calculation of technical-economic and risk indicators, the following formulas were used:

ME = Fe+Be+Me+Oe .....(5)

where:
ME - material expenses, Fe - feed expenses, Be - biological material, Me - medicines, Oe - other material expenses.

UC = VM/Pm.....(6)

where:
Pm - average production per head.

P = UC-UP.....(7)

where:
P - profit, UP - unit price.

MVE = VP-VE.....(8)

where:
MVE - Margin on variable expenses.

MVE% = MVE/VP*100.....(9)

where:
MVE% - Margin on variable expenses %.
BPval = FE per head/MVE%.....(10)

where:
BPval - Breakeven point in value units.

BPfiz = BPval/UP.....(11)

where:
BPfiz - Breakeven point in physical units.

RR = BPval/VM per head*100.....(12)

where:
RR - Exploitation risk rate.

SI = (VM per head-BPval)/VMper head....(13)

where:
SI - Security index.

RESULTS AND DISCUSSIONS

Cow milk

For cow's milk production, 2 production levels were considered: 3,500 l/head/year and 6,000 liters/head/year. For a production level of 3,500 liters per head per year, the total value of production is 8,604.51 lei/head, while the total cost of production reaches 8,057.47 lei/head (Figure 1).
Without subsidies, the farm records a loss of approximately -427 lei, and the taxable income rate is negative (-5.31%), which indicates unprofitability. Variable expenses dominate the cost structure, especially feed [10], and within fixed expenses, labor is the main component. The activity is economically fragile, heavily dependent on subsidies. Measures are needed to streamline costs [7] and increase productivity, by optimizing production costs (especially feed), increasing production levels, and even diversifying products [8] or their sales channels. In this regard, [11] stated that the optimal system for cows with higher genetic potential for milk production is a high level of concentrate supplementation.
Producing a liter of milk at this low level of production of 3,500 liters is unprofitable without subsidies, the cost being higher than the selling price (Figure 2).

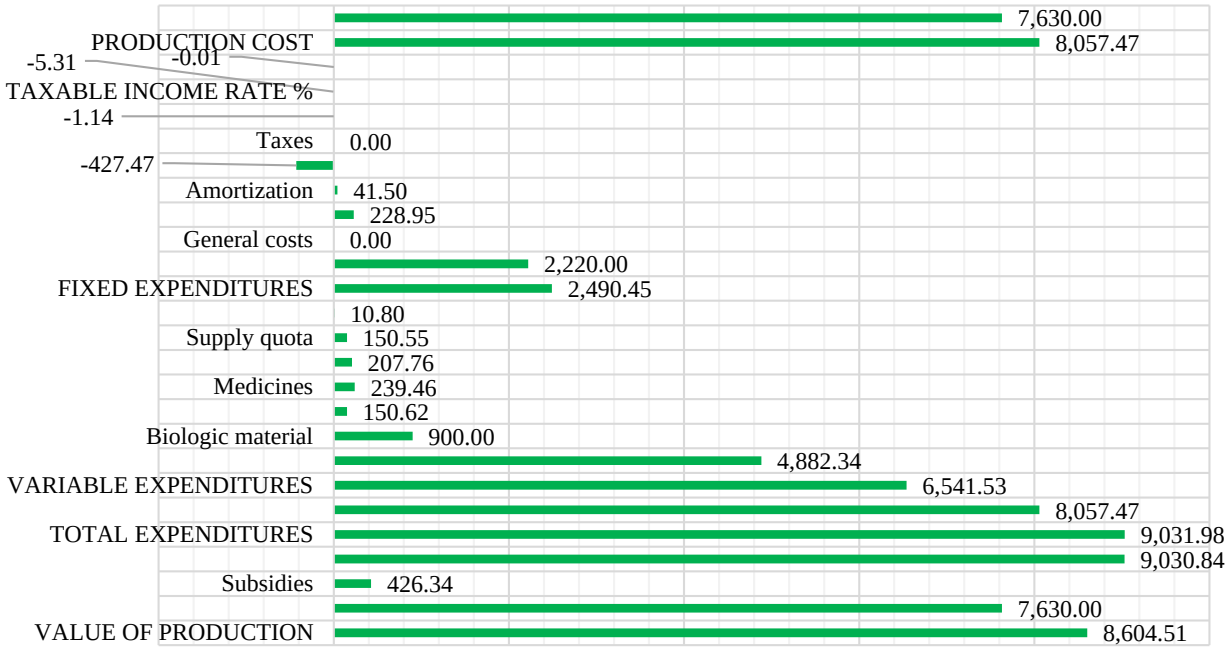


Fig. 1. Income and expense budget per cow per year, at a production of 3,500 liters of milk per head (lei/cow/year)
Source: Own results.

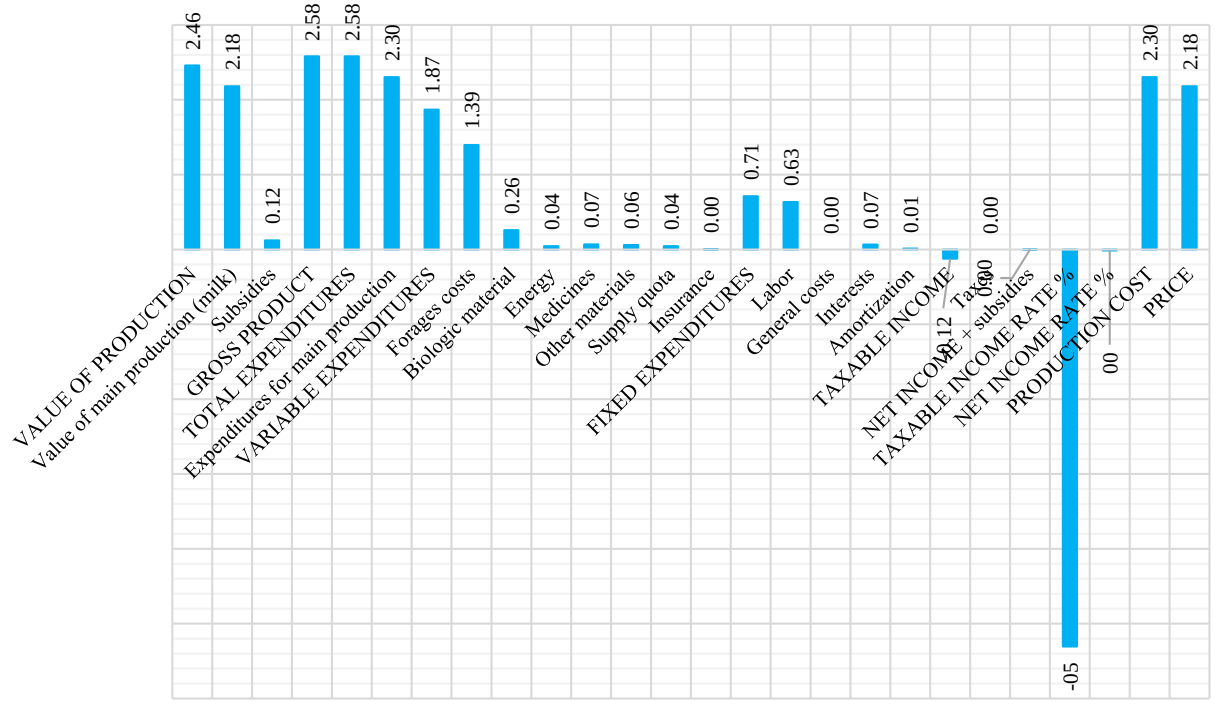


Fig. 2. Income and expense budget per liter of milk, at a production of 3,500 liters of milk per head (lei/liter)
Source: Own results.

Expenses are dominated by feed costs. The selling price of milk is 2.18 lei/liter, while the production cost is higher, 2.30 lei/liter, resulting in a loss of 0.12 lei/liter. The subsidy of 0.12 lei/liter covers this loss, but does not bring profit.

Table 1 shows the economic and risk indicators of the activity. The exploitation risk rate is very high (136.14%), indicating an economic activity vulnerable to price or cost fluctuations.

Table 1. The economic and risk indicators for production of 3,500 liters of milk per cow

Indicators	Measure unit	Values
Labor costs per 1,000 lei of total production	lei	258.00
Material costs per 1,000 lei of total production	lei	723.99
Expenses per 1,000 lei main production	lei	1,056.03
Margin on variable expenses	lei	0.59
Margin on variable expenses %	%	23.98
Breakeven point in value units	lei	10,387.45
Breakeven point in physical units	l/head	4,764.89
Exploitation risk rate	%	136.14
Security index		-0.36

Source: Own results.

The profitability level could be reached at a production of 4,764.89 liters per capita. Security index has a negative value (-0.36) and shows that production is below the minimum profitability threshold. The activity is unprofitable for this level of production and is carried out below the profitability threshold. Figure 3 illustrates the budget per cow for a production of 6,000 liters/head/year.

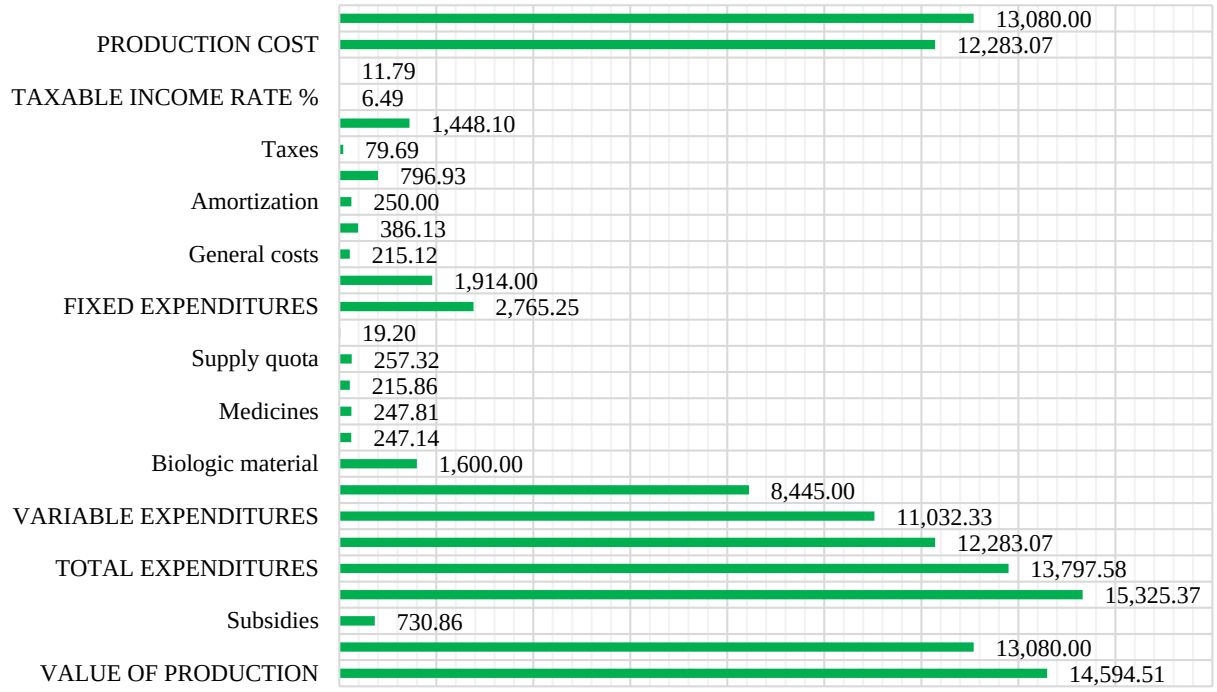


Fig. 3. Income and expense budget per cow per year, at a production of 6,000 liters of milk per head (lei/cow/year)
Source: Own results.

The annual budget highlights a profitable activity, but largely supported by subsidies. The total value of production is approximately 14,595 lei, the value of main production (milk) being 13,080 lei, while total costs amount to 12,283 lei. The net profit plus subsidies is of approximately 1,448 lei per cow. The largest part of the expenses is feeding, with over 8,400 lei, followed by labor and biological material expenses. Support through subsidies plays an important role in ensuring profitability. Without it, the level of net profit would be diminished, which indicates a high dependence on external aid. Figure 4 shows the components of income and expenses per liter of milk, for the production of 6,000 liters.

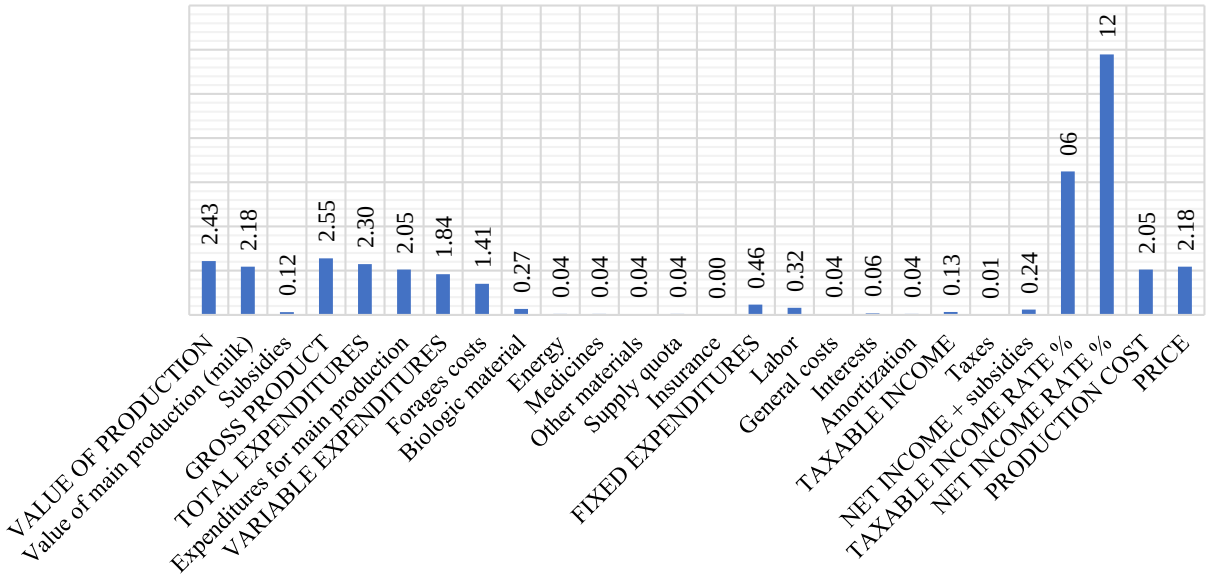


Fig. 4. Income and expense budget per liter of milk, at a production of 6,000 liters of milk per head (lei/liter)
Source: Own results.

The selling price is 2.18 lei/liter, and the production cost is 2.05 lei/liter, which generates a very small profit — only 0.13 lei/liter. The profit rate is 6.5%, which indicates a slightly profitable activity. However, after including subsidies (0.12 lei/liter), profitability increases, leading to a net income plus subsidies rate of 11.8%.
Table 2 shows economic and risk indicators for the production of 6,000 liters of milk per cow.

Table 2. The economic and risk indicators for production of 6,000 liters of milk per cow

Indicators	Measure unit	Values
Labor costs per 1,000 lei of total production	lei	131.15
Material costs per 1,000 lei of total production	lei	720.04
Expenses per 1,000 lei main production	lei	939.07
Margin on variable expenses	lei	0.594
Margin on variable expenses %	%	24.4
Breakeven point in value units	lei	11,329
Breakeven point in physical units	l/head	5,196.99
Exploitation risk rate	%	87
Security index		0.13

Source: Own results.

In this case, the material costs are 720.04 lei per 1,000 lei of production, indicating a high dependence on material inputs. The variable cost margin is 0.594 lei/liter, representing 24.4%, a value that suggests that production is profitable at the operational level. The physical breakeven point is reached at a production of 5,197 liters of milk/cow/year. However, the exploitation risk rate is 87%, indicating medium to high economic vulnerability, and the security index is 0.13, suggesting that only 13% of current production exceeds the minimum breakeven point.

Sheep's milk

As illustrated in the Figure 5, the annual budget per sheep shows a relatively financially balanced activity, but dependent on subsidies. The value of production is approximately 843 lei per head per year, while total costs reach 841.9 lei, leaving a very small profit. The largest expenses are those for feed, which represent over 543 lei of the total. The activity

has a very low profit margin, sensitive to costs, but supported by subsidies to remain economically viable.

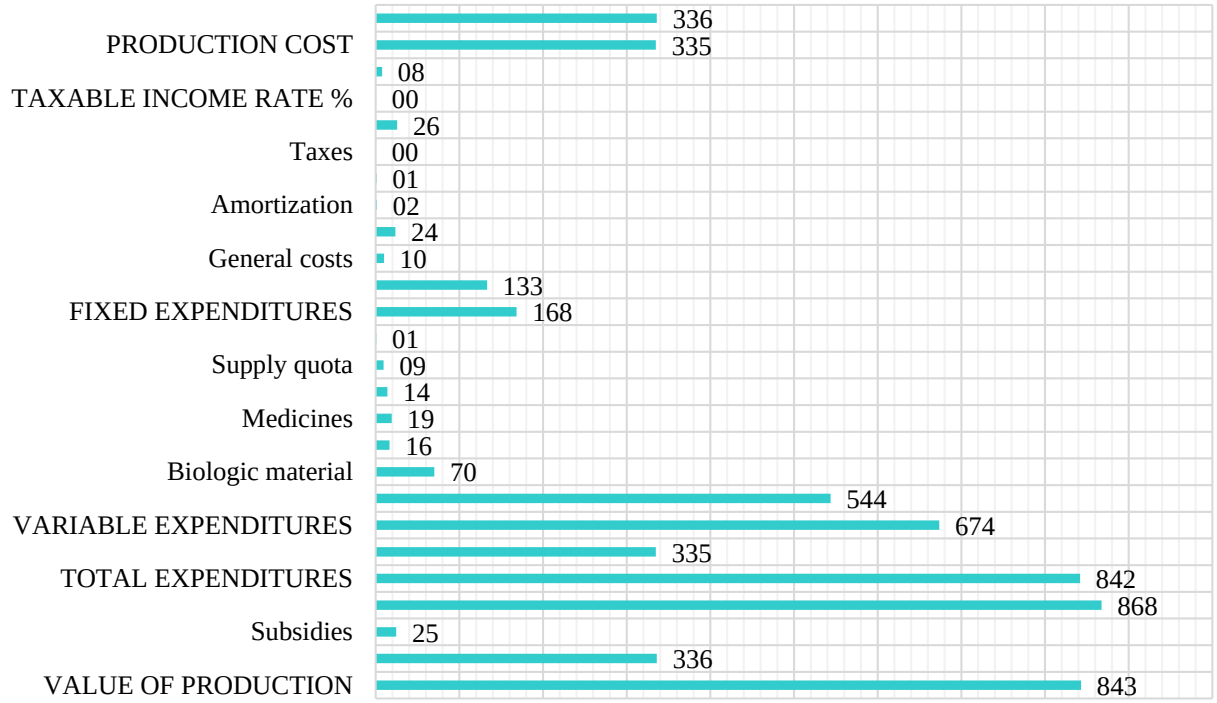


Fig. 5. Income and expense budget per sheep per year, at a production of 60 liters of milk per head (lei/sheep/year)
Source: Own results.

The price obtained per liter of milk is 5.60 lei, and the cost of production reaches 5.58 lei. Therefore, the gain is almost symbolic — only 0.02 lei/liter — which means that any negative variation in prices or costs could turn the activity into a loss.

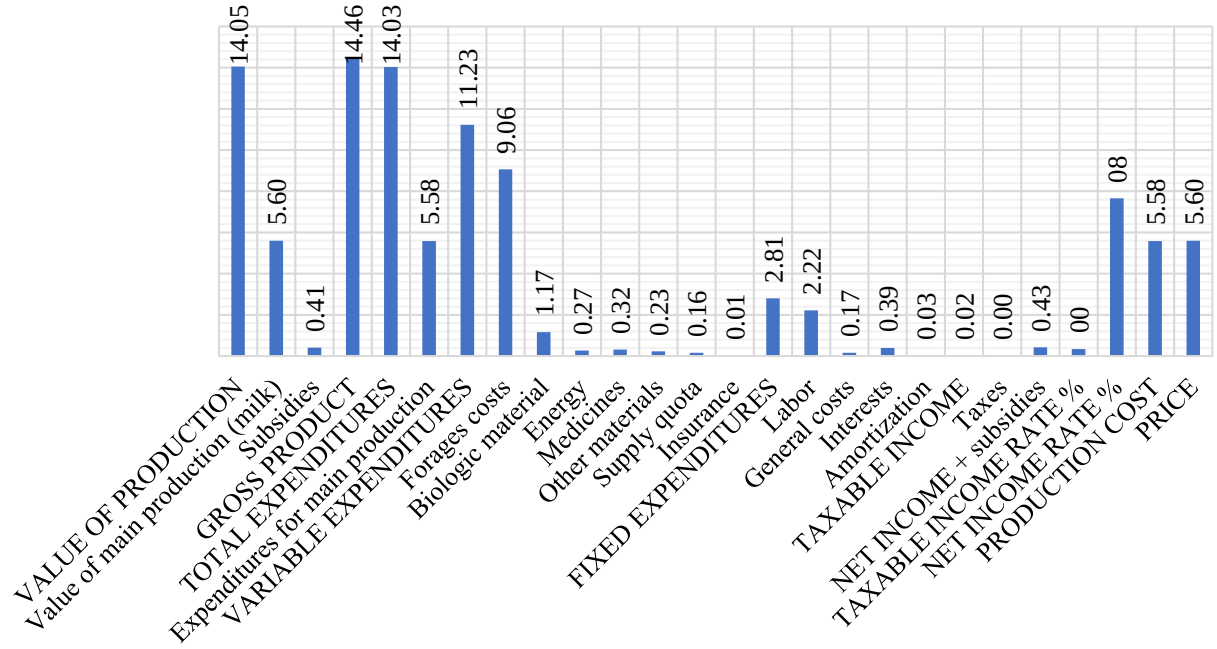


Fig. 6. Income and expense budget per liter of milk, at a production of 60 liters of milk per head (lei/liter)
Source: Own results.

Table 3. The economic and risk indicators for production of 60 liters of milk per sheep

Indicators	Measure unit	Values
Labor costs per 1,000 lei of total production	lei	158.01
Material costs per 1,000 lei of total production	lei	767.24
Expenses per 1,000 lei main production	lei	996.59
Margin on variable expenses	lei	2.824
Margin on variable expenses %	%	20.1
Breakeven point in value units	lei	837
Breakeven point in physical units	l/head	149.52
Exploitation risk rate	%	249
Security index		-1.49

Source: Own results.

Prices for sheep products are the most important factor for marginal economic values [9]. The net profit is partially supported by subsidies (approximately 0.41 lei/liter), without which the activity would be unprofitable (Figure 6).

According to the data in Table 3, material costs are dominant, with a share of over 76%. Total costs for 1,000 lei of main production are 996.59 lei, very close to the value received, which indicates a low profit margin.

The break-even point is relatively high: almost 150 liters of milk per sheep would have to be sold to cover total costs.

The exploitation risk rate is very high, which shows high instability, and the security index is negative, a clear signal that the activity is below the economic safety threshold and is unsustainable without interventions (subsidies, optimization, etc.).

Goat's milk

In the case of goat milk, for an average level of 270 liters per head per year, the value of milk production is 1,269 lei, while the related cost is slightly lower, 1,178.87 lei, which generates a net profit of approximately 106 lei per goat (Figure 7).

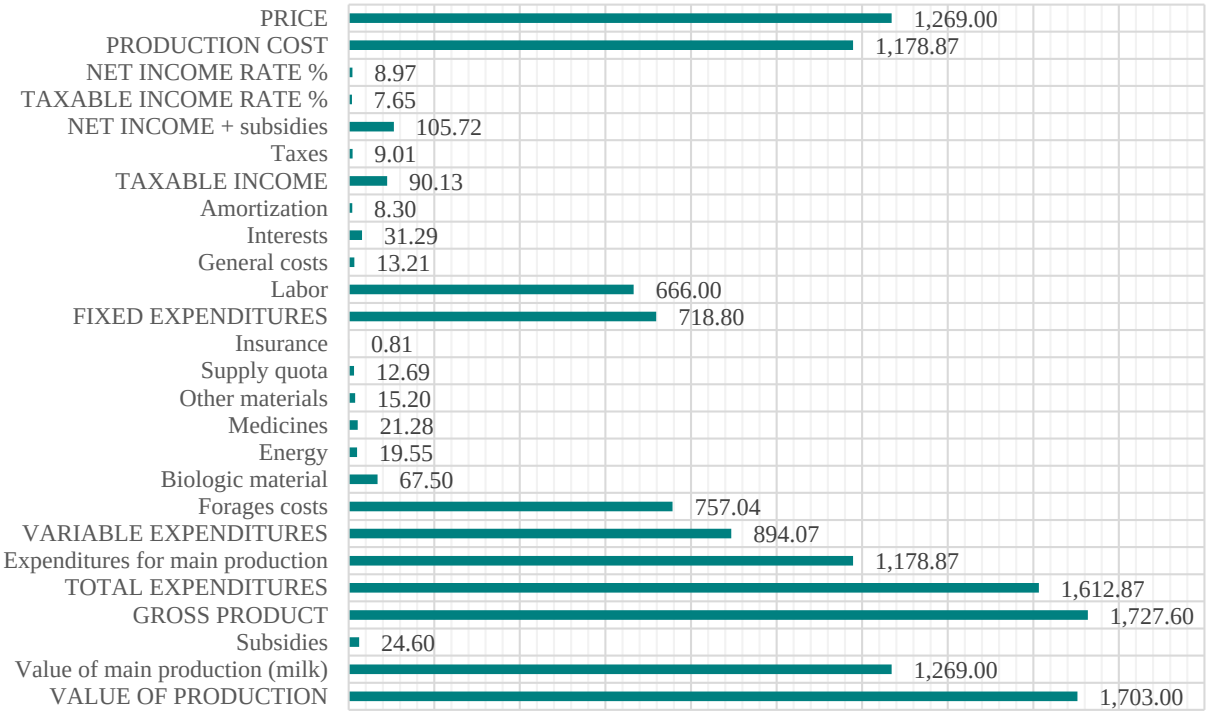


Fig. 7. Income and expense budget per goat per year, at a production of 270 liters of milk per head (lei/goat/year)
Source: Own results.

The net profit rate is 8.97%, which indicates a profitable activity, but with a modest margin. Therefore, milk production per goat is profitable and sustainable, and the dependence on subsidies is moderate. Feed costs remain the highest and can be optimized to improve the level of profitability. On liter of milk, the cost of production is 4.37 lei/liter, while the price is 4.70 lei/liter. The net profit per liter is small, but positive, also supported by subsidies.

In the absence of the subsidy, the activity would remain profitable, but with a very small margin (Figure 8). The margin on variable costs is high, at 47.5%.This indicates that, after covering variable costs, there is enough room left to cover fixed costs and make a profit (Table 4). The break-even point is relatively high, and the operating risk rate is high (119%), which means that income is very sensitive to price or production variations. In other words, the farmer is in the risk zone and needs to increase productivity or reduce costs to be on a safe profit.

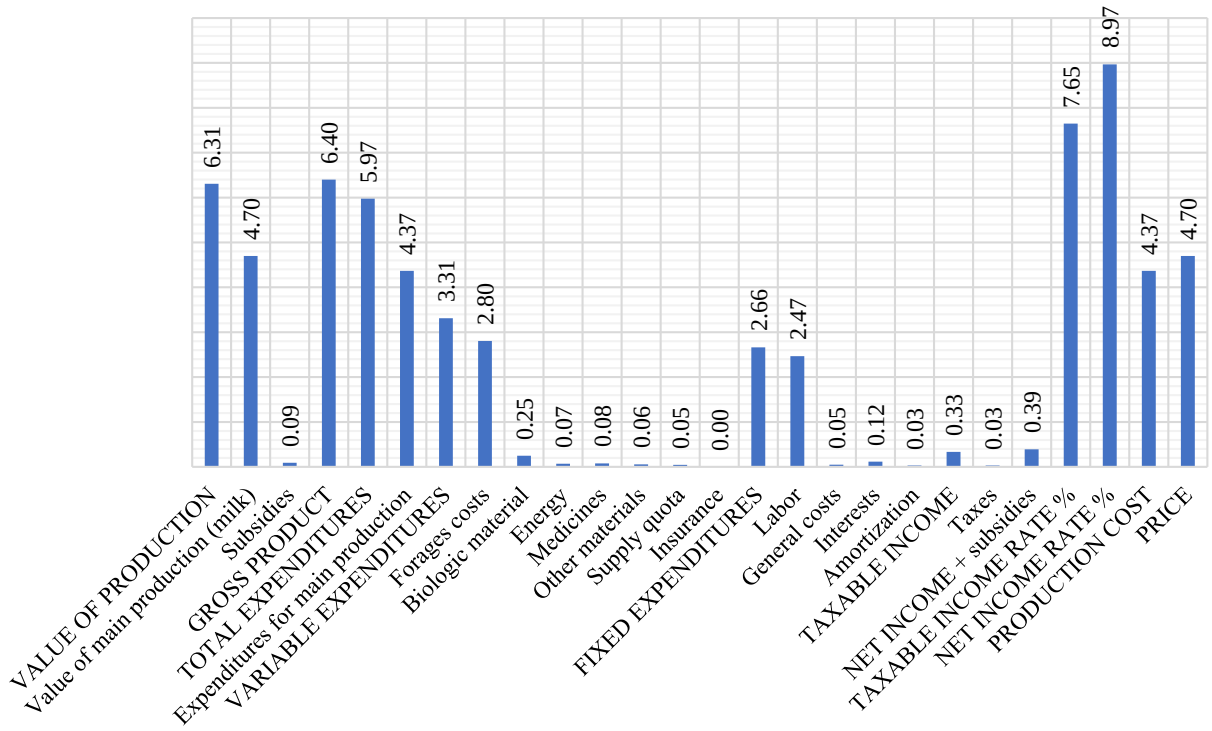


Fig. 8. Income and expense budget per liter of milk, at a production of 270 liters of milk per head (lei/liter)
Source: Own results.

Table 4. The economic and risk indicators for production of 270 liters of milk per goat

Indicators	**Measure unit**	**Values**
Labor costs per 1,000 lei of total production	lei	391.07
Material costs per 1,000 lei of total production	lei	505.59
Expenses per 1,000 lei main production	lei	928.98
Margin on variable expenses	lei	2.996
Margin on variable expenses %	%	47.5
Breakeven point in value units	lei	1,513
Breakeven point in physical units	l/head	321.97
Exploitation risk rate	%	119
Security index		-0.19

Source: Own results.

CONCLUSIONS

The analyzes carried out in this paper highlight the fact that of the three types of production analyzed for Romania, at the level of 2024 – cow's milk, sheep's milk, and goat's milk – the most balanced and sustainable economic activity is goat's milk production.

It manages to be profitable even without subsidies, with at least 7.6% gross profit, thanks to a good balance between income and expenses and a sufficient operating margin to cover fixed costs and generate profit.

Cow milk production in Romania is viable only if a high level of productivity is achieved, as in the calculated model of 6,000 liters/head.

At low levels of production, of 3,500 liters/head, the activity is unprofitable, and farmers depend on subsidies to cover losses.

With good cost management, especially those related to feeding, and with financial support, this activity can become profitable.

Sheep milk production is very fragile from an economic point of view.

Without interventions to increase productivity or reduce costs, as well as without subsidies, it cannot become sustainable.

ACKNOWLEDGEMENTS

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ROMANIA'S RURAL HUMAN CAPITAL INDEX

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Abstract

The author took into consideration, in the construction of the Rural Human Capital Index in Romania, that for a sustainable development of the rural human capital it is not sufficient to intervene only in the educational and health care process, but also in the demographic and economic development of rural areas. The selected indicators are structured by three major dimensions: the demographic dimension to make a diagnosis of the primary development potential of human capital; the social dimension to provide concrete information on the human capital stock (health care and education) and the economic dimension to provide information on the economic performance of human capital. The development of rural human capital depends simultaneously on the demographic, social and economic conditions. These three dimensions of human capital influence each other, functioning as an ecosystem in which the demographic dimension provides the basis, the social dimension provides quality and the economic dimension provides functionality. The main conclusion of the paper is that in Romania, the rural human capital develops where it has favourable conditions, so that the predominantly urban areas have a much higher index than the intermediate and predominantly rural areas. The index calculated for the period 2007-2023 reveals that those rural areas that have no access to infrastructure, to quality basic services, with poorly developed economies, have been on a human decapitalisation trend over time.

Key words**:** *rural area, human capital, rural development*

INTRODUCTION

In this paper, the starting point in assessing the rural human capital is the area it belongs to, and the Romanian rural area is undergoing a significant transformation process. As major trends, we can mention the urbanisation of the peri-urban countryside, on the one hand, and the deruralisation/disappearance of many rural communities in the deep/remote countryside, on the other hand. The current trends are divergent, and the rural human capital, in order to cope with the new rural realities, should be healthy and educated, have the necessary training and skills so that the rural areas it belongs to fulfil its main functions, namely: ensuring food security, maintaining an ecological balance, and preventing climate change, as well as preserving and protecting local traditions and customs, etc.

Given that the importance of supporting rural human capital is obvious, and the Romanian rural area is subject to different socio-economic conditions, this is reflected in the degree of development of both rural area and rural capital.

Most often, the rural human capital in the less-favoured areas is caught in a vicious circle from which it can only escape by migrating to other more promising areas or falling into a state of deprivation that generates nothing good, except precarious employment and extreme poverty, leading to social exclusion [2].

Thus, for example, the lack of basic technical communal infrastructure (lack of electricity or running water, overcrowded housing) directly hinders children's ability to study effectively, thus undermining educational capital. Similarly, the absence of formal employment opportunities reduces motivation for educational activity, which will perpetuate the state of poverty, which will be reflected in a precarious health condition. Thus, the human capital in a given rural area is not only the sum of individual attributes, but rather the collective capacity for well-being and productivity, strongly constrained by environmental and economic factors. This

broader understanding implies that policy interventions aimed at improving rural human capital should adopt a holistic and integrated approach. It is not sufficient to invest only in educational programmes or healthcare services. Sustainable development needs simultaneous investments in economic development, through the creation of formal jobs, and in basic infrastructure, in the improvement of living conditions. Neglecting these interconnected aspects results in limited effectiveness and perpetuation of deprivation cycles in rural areas [10].

MATERIALS AND METHODS

The construction of a rural human capital index adapted to the Romanian countryside can be useful both for researchers and policy makers at local, county, regional or national level. The index can be a useful tool in quantifying human capital both in terms of development level and involvement in the demographic and economic sphere.

Human capital indices have a lower predictive value at national level, due to the homogenisation effect of national statistics, than at local level, where the different level of human capital development in different areas can be captured. Due to the lack of data at local level, in the case of the present paper, statistical indicators of rural human capital performance at county and regional levels will be used. However, where interest exists, the rural human capital index model can be replicated without problems (it can even be improved by adding specific indicators) at granular level – at area level (LAG), at commune level.

In the construction of Rural Human Capital Index, three dimensions were considered: demographic, social and economic. Because no matter what human capital entails (skills, competences, health) [1], it cannot be evaluated outside its demographic dimension that creates an image of the initial human capital stock, or outside its economic dimension, which highlights the level of human capital integration in the economy, in the labour market. And the analysis of each dimension of the index may suggest the need for different policy measures depending on the development level reached by the human capital.

The demographic dimension is very important for a correct analysis of human capital, as this helps to understand the viability of a rural area, taking into consideration that the most important problems that rural areas are facing are ageing and depopulation. This dimension captures the primary potential of human capital, as without a demographic dimension we cannot talk about human capital.

Demographic dimension and human capital influence each other, as follows: demographic changes (such as population ageing, demographic decline or migration) directly affect the stock and quality of human capital, and the quality of human capital influences the demographic decisions and the adaptive capacity of society.

The two concepts are inseparable. The demographic dimension indicates the potential, and the human capital provides information on the capacity to capitalise on this potential. Effective rural policies should integrate both the demographic aspects (encouraging natality, managing migration), and those aspects regarding the human capital stock (investments in education, vocational training and healthcare) to ensure a sustainable rural development.

The social dimension refers to the health and educational component, being the dimension that captures the stock of human capital. The health component is important in terms of supporting human capital at its maximum potential of social and economic efficiency, a healthy population presupposing constant involvement in individual development and support to gainful activities. The educational component is decisive in the substantial growth of human capital, generating the greatest added value [12], [8], [1], [11], [13], [5]. ***The economic dimension*** presents the economic impact of human capital. The human capital is considered a key driver of sustainable economic growth and societal development. The more developed human capital is, the greater its potential to support economic activities. Even though this theory has existed for decades, it is still almost impossible to

accurately measure the human capital stock, as well as its impact on economic growth [1], [3], [7], [8], [9], [6], [14].

Table 1. Structure of rural human capital index – dimensions, indicators, source

	Indicators – at county, rural level	Source: NIS tempo-online
Demographic dimension – *captures the potential aspect of human capital*		
Demographic volume and structure	Population number Average population per commune	POP105A POP105A, ADM101A
	Ageing rate	POP105A
Natural movement of the population	Natural increase	POP215A
Migratory movement of the population	Migration rate	POP306A
Social dimension – *captures the stock of human capital*		
Health:	Infant death rate	POP209A
	Life expectancy at birth	POP217A
	Access to family physician	SAN104B, POP105A
Education:	School enrolment rate (pre-school, primary, secondary, high school) = school population / school-age population	SCL103E POP105A
	Share of primary and secondary school graduates	SCL109B, POP105A
	PC/school population	SCL112B, POP105A
Economic dimension – *captures the productive aspect of human capital*		
Labour force	Employment rate (Share of population engaged in agriculture in total population 15-64 years)	FOM103D POP105A
	Share of employees in the population 15-64 years	FOM104D
	Unemployment rate (share of unemployed in the population 15-64 years)	SOM101E

Source: Author's own conception.

In modern economic theories, mainly in endogenous growth theories, human capital is not only an exogenous variable, it is a main source of progress. The quality of human capital increases labour productivity. A better educated and healthier labour force is more efficient in using physical capital and technology, and thus produces more added value. The economic dimension of a given area is deeply influenced by the quality and stock of its human capital.

Within the index, each dimension and each indicator related to each dimension will have the same specific weight.

The first step in the construction of the index is the conceptualisation of the theoretical matrix regarding the human capital. The next step is the collection of statistical data and the construction of databases (SPSS and Excel).

Each selected indicator will go through the normalisation process, using the following formula:

$$In = (X - Xmin)/ (Xmax - Xmin) \quad (1)$$

where:
In – value of normalised indicator;
X – current value of indicator;
Xmin – minimum value of indicator;
Xmax – maximum value of indicator.

For each normalised indicator, a value in the range 0-1 results, where 0 is the lowest value, and 1 the highest value.

For each dimension, the dimension index will be calculated according to the formula:

$$Id = (Ind1 + Ind2 + ... + Indn)/n \quad (2)$$

where:
Id – dimension index;
Ind1, Ind2 .... Indn – normalised indicators;
n – number of selected indicators.

The global index is calculated according to the following formula:

$$Ig = (Id1 + Id2 + ... + Idn)/n \quad (3)$$

where:
Ig – global index;
Id1 ... Idn – dimension index;
n – number of dimensions related to the model.

Given the complexity of phenomena governing human capital, its evolution is not exclusively explained by the action of global index, but as a result of several dimensions/indicators. To identify the main aspects that influence the degree of rural human capital development, the Pearson correlation analysis was used, which highlights the intensity of the relationship between two analysed variables. The values of correlations range from -1 to 1 and the following situations may occur: a. the intensity of the relationship is stronger the closer the value is to 1; b. strongly negative intensity the closer the value is to -1; weak intensity the closer the value is to 0.

RESULTS AND DISCUSSIONS

Significant discrepancies exist in Romania between urban and rural areas, as well as between different rural areas.
The paper aims to analyse the development level reached by human capital after 2007 to this day, in the rural area, at county level, as well as the factors that influence it.

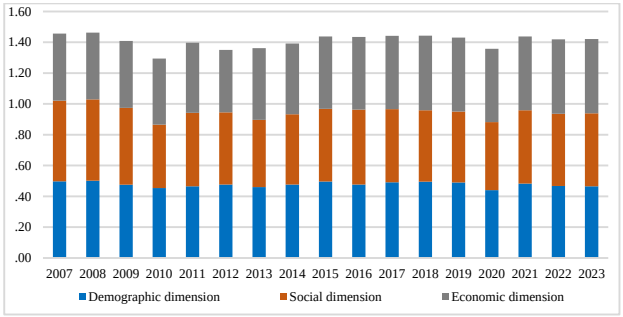


Fig. 1. RICU index dimensions in the period 2007-2023
Source: Author's own calculations based on NIS tempo online official statistical data [4].

The rural human capital index (RICU) in Romania slightly decreased from 1.46, in the year 2007, to 1.42, in the year 2023. Two dimensions of the index slightly decreased: the demographic dimension, from 0.50 in 2007 to 0.47 in 2023; the social dimension, from 0.52 in 2007 to 0.48 in 2023); only the economic dimension slightly increased from 0.44 in 2007 to 0.48 in 2023. This denotes a loss of human capital both in demographic terms (numerically and structurally), and in social terms through lower access to healthcare, and slight but constant degradation of formal education process. Only the economic dimension appreciated over this period, but this was not the result of endogenous growth (from the increase of the human capital stock through the educational process and basic healthcare services) but as exogenous growth, from investments in infrastructure and business sector. But these investments (from EU or from public or private funds) are made only in certain areas, which results in the increase of major discrepancies between rural areas (Fig. 1).

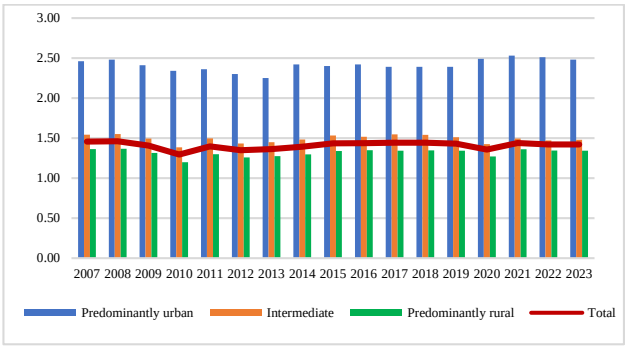


Fig. 2. RICU by degree of rurality, in the period 2007-2023
Source: Author's own calculations based on NIS tempo online official statistical data [4].

Thus, depending on the degree of rurality, the differences related to the RICU index, over the analysed period, are significant in favour of predominantly urban areas (2.48 in the year 2023) with a score almost double compared to the other areas (intermediate rural 1.48 and predominantly rural 1.34 in 2023) (Fig. 2).
The correlations of the RICU index with its components are strongly positive in the case of the economic dimension 0.918** and demographic dimension 0.740**. A weak correlation is noticed with the social dimension 0.227 (health and education), which denotes that there are other factors/determinants that influence the level of human capital development and that influence the quality of healthcare services and education provided. In the analysed period, the influence of social dimension on RICU decreased, from a moderately positive correlation (+0.421**) in 2023 to a weakly positive correlation (+0.227) in 2023. At the same time, the relationship between this index and the demographic

dimension slightly increased (from +0.735** in 2007 to +0.740** in 2023); the relationship with the economic dimension slightly decreased (from +0,932** in 2007 to +0.918** in 2023), yet the correlations remained strongly positive throughout the analysed period (Fig. 3).

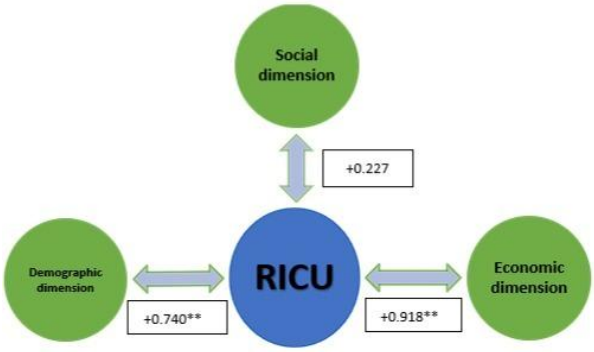


Fig. 3. RICU index correlations with its dimensions, 2023
Source: Author's own calculations based on NIS tempo online official statistical data [4].

When translated into the rural reality, these connections highlight that where a young and numerous population exists (*a human capital with development potential*), the rural economy is stronger and more diversified, and vice versa. This situation is generally found in peri-urban areas, tourist areas and rural areas with significant investments, and *the human capital develops (skills, competences) in the workplace.* These jobs do not often require a high educational level for employees (warehouse handlers, construction workers, textile workers, cooks, housekeepers, etc.). However, these more developed areas do not necessarily correlate with better healthcare or educational services.

The correlations between the RICU index dimensions denote a strongly positive relationship between the demographic dimension and the economic dimension, which intensified, over the analysed period, from +0.623** in 2007 to +0.738** in 2023. This situation reveals that supporting the economic and demographic activities positively reinforce each other.

In contrast, the correlation between the social dimension and the demographic dimension, which was weakly negative initially (-0.202 in 2007), became moderately negative (-0.383*). This situation denotes that overall, a more numerous and younger population is not exposed to social conditions that are favourable to the educational and healthcare process, quite the contrary (Fig. 4).

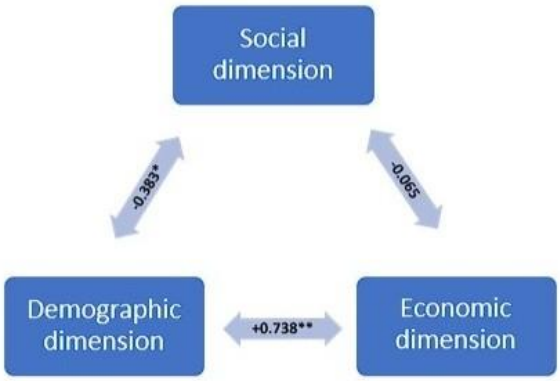


Fig. 4. Correlations between RICU index dimensions, 2023
Source: Author's own calculations based on NIS tempo online official statistical data [4].

There is a weakly negative relationship between the social dimension and the economic dimension in the analysed period (+0.286 in 2007; -0.065 in 2023), which can be explained by the multiple dysfunctions in the Romanian countryside. Ideally, we should have a strong and reciprocal relationship between these two dimensions, in which a well-educated and healthy society (social dimension) is the foundation of a performing economy (economic dimension), and a strong economy provides the necessary means to support and further develop the human capital.

Between the RICU index and the degree of rurality there is a strongly negative relationship throughout the analysed period (-0.517** in 2007 to -0.494** in 2023), which means an inversely proportional correlation between these. Thus, the higher the degree of rurality, the lower the RICU index values. This correlation is also found between the demographic dimension, the economic dimension respectively and the degree of rurality.

The strongly negative correlation between the demographic dimension and rurality increased from -0.413** in 2007 to -0.536** in 2023, which highlights the negative demographic phenomena present in the predominantly rural

areas. These phenomena improved in the intermediate rural areas, to even reach positive demographic phenomena in the predominantly urban areas, with numerous and younger populations, with a positive migratory balance.
A strongly negative correlation is also present between the economic dimension and the degree of rurality, which increased in the analysed period, from -0.400** in 2007 to -0.446** in 2023, which highlights a precarious rural economy, poorly diversified as the degree of rurality increases.
The social dimension is not influenced by the degree of rurality, a weak relationship existing between them, although an improvement can still be noticed in the analysed period, from a weakly negative correlation in 2007 (-0.292) to a weakly positive correlation in 2023 (+0.057).
The indicators related to each dimension of the RICU index behave differently depending on the degree of rurality.
In the case of all demographic and economic indicators, the predominantly urban areas stand out, with the best values. The strongest correlation is found in the case of indicator "Average population per rural community" (-0.593**), even though negative, which highlights that the average size of a predominantly urban community (8,367 inhabitants/commune) is much larger than that of an intermediate rural community (3,693 inhabitants/commune) or compared to a predominantly rural community (2,995 inhabitants/commune). A weakly negative correlation appears in the case of indicators "population ageing" (-0.272) and "migration balance" (-0.213).
In the case of predominantly urban areas, all demographic indicators have improved considerably, a substantial gap existing compared to the other rural areas. At the same time, a slight gap is envisaged between the intermediate areas and predominantly rural areas in favour of intermediate areas, yet this gap is small.
In the case of social indicators, differences by area are no longer as obvious as in the case of demographic indicators, yet the predominantly urban areas have the best values (Table 2).

Table 2. RICU indicators by degree of rurality, 2007 and 2023

		Degree of rurality			
		Predominantly urban	Intermediate	Predominantly rural	**Total**
Demographic dimension					
Rural population	2007	168,857	4,064,642	5,505,343	**9,738,842**
	2023	267,764	4,197,509	5,159,142	**9,624,415**
Average population per rural community	2007	5,277	3,587	3,199	**3,391**
	2023	8,368	3,693	2,995	**3,381**
Population ageing	2007	118.61	100.72	109.89	**106.75**
	2023	79.73	111.59	129.25	**121.58**
Natural increase of the population	2007	-2.00	-4.19	-4.53	**-4.34**
	2023	-0.80	-4.80	-4.53	**-4.54**
Migration balance	2007	468	-814	-984	**-886**
	2023	1,865	-705	-683	**-629**
Social dimension					
Infant death rate (‰)	2007	7.70	13.65	14.30	**13.90**
	2023	5.20	6.37	6.51	**6.43**
Average life expectancy	2007	71.23	71.62	71.61	**71.61**
	2023	75.20	73.81	74.01	**73.96**
Access to family physician	2007	5.03	4.92	4.43	**4.62**
	2023	4.52	4.19	4.15	**4.17**
School enrolment rate	2007	87.92	67.89	69.00	**69.06**
	2023	65.37	56.52	58.87	**58.17**
Number of students per PC	2007	27.09	28.01	28.85	**28.50**
	2023	4.55	5.22	4.42	**4.72**
Share of graduates in school population	2007	15.48	9.80	9.80	**9.94**
	2023	10.37	8.46	8.78	**8.70**
Economic dimension					
Share of employees in the population aged 15-64 years	2007	31.33	13.05	9.99	**11.63**
	2023	42.53	17.77	12.74	**15.30**
Share of unemployed in the population aged 15-64 years	2007	2.33	5.96	5.93	**5.85**
	2023	0.42	2.86	2.91	**2.83**
Employment rate in agriculture	2007	29.42	39.73	41.14	**40.34**
	2023	6.71	13.17	14.92	**14.08**
Rural Human Capital Index					
2007		2.46	1.54	1.36	**1.46**
2023		2.48	1.48	1.34	**1.42**

Source: Author's own calculations based on NIS tempo online official statistical data [4].

The correlations between social indicators and rurality are very weak for all indicators. In the case of economic indicators, their correlation with rurality is strongest for the indicator "Share of employees in the population aged 15-64 years" (-0.473*); this is moderately negative, indicating a significant gap between predominantly urban areas (42.53%) and other areas (12.74% in the intermediate rural areas and 17.77% in the predominantly rural areas. In the case of indicator "share of unemployed in the population aged 15-64 years", there is a

positive, but very weak correlation with rurality. A moderately negative correlation is found in the indicator "employment rate in agriculture" (-0.356* in 2023), up from -0.172 în 2007.

The economic indicators for the predominantly urban areas have improved considerably and, at the same time, a gap is also emerging between the intermediate rural areas and the predominantly rural areas, to the detriment of the latter.

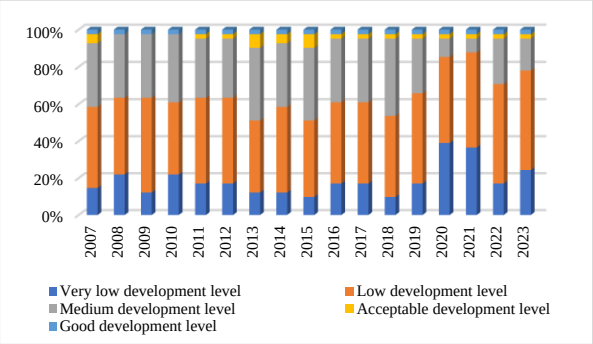


Fig. 5. Share of rural human capital by development level of the counties in the period 2007-2023
Source: Author's own calculations based on NIS tempo online official statistical datan [4].

The distribution of counties, by development level reached by RICU, reveals the high share of counties with low and very low development level of rural human capital. Until 2019, the share of these two categories fluctuated from 51.22% to 65.85%, while in 2020 and 2021 (Covid crisis) reached historical highs of 85.37%, and 87.80% respectively, to decrease significantly afterwards, yet well above the previous level, to 70.73% in 2022 and 78.05 in 2023.

The number of counties with acceptable and good level remained the same as in 2016, in two counties (4.88%), namely Ilfov and Timiș. Until 2016, the share of counties from these categories ranged from 2.44% to 9.76%.

In the year 2023, the distribution of counties by development level of rural human capital is the following:

- *Counties with very low development level* (10 counties, 24.39%): Teleorman, Dolj, Ialomița, Hunedoara, Tulcea, Mehedinți, Covasna, Caraș-Severin, Satu Mare, Buzău;
- *Counties with low development level* (22 counties, 53.66%): Olt, Vrancea, Galați, Vâlcea, Sălaj, Alba, Brașov, Călărași, Maramureș, Neamț, Harghita, Vaslui, Botoșani, Brăila, Giurgiu, Sibiu, Bacău, Cluj, Mureș, Bihor, Suceava, Argeș;
- *Counties with medium development level* (7 counties, 17.07%): Constanța, Gorj, Arad, Bistrița-Năsăud, Dâmbovița, Iași, Prahova;
- *Counties with acceptable development level* (1 county, 2.44%): Timiș;
- *Counties with good development level* (1 county, 2.44%): Ilfov.

Table 3. Contribution of dimensions to RICU index, by development level

		DEMOGRAPHIC dimension	SOCIAL dimension	ECONOMIC dimension	RICU
Classification of Rural Human Capital Index 2023	Very low development level	0.36	0.43	0.31	1.11
	Low development level	0.47	0.47	0.49	1.42
	Medium development level	0.52	0.53	0.58	1.63
	Acceptable development level	0.67	0.44	0.89	2.00
	Good development level	0.83	0.65	1.00	2.48
	Total	**0.47**	**0.47**	**0.48**	**1.42**

Source: Author's own calculations based on NIS tempo online official statistical data [4].

Ilfov county is the only county in the ***category of counties with a good human capital development level***, with a value of the index of 2.48, well above the national average of 1.42 (Table 3).

All component dimensions of the index had values well above national average, namely:

- the economic dimension has the largest gap between the category average of 1.00 and the national average of 0.48; it is characterised by a high share of employees in the population aged 15-64 years (42.53%), the lowest share of unemployed in the population aged 15-64 years (0.42%) and the lowest share of employment in agriculture (6.71%);
- the demographic dimension (0.83 category average and 0.47 national average) has the largest communes (8,368 inhabitants per

commune), the lowest degree of ageing (79.73), with a negative natural increase of the population, yet better compared to the other categories (0.80) and a great attractiveness level for the population, with the highest migration balance (+1,865 people);
- the social dimension (0.65 category average and 0.47 national average), which includes the health sub-dimension with favourable indicators much above national average, yet not with the best recorded levels (5.20‰ infant death rate, 75.20 years ani average life expectancy, 4.52 physicians in 10,000 inhabitants) and the education sub-dimension with the bet values for all analysed indices (65.37% school enrolment rate, 10.37% share of graduates in total school population and 4.55 pupils per PC).

Timiș county is the only county in the ***category of counties with acceptable human capital development level***, with a RICU index of 2.00, above the national average of 1.42.

The *economic dimension* has the highest contribution to index (0.89 category average compared to 0.48 national average) with the highest share of employees in total population aged 15-64 years, 42.74% (as compared to 15.30% national average), a rate of unemployment in the population aged 15-64 years of 0.67% (as against the national average of 2.83%), low employment rate in agriculture, i.e. 11.67% (as compared to 14.08% national average).

The demographic dimension related to this category (0.67) has a contribution above the national average (0.47), with leading positions in terms of degree of ageing (87.78) as against 121.58 national average and migration balance (164 persons) as against -629 persons national average.

The social dimension related to this category (0.44) is below the national average of 0.47. (Table 3).

In this case, there is an interesting dichotomy between the component sub-dimensions: the health sub-dimension has the best values, both compared to the national average and to the other categories (infant death rate 3.90 ‰, as against 6.43‰ national average; average life expectancy 75.90 years, as against 73.96 years national average; access to family physician 4.54 physicians/10,000 inhabitants, as against 4.17 physicians/10,000 inhabitants national average), while the education sub-dimension has the lowest values for all indicators (school enrolment rate 53.53 as against 58.17 national average; number of pupils/PC, 6.10 compared to the national average of 4.72; share of school graduates 7.24% as against 8.70% national average).

The category of counties with medium human capital development level has a RICU index of 1.63, higher than the national average of 1.42. The following counties are in this category: Prahova 1.76, Iași 1.69, Dâmbovița 1.61, Bistrița-Năsăud 1.61, Arad 1.61, Gorj 1.58 and Constanța 1.57. The contribution of dimensions to RICU is the following: 0.52 demographic dimension, 0.53 social dimension and 0.58 economic dimension.

It can be noticed that the *economic dimension* has the most important contribution to index, and all the counties in this category, except for Constanța, had values well above the national average. In the case of the economic dimension, the counties with the highest values are Prahova 0.70 and Arad 0.61, and the lowest values are found in Constanța 0.47 and Gorj 0.55.

In the case of the *demographic dimension*, the counties with highest values are Iași, with 0.68 and Constanța, with 0.60, values well above the national average.

In the case of the *social dimension*, the counties with the highest contribution is Gorj (0.68), while Iași county is at the opposite pole (0.43).

The category of counties with poorly developed human capital has values of RICU index and related dimensions quite similar to the national average. The RICU index values of this category range from 1.26 in Olt County to 1.56 in Argeș.

The counties with RICU index below the national average represent 45.45%; by dimensions, the situation is the following: counties with values under the national average in terms of demographic dimension represent 40.91% (9 counties of 21 counties in this

category), social dimension 50% (11 counties), economic dimension 31.82% (7 counties).
Cluj county ranks 5th in terms of RICU index value in this category, with values of demographic and economic dimensions well above the category values or the national average, but with values among the lowest in the case of social dimension, of which educational indicators have the lowest values, with the lowest share of graduates (6.33%) and the lowest school enrolment rate (50.62%).
Olt and Alba counties are atypical counties, this time at the bottom of the ranking, with low values of demographic and economic dimensions and with high values of the social dimension.
The category of counties with very poorly developed human capital has an average RICU index of 1.11, ranging from 0.96 in Teleorman to 1.25 in Buzău county. The lowest contributions are generated by the economic dimension (0.31 as compared to the national average of 0.48) and the demographic dimension (0.36 compared to 0.47 national average). The social dimension also has values below the national average, yet slightly closer to it. The lowest values of the economic dimension are found in Dolj 0.12, Teleorman 0.19, Mehedinți 0.21, Hunedoara 0.22 counties, and the highest values, yet under the national average, are found in the counties Tulcea 0.46, Satu Mare 0.45, and Covasna 0.41.
In the case of the demographic dimension, only one county exceeds the national average, namely Satu Mare (0.53), while Hunedoara (0.22) and Teleorman (0.25) lie at the opposite pole.
On the other hand, in the case of the social dimension, Hunedoara County is the leader (0.61), much above the national values and the category it belongs to. Above-average values are also found in the counties Mehedinți 0.55, Caraș-Severin 0.54, Teleorman 0.52, and Buzău 0,51.

CONCLUSIONS

The main conclusions of this paper are the following:

- The development level of rural human capital is heavily dependent on the demographic, social and economic dimensions. One cannot speak about development in the absence of a set of factors that enhance it. The development of rural human capital depends simultaneously on the demographic, social and economic conditions. These three dimensions of the human capital influence each other, functioning as an ecosystem in which the demographic dimension provides the basis, the social dimension provides the quality and the economic dimension provides functionality.
- The rural human capital index (RICU) in Romania, in the analysed period, slightly decreased from 1.46, in the year 2007, to 1.42, in 2023, as a result of the discrepancy between the rural areas and the particular development of only a few rural areas that have favourable conditions (proximity to urban poles, attraction of European and private funds, tourist areas, etc.).
- Two dimensions of the index are slightly decreasing (demographic and social dimension), only the economic dimension is slightly increasing; this denotes a loss of human capital both in demographic terms (numerically and structurally), and social terms through decreased access to healthcare and the slight, but constant degradation of formal educational process. Only the economic dimension registers an appreciation, but this does not come as endogenous growth (from the increase of the human capital stock based on the educational process and the provision of basic healthcare services), but as exogenous growth from investments in infrastructure and business sector. But these investments (from EU or public or private funds) are made only in certain areas, resulting in the increase of major discrepancies between rural areas.
- The correlations of RICU index with its component dimensions are strongly positive in the case of the economic and demographic dimensions. A weak correlation with the social dimension (healthcare and education) can be noticed, which denotes that there are other factors/determinants that influence the human capital development level influencing the quality of healthcare and education services

provided. In the analysed period, the influence of the social dimension on RICU decreased, from a moderately positive correlation in 2007, to a weakly positive correlation in 2023. The relationship between this index and the demographic dimension slightly increased, while the relationship with the economic dimension slightly decreased, but the strongly positive correlations were maintained throughout the investigated period.

- When translated into rural reality, these relationships highlight that where a young and numerous population exists (a human capital with development potential), the rural economy is stronger and more diversified, and vice versa. And this situation is found, in general, in the peri-urban areas, tourist areas, as well as in the rural areas with significant investments, and human capital (skills, competences) develops in the workplace. Most often, these jobs do not require a high educational level for employees (warehouse handlers, construction workers, textile workers, cooks, housekeepers, etc.). However, these more developed areas do not necessary correlate with better healthcare or educational services.
- There is a strongly negative relationship between the RICU index and the degree of rurality throughout the investigated period, which means an inversely proportional correlation between these. Thus, the higher the degree of rurality, the lower the RICU index values. This correlation is also found between the demographic dimension, the economic dimension respectively and the degree of rurality.
- The distribution of counties, by the development level reached by RICU, highlights the high share of counties with low and very low level of rural human capital development.

As highlighted in the analyses carried out, the level of the social dimension of human capital (education and health) does not impact with RICU. The main reason is that during the period under review there were no developments as regards more educated and healthier communities (able to support an endogenous economic growth/rural development based on solid foundations), but of those communities that accessed important European funds and attracted public and private investments (based on exogenous economic growth/rural development that if it does not impact on the growth of human capital, it will not become sustainable in the long run). And these more developed rural communities represent only a small part of rural Romania, which is concentrated only in certain areas (around urban poles and in attractive touristic areas). On the other side, the vast majority of Romanian rural communities are facing a constant human decapitalization reaching in certain areas even the massive depopulation of villages.

As a general conclusion, rural development generated only on external action, through investments (private, public, European funds) in rural areas deepen the disparities between them.

Future rural policies to address these shortcomings require a holistic approach. You cannot have a strong rural economy without a healthy and educated workforce and you cannot keep young people in rural areas without a modern infrastructure.

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ECONOMIC EVALUATION OF FODDER PRODUCTION FROM BIRD'S-FOOT TREFOIL AFTER ORGANIC FERTILIZATION

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Abstract

Recently, developments in agriculture have necessitated the search for technological solutions that ensure the production of highly productive and economically efficient grass fodder. Continuous climate change has led to research into economically efficient agricultural practices for production. In this context, a scientific research experiment conducted in 2024-2025 at the experimental field of the Research Institute of Mountain Stockbreeding and Agriculture, Troyan studied the impact of the organic fertilizers Azo Smart, Lieta-veg, and Petro 330 on the economic efficiency of grassland production from Bird's-foot trefoil. The data presented show that organic fertilization of Bird's-foot trefoil is an economically profitable agrotechnical measure. The organic fertilizer Lieta Veg, applied in doses of 200 and 300 ml/da on Bird's-foot trefoil grassland, ensures maximum profitability (819.96% and 829.21%) with minimal production costs (15.01 and 15.17 EUR/da) and low cost price (0.016 EUR/kg). Linear regression analysis revealed positive correlations between average dry matter yield and gross revenue ($y = 0.1497x – 2.8435$) and between production costs and cost price $y = 0.0009x + 0.0019$, with very high coefficients of determination. The results obtained determine the practical application of organic fertilization as an appropriate agrotechnical measure in the production of fodder from Bird's-foot trefoil in mountainous conditions with acidic soils, while eliminating any risks to the environment.

Key words**:** *Bird's-foot trefoil, fodder production, economic indicators, regression analysis*

INTRODUCTION

Most perennial fodder crops are grown because of their high productivity and low moisture requirements [23], which makes them suitable for climate change. Their economic importance is due to their perennial nature, whereby the main agrotechnical activities such as plowing, discing, sowing, rolling are performed only once in the year of establishment of the grassland, protecting the soil from degradation in subsequent years. One such perennial fodder crop is Bird's-foot trefoil, which is a key component in the creation of highly productive mixed grasslands. It is a plant with high adaptability to acidic soils in mountainous and semi-mountainous regions [3]. Along with its high productivity as a legume crop, it accumulates organic nitrogen in the soil due to its nitrogen-fixing ability [8]. This makes it possible to reduce production costs, especially when grown together with perennial grasses, due to the possibility of supplying the necessary amount of nitrogen through nitrogen fixation [14]. Bird's-foot trefoil and alfalfa, included in the composition of grass mixtures, increase the share of relative net income by $83 compared to cereal crops [1], and the price is decisive for the profitability of grass agrophytocenoses and affects the amount of costs [20].

The main task in the production of fodder crops at the present stage is to increase its profitability by increasing agricultural production with minimal energy and resource costs [11, 26]. This involves the correct combination of production technology elements that lead to a reduction in the cost of growing fodder crops and an increase in profits. The lack of resource potential and pricing policy are the main tools that are an integral part of the development of agronomic crops.

Research on this crop has mainly focused on biological characteristics, growth and development, productive and quality characteristics [9] and, to a lesser extent, on economic efficiency. Economic analyses are a

critical but often overlooked aspect of forage production research, where practical applicability for producers and relevance to scientific and technological advances are essential.

The production of fodder crops requires the assimilation of all elements of technical progress scientific and economic in all its aspects that determine productivity, quality and economic efficiency [7, 15]. The economic results of grass fodder production allow them to be used as reference values for subsequent production with approaches that justify the proposed economic solutions [12, 13]. The technology of grassland cultivation is related not only to the effectiveness of differentiated fertilization on production, but also to the influence of fertilizers determining the development of soil fertility and fodder quality [6, 19]. The application of nutrients in specific doses and ratios in accordance with the requirements of fodder crops largely determines the economic efficiency of the fodder produced [27] [4]. The application of nutrients through organic fertilizers determines the ecological effect in the production of organic fodder [21].

Recently, the constant search for environmental sustainability has directed scientific research towards the need to rethink agricultural production systems. In this regard, leguminous fodder crops, including Bird's-foot trefoil, play a key role in the development of sustainable agricultural production systems, i.e. through the accumulation of nitrogen in the soil.

The aim of the study is to make an economic assessment of the application of organic fertilization in the production of Bird's-foot trefoil in the mountainous conditions of Central Northern Bulgaria.

MATERIALS AND METHODS

The experiment was conducted during the period 2024-2025 in the experimental field of the Research Institute of Mountain Stockbreeding and Agriculture – Troyan with bird's-foot trefoil, cultivar "Leo", treated with the biofertilizers Azo Smart, Lieta-veg, and Petro 330. The variants of the experiment are: 1. Control (not fertilized); 2. Azo Smart – 35 kg/da; 3. Azo Smart – 70 kg/da; 4. Lieta-veg – 200 ml/da; 5. Lieta-veg – 300 ml/da; 6. Petro 330 – 50 kg/da; 7. Petro 330 – 100 kg/da. The experiment was conducted in mountainous conditions on light gray pseudopodzolic soil with an acidic reaction. Sowing was carried out at a sowing rate of 1.2 kg/da, and fertilizers were applied at the beginning of budding.

Azo Smart organic fertilizer is a highly concentrated complex of unique microbial strains. They were developed by "Agriges" and are registered in an international reference microbial catalog. The microbial strains in Azo Smart have a high capacity to capture atmospheric nitrogen and stimulate photosynthesis. The aim is to increase the availability of nitrogen for the crop and improve the efficiency of the fertilizer applied. Azo Smart organic fertilizer has the following composition: Rhizosphere bacteria - Azotobacter chrococcum LS132; Azospirillumbrasilense AGS608; Bacillus amyloliquefaciens AGS282; uncomposted plant soil improver - Mycorrhizae (Glomus spp.); fungal isolates, including: Trichoderma longibrachiatum AGS799.

Petro 330 organo-mineral fertilizer comes in the form of pellets for soil application and is applied by mixing with the soil. Its composition includes: Total nitrogen (N) 3%; Organic nitrogen (N) 3%; Total phosphorus (P_2O_5) 3%; Total calcium (CaO) 8%; Total sulfur (SO_3) 6%. Organic carbon (C) 19%; Organic matter of animal origin 38% - meat and bone meal, dried poultry and cattle manure.

Lietta Veg has the following composition: Organic matter 30% w/w: plant extracts and Ascophyllum nodosum seaweed extract; Nitrogen (N) organic 2.5% w/w; Carbon (C) organic 18% w/w. pH.Lieta-veg is manufactured by "AGRIGES" s.r.l.

The grassland was harvested by mowing during the two experimental years in the budding-early flowering stage.

The dry matter yield was determined by mowing, years, and average for the period, by drying average samples to a constant weight at 105^0C and recalculated according to the

percentage of dry matter in the green mass (kg/da).

The economic indicators were calculated based on the average dry matter yield for a two-year period (kg/da), as reported in the ZFTK 36 project reports (2024 and 2025) in Agricultural Academy of Bulgaria [28]. The economic indicators were calculated and the results were analyzed using a tabular and graphical method. For this purpose, technological maps were developed [17], which were used to calculate production costs (EUR/da), cost price (EUR/kg), gross revenue (EUR/da), gross profit (EUR/da), and profitability (%) of the produced fodder.

The regression coefficient is an indicator of the change (+/-) when the i-th factor changes (+/-) by the same unit [24] and is presented in dependencies showing the highest values of correlation coefficients.

The mathematical processing of the yield was performed using the method of variance analysis by calculating statistically proven differences [16].

RESULTS AND DISCUSSIONS

The analysis of the results from the first experimental year clearly shows the stimulating effect of organic fertilizers on dry matter yields (Table 1) in grasslands from bird's-foot trefoil. In the year of establishment of the grasslands, yields of this species ranged from 580.0 to 666.68 kg/da. An excess of fresh mass compared to the control was reported when treated with the organic fertilizer Azo Smart in both doses (var. 2 and 3), respectively by 7.2%. The relatively high effect of the applied biofertilizers can be attributed to the favorable climatic conditions during the first vegetation period of the plant growth cycle. The dry mass yield in all fertilization variants exceeded that of the control. Fertilization with Azo Smart at a dose of 70 kg/da had the highest effect, achieving a yield exceeding the control by 14.9%. For the other biofertilizers and their application doses, the increase ranged from 3.2 to 9.2%.

Table 1. Dry matter yield (kg/da) from Bird's-foot trefoil by year and average for the period 2024-2025

Variants	2024	2025	Average for the period
1. Control	580.01	1,478.49	1,029.25
2. Azo Smart – 35 kg/da	633.35	1,435.80	1,034.57
3. Azo Smart – 70 kg/da	666.68	1,514.39	1,090.53
4. Lieta-veg – 200 ml/da	633.35	1,250.02	941.68
5. Lieta-veg – 300 ml/da	610.01	1,310.15	960.08
6. Petro 330 - 50 kg/da	621.68	1594.63	1,108.15
7. Petro 330 -100 kg/da	598.35	1,577.76	1,088.05
LSD 5 %	323.8	125.24	**81.62**
LSD 1 %	454.5	175.80	**114.57**
LSD 0.1 %	641.7	248.19	**161.75**

Source: Data from annual reports on project ZFTK 36 of Agricultural Academy of Bulgaria [28] and own calculations.

The positive effect of biofertilizers can be explained by the synergistic interaction between the microbial composition of biofertilizers and the crop, which stimulates photosynthesis efficiency, improves the growth cycle, and increases yields. The microorganisms contained in Azo Smart have been identified and characterized as capable of promoting plant growth, improving their stress resistance, and fixing nutrients contained in the atmosphere, especially nitrogen. The complex of microbial bacteria belonging to different genera (Bacillus, Azotobacter, Pseudomonas) is characterized by a strong effect on plant growth. The microorganism Agriges Azotobacter chrococcum, strain LS132, releases the largest amount of ammonium nitrogen compared to the other strains analyzed, i.e., it has the highest activity in terms of fixing nitrogen from the atmosphere.

During the second experimental year, the Azo Smart and LietaVeg biofertilizers recorded lower productivity than the control. The Petro 330 fertilizer performed well, with dry matter yields exceeding the control by 7.85% (var. 6) and 6.71% (var. 7), respectively. The dry

matter productivity when fertilized with Azo Smart at a dose of 70 kg/da was 2.42% higher than that of the control. The effect of biofertilizers is explained by the favorable climatic conditions during the formation of the first growth in the second experimental year and the rapid growth and development of the crop. The positive effect of the organic-mineral fertilizer Petro 330 is also determined by its composition, which includes nitrogen (N) total 3%; nitrogen (N) organic 3%; phosphorus (P_2O_5) total 3%; calcium (CaO) total 8%; Sulfur (SO_3) total 6%. Carbon (C) organic 19%. The organic matter in this fertilizer is 38% of animal origin- meat and bone meal, dried poultry and cattle manure, which determines the ecological effect of its application. The complex of elements it contains ensures better absorption of nutrients, activates metabolism and growth, and creates better plant resistance to stress. The presence of a humic-organic complex, which is completely natural, rich in organic substances and humic acids, stimulates the development of the root system and enhances the absorption of nutrients.

The average for the study period showed that Petro 330 organic fertilizer was the most productive in both doses, with yields of 1,108.15 and 1,088.05 kg/da, respectively. The Azo Smart fertilizer applied in doses of 35 and 70 kg/da also recorded yields of 1,034.57 and 1,090.53 kg/da. The least productive fertilizer was Lieta-veg, as can be seen from the values presented, 941.68 and 960.08 kg/da, respectively.

The obtained results give reason to claim that different organic fertilizers have different effects on the productivity of bird's foot trefoil, and their action depends on the type, the dose applied in combination with the soil and climatic conditions and the biological characteristics of the crop.

Production costs (Table 2) are presented (*EUR/da*) based on average yields from two harvest years, with emphasis on the impact of fertilizer doses on economic indicators. Production costs ranged from 8.93 *EUR/da* to 117.24 *EUR/da* and were mainly determined by the type, dose, and price of fertilizer. The lowest costs for growing bird's-foot trefoil were observed in the control variant, where they amounted to 8.93 *EUR/da*. Fertilizers represent the largest part of the cost structure, followed by seeds. Excluding the control, which reported the lowest costs due to the lack of imported fertilizers, it is clear that fodder production after fertilization with Lieta Veg organic fertilizer, applied at doses of 200 and 300 ml/da, has similar values, 15.01 and 15.17 *EUR/da*. The high dry matter yield when fertilizing with Azo Smart at a dose of 50 kg/da, which also achieved the highest productivity, has production costs of 66.15 *EUR/da*, which are nearly twice as low as those with twice the fertilizer rate. This shows a downward trend in costs with increasing yields.

Table 2. Economic indicators of fodder produced with applied organic fertilization of bird's-foot trefoil on average for the period 2024-2025

2024-2025	**Production costs**	**Cost price**	**Gross income**	**Gross profit**	**Profitability**
Option for fertilization	*EUR/da*	*EUR/kg*	*EUR/da*	*EUR/da*	*%*
1. Control	8.93	0.009	151.49	142.56	1,596.38
2. Azo Smart – 35 kg/da	44.57	0.043	152.02	107.45	241.08
3. Azo Smart – 70 kg/da	74.15	0.068	160.25	86.10	116.11
4. Lieta-veg – 200 ml/da	15.01	0.016	138.09	123.08	819.96
5. Lieta-veg – 300 ml/da	15.17	0.016	140.96	125.79	829.21
6. Petro 330 - 50 kg/da	66.15	0.060	163.11	96.96	146.58
7. Petro 330 -100 kg/da	117.24	0.108	160.22	42.98	36.66

Source: Own calculations.

A similar yield was obtained with Petro 100 kg/da (1088.051 kg/da), with the highest costs recorded (117.24 *EUR/da*). The dose has a significant impact on production costs when using Azo Smart fertilizer. With an increased dose from 35 kg/da to 70 kg/da, there is a trend

of increasing production costs from 44.57 *EUR/da* to 74.15 *EUR/da*, which is almost twice as much.

The cost price depends more on production costs than on yields. There is a tendency for the cost price to increase with rising production costs when fertilizing with Azo Smart and Petro. For this reason, fertilization with Petro biofertilizer at a dose of 100 kg/da has the highest production costs (117.24 EUR/da) and the highest cost price (0.108 EUR/kg) of the produced fodder. Fertilization with Lieta Veg organic fertilizer at doses of 200 and 300 ml/da has the lowest yield, lowest production costs, and lowest cost price. Only with this fertilizer does the fertilization dose not affect the cost price of production, which is evident from the identical values for the two variants. This is also due to the similar dry matter yields, which are 941.685 and 960.081 kg/da, respectively, and the lower selling prices of this fertilizer compared to the prices of the other two fertilizers. The data obtained are in line with the statements of Scherner et al. (2016)[22] that the economic efficiency of fodder from meadow grasses is largely determined by the cost of establishing the grasslands, as they account for the largest share of all costs [2].

Gross income is mainly determined by the yield of fodder. The highest yield (1108.155 kg/da) achieved with Petro biofertilizer (50 kg/da) generated the highest revenue (163.11 EUR/da), followed by Azo Smart (70 kg/da) and Petro (100 kg/da). The lowest dry matter yield and lowest gross revenue, 138.09 and 140.96 EUR/da, respectively, were achieved with fodder fertilized with Lieta Veg at doses of 200 and 300 ml/da.

The gross profit values are highest when fertilizing with Lieta Veg at doses of 200 (123.08 EUR/da) and 300 ml/da (125.79 EUR/da), and it is clear that the difference between the different doses is minimal. For the other fertilizers tested, Azo Smart and Petro, a tendency towards a decrease in gross profit with an increase in the fertilization rate was observed. This is determined by the amount of production costs, which also increase with increasing fertilization rates. Omokanye et al. (2019)[18] also prove that the economic efficiency of grasslands depends on the costs and returns associated with fodder production.

Profitability is a key economic indicator for fodder production, reflecting the practical application of scientific and technical achievements by producers. With market prices for fodder ranging from 0.15 EUR/kg to 0.16 EUR/kg, the profitability of fertilizing with Lieta Veg in low doses (200 and 300 ml/da) is highest, at 819.96 and 829.21% respectively, and in our study, it is the most profitable way to grow bird's foot trefoil. Fertilization with this fertilizer minimizes the costs per decare at the prices of the organic fertilizer used. A comparison of the economic indicators for the types and doses of organic fertilizers applied shows that the increase in yield as a result of fertilization, as indicated in the data analysis, does not improve profitability overall.

In the presented scientific research experiment, production costs serve as an indicator of the effectiveness and practicality of fertilizing with organic fertilizers in the production of fodder from bird's foot trefoil. Costs increase significantly with an increase in the fertilizer rate of Azo Smart, but the yield also increases, from 1,034.574 to 1,090.535 kg/da, respectively. Production costs, cost price, and gross revenue increase, while gross profit and profitability decrease. The increased dose of Petro fertilizer from 50 to 100 kg/da reduced the yield from 1,108.155 to 1,088.051 kg/da, *increased production costs and cost price, and reduced gross revenue, gross profit, and profitability*.

An important economic indicator for the effectiveness of fertilization as an agrotechnical practice related to organic production is the determination of profitability. The cost of producing fodder from bird's-foot trefoil, with organic fertilization with Lieta Veg biofertilizer, is 0.016 EUR/kg, regardless of the fertilization rates. The lowest costs for growing bird's-foot trefoil were observed in the control variant, where they amounted to 8.93 EUR/da. The value of the costs also determines the lowest cost price and the highest levels of gross revenue, gross profit, and profitability. Fertilization, and especially the price of

fertilizers, are the basis for the above-mentioned values of the studied indicators. This is proven by the values of the economic indicators obtained in the variant without fertilization (var. 1), which generates a gross profit of 142.56 EUR/da, with a cost price of 1 kilogram of fodder – 0.009 EUR/kg, production costs – 8.93 EUR/da, and a profitability level – 1,596.38%.

The production of fodder from a given crop is economically stable if the profit is high enough to carry out economic activity and can cover potential risks (Turebayeva et al., 2022)[25]. The data on yields by year presented in Table 1 show that the existing risks in organic farming are mainly related to climate change, where temperature and precipitation are decisive for the level of fodder yield from grass crops (Karatayev et al., 2022)[10]. Properly determined technological solutions in the production process are key criteria for minimizing costs and increasing profitability. The study shows that the gross profit established with the application of organic fertilization in different doses does not prove significant differences in yield, and the revenues from the sale of the products are close in value. This proves that as costs increase, profits decrease. The most profitable fertilization option is with Lieta Veg organic fertilizer at doses of 200 and 300 ml/da for fodder production from bird's-foot trefoil, where revenues were higher and yields and fertilizer costs were lower than for other types and doses of fertilizer.

The analysis of the data shows that as fertilizer doses increase, the share of fertilizer costs also increases. When developing technological maps by year and on average for the period, which include the entire technology of the production process for creating grassland, it can be seen that bird's-foot trefoil does not require the use of insecticides and fungicides during the harvesting period, which explains the savings in costs for chemical protection products. This is due to its resistance to diseases and pests and proves the environmental benefits of its inclusion as a suitable leguminous fodder crop in the structure of agricultural production. A number of studies show that bird's-foot trefoil is successfully grown on acidic soils in mountainous conditions [5], which is confirmed by the economic indicators cited above.

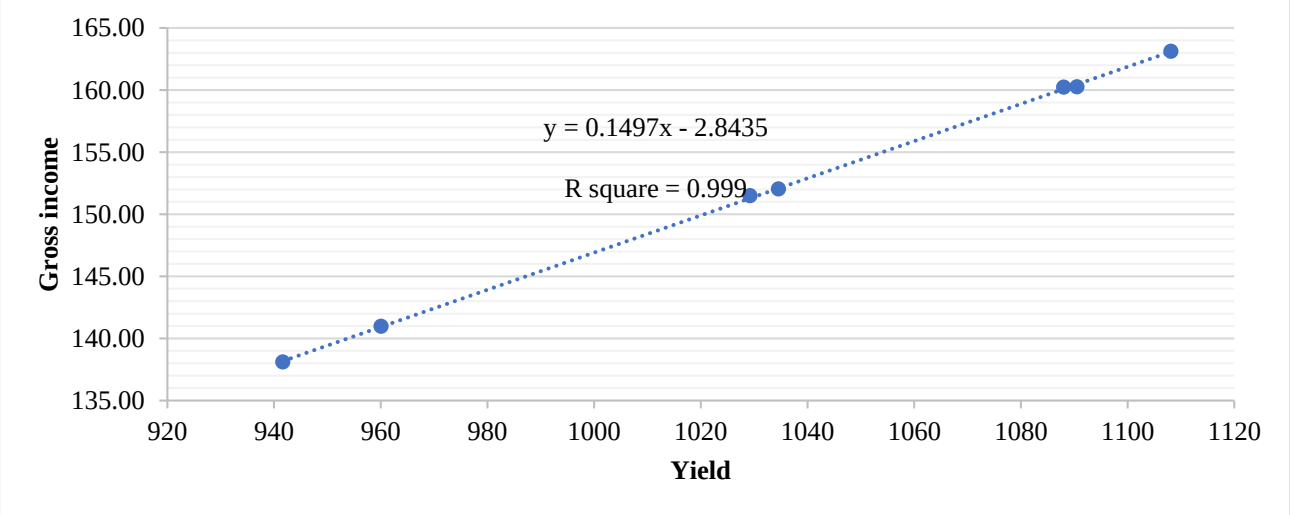


Fig. 1. Regression dependence between yield and gross income in fodder production after fertilization with organic fertilizers
Source: Own calculations.

During the study, plant samples were taken for chemical analysis to determine the basic chemical composition and structural fiber components of the cell walls, which will be the subject of another publication. This will provide a comprehensive assessment of productivity, quality, and economic efficiency.

Linear regression analysis revealed positive correlations between the levels of organic fertilizer application and the economic results of bird's-foot trefoil cultivation.

A very high positive regression relationship (Fig. 1) was observed between the average dry matter yield and gross revenue according to the equation y = 0.1497x – 2.8435 with an extremely high coefficient of determination R^2 = 0.9998.

A similarly high correlation was found between production costs and cost price (Fig. 2), represented by the regression y = 0.0009x + 0.0019 (R^2 = 0.9993), which shows that as production costs increase, the cost price of the feed produced also increases. The high coefficient of determination highlights a strong linear relationship between production costs and the cost price of feed production.

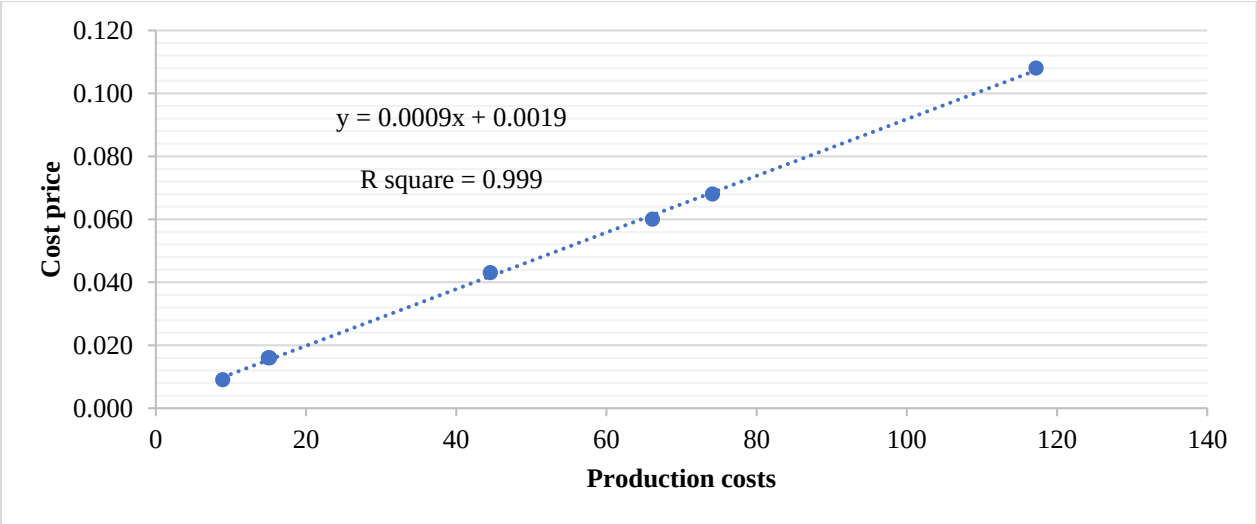


Fig. 2. Regression dependence between production costs and cost price in fodder production after fertilization with organic fertilizers
Source: Own calculations.

CONCLUSIONS

The results from the scientific experiment show that, from an economic point of view, the right agronomic practice is to fertilize bird's foot trefoil with Lieta Veg organic fertilizer, which is linked to organic fodder production. Fertilizing the grassland with this fertilizer ensures maximum profitability with minimum production costs and low cost of the obtained production.

Among the tested fertilization rates, the application of Lieta Veg organic fertilizer at doses of 200 and 300 ml/da has led to the best results in terms of economic performance. This demonstrates the practical feasibility of organic fertilization of bird's foot trefoil grass in mountainous conditions with acidic soils, while avoiding any environmental risks associated with excessive nutrients and reduced profits. Linear regression analysis revealed positive correlations between average dry matter yield and gross revenue (y = 0.1497x – 2.8435) and between production costs and cost price y = 0.0009x + 0.0019 (R^2 = 0.9993), with very high coefficients of determination.

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CAREER MOTIVATION AMONG STUDENTS IN VOCATIONAL AND TECHNICAL EDUCATION IN ILFOV COUNTY, ROMANIA

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Abstract

This study examines career motivation among students enrolled in vocational and technical education in Ilfov County, Romania, with the aim of identifying the key factors shaping career choice and students' engagement in the development of profession-specific skills. The research was carried out between October and November 2025 and employed a sociological survey design, using a structured questionnaire as the primary data collection instrument. A total of 671 valid responses were obtained from students across multiple specializations within technological high schools. The findings, interpreted in relation to the specialized literature, indicate that career motivation is influenced by a combination of intrinsic and extrinsic factors, as well as by the level of educational support and the broader socio-economic context. Based on these results, the study formulates practical recommendations for educational policy and practice, including the strengthening of career guidance programs, increased investment in school infrastructure, and greater involvement of families in the career counselling process. Overall, the research provides a comprehensive perspective on career motivation among vocational and technical education students and offers a solid empirical basis for the development of targeted support strategies and educational policies.

Key words**:** *vocational and technical education, labor market integration, school-to-work transition, career guidance, career motivation*

INTRODUCTION

Career motivation constitutes a central component of students' professional development, shaping not only their choice of field of study but also their level of engagement in the educational process and, ultimately, their academic performance. In the context of vocational and technical education (VTE), students are at a crucial stage of career orientation, where their educational choices determine their future pathways and employment prospects. Analyzing career motivation at this level is essential for identifying factors that either enhance or reduce students' involvement in professional preparation and for formulating educational policies tailored to their needs [8] [10].

At the level of Ilfov County, characterized by socio-economic diversity and a continuously evolving educational system, VTE students face specific challenges, such as the lack of effective career guidance programs and insufficient information about available professional opportunities. In this context, career motivation may be influenced by factors such as family support, the quality of school instruction, the availability of internships, and students' perceptions of their professional future [4] [13].

The main objective of this study is to investigate career motivation among students in vocational and technical education (VTE) in Ilfov County. The study aims to identify the key factors that influence students' motivation and to provide a clear picture of their attitudes and perceptions regarding their professional pathways.

The research questions guiding this study are:

-What is the level of career motivation among VTE students in Ilfov County?

-What are the main factors that influence the career motivation of VTE students?

-To what extent do family support, access to information, and the quality of instruction influence career motivation?

The analysis of career motivation provides an opportunity to understand the interaction between individual and contextual factors that shape students' decisions. Intrinsic factors, such as personal interest and the desire for self-fulfilment, combine with extrinsic factors, including salary, job stability, and family influence, creating a complex framework that determines professional choices. Understanding this interdependence is essential for designing educational programs that foster student engagement and reduce perceived barriers [6] [7].

Furthermore, research on career motivation has significant implications not only at the individual level but also at the institutional and social levels. The results can guide decision-makers in curriculum planning, investments in school infrastructure, and the implementation of more effective counselling and career guidance programs. In the context of a continuously changing labor market, adapting educational strategies to the needs and motivations of VTE students becomes a key factor in reducing skills gaps and facilitating an effective transition to professional careers [6] [7] [11].

This endeavor aims not only to identify the determinants of career motivation but also to formulate recommendations for improving career guidance programs and the educational support provided to students, thereby contributing to the enhancement of the attractiveness and effectiveness of vocational and technical education.

MATERIALS AND METHODS

Career motivation is a multidimensional concept, influenced by both intrinsic and extrinsic factors, which determines students' choice of professional pathways and their engagement in the educational process. In the context of vocational and technical education (VTE), student motivation is particularly important, as this type of schooling aims to develop the specific skills required for a trade and to facilitate rapid labor market integration. Students with high levels of career motivation are more likely to actively participate in practical activities, pursue academic achievement, and strategically plan their professional pathways. [8] [10]

Research on career motivation highlights several determining factors. Intrinsic factors include personal interest in the field, the desire for self-fulfilment, and anticipated professional satisfaction, while extrinsic factors encompass family support, perceptions of employment opportunities, financial rewards, and the influence of teachers or school counsellors. Studies conducted in Romania have emphasized that students in vocational education often face a lack of adequate resources, limited access to internships, and insufficient information about career opportunities, which can reduce motivation and increase the risk of school dropout [13] [14].

Several international and national studies emphasize the role of family and the social environment in shaping career motivation. Support from parents and teachers can strengthen students' confidence in their own abilities and facilitate well-informed educational and professional decisions. Conversely, the lack of such support can generate uncertainty and reduce students' engagement in professional development [6].

Although studies focusing on Ilfov County are limited, they indicate socio-economic and educational diversity that influences the motivation of VTE students. Students face challenges such as limited access to well-equipped laboratories, the absence of comprehensive career guidance programs, and insufficient information about labor market requirements. In this context, evaluating career motivation becomes essential, as it provides relevant insights for adapting educational strategies and enhancing the attractiveness of vocational training programs [1] [4] [15].

Furthermore, the specialized literature suggests that integrating career guidance activities into the school curriculum, as well as promoting mentoring programs and internships, can significantly enhance students' intrinsic motivation and strengthen the skills necessary for professional success. These interventions are particularly essential in counties with variable educational

infrastructure, such as Ilfov, where disparities between different educational institutions can influence students' perceptions of career opportunities [8][1].

Analyzing career motivation among VTE students in Ilfov County is a necessary endeavor for understanding the factors that support or diminish students' engagement in professional training. Studying this phenomenon can guide the development of educational programs tailored to students' actual needs and contribute to enhancing the effectiveness of career guidance processes, supporting their integration into the labor market in a sustainable and coherent manner [6] [7] [12].

This study employed a sociological survey using a questionnaire as the primary data collection method. A sociological survey is a standardized method for investigating the opinions, attitudes, and behaviours of a group of individuals, frequently used in educational research and in the analysis of career motivation. Through the questionnaire, the researcher can collect both quantitative and qualitative information about respondents' perceptions and experiences, facilitating comparison and statistical analysis of the data. This method is particularly suitable for studies involving students, as it allows for the collection of a large number of responses in a short period of time and ensures participant anonymity, which contributes to the honesty of the responses [2] [3] [5] [9].

In this study, the questionnaire was specifically designed to investigate career motivation among students in vocational and technical education in Ilfov County. The questionnaire was distributed to the educational institutions that enroll students in the technological track, and it was administered online via the Google Forms platform. This data collection method provided accessibility and convenience for students, and it yielded a total of 671 valid responses, offering a representative sample of the targeted institutions in Ilfov County.

The questionnaire was designed to cover four main dimensions:

Section A – ***General information***: this section aims to segment the data according to demographic and educational characteristics: grade level, gender, area of origin, and specialization of study. This information allows for the analysis of differences between subgroups and contributes to a more detailed interpretation of the results.

Section B – ***Career motivation***: this section measures both intrinsic motivation, related to personal interest in the field of study, and extrinsic motivation, influenced by factors such as salary, financial stability, or family support. Additionally, the questions in this section assess students' engagement in the decision-making process regarding their own careers.

Section C – ***External influences and perceptions of the labor market***: the questions in this section investigate how external factors, such as family, teachers, or the social environment, influence career choice, as well as students' perceptions of existing opportunities and challenges in the labor market.

Section D – ***Personal motivation and perceived obstacles***: this section provides information on the obstacles students perceive in achieving their professional goals and their level of motivation to overcome these barriers. By analyzing these data, the research identifies factors that may either limit or stimulate students' engagement in career development.

The collected data were subsequently processed and analyzed quantitatively, using descriptive and inferential statistical methods to highlight general trends and relationships among the investigated variables. Through this methodological approach, the study provides a clear and detailed picture of career motivation among VTE students in Ilfov County, contributing to the foundation of educational and practical recommendations.

RESULTS AND DISCUSSIONS

The questionnaire responses were collected between October and November 2025, with a total of 671 valid responses recorded from students in vocational and technical education in Ilfov County. This section presents the analysis of the collected data, structured

around the four dimensions investigated through the questionnaire: students' demographic characteristics, intrinsic and extrinsic motivation for career choice, external influences and perceptions of the labor market, and perceived obstacles, along with levels of personal motivation.

The results are presented in the form of descriptive statistics, tables, and charts to highlight general trends, differences between subgroups, and relationships among the analyzed variables. The analysis aims to provide a detailed picture of career motivation among VTE students, as well as the factors that stimulate or limit their engagement in professional development. This approach allows for the interpretation of data within the context of the study objectives and provides relevant information for formulating educational recommendations and support strategies for students.

Section A – General information

Question 1: Grade level:

The analysis of the distribution of students by grade level shows a balanced participation, with a slight increase in representation as students advance through high school. Survey responses reveal that 16% of respondents are in 9th grade, 26% in 10th grade, 27% in 11th grade, and 31% in 12th grade. This distribution indicates a higher presence of students in the upper grades, which may be associated with increased interest in career planning and active engagement in decision-making regarding their professional pathways.

The lower representation of 9th-grade students can be explained by the fact that they are at the beginning of their vocational educational pathway, with limited experience regarding career choice and professional planning. In contrast, students in 11th and 12th grades, who are approaching the completion of their studies, demonstrate more active engagement and a greater concern for making decisions about their professional future.

This sample structure allows for a detailed analysis of career motivation according to years of study and contributes to identifying the factors that influence students' level of engagement and their perceptions of professional opportunities among vocational and technical education students in Ilfov County.

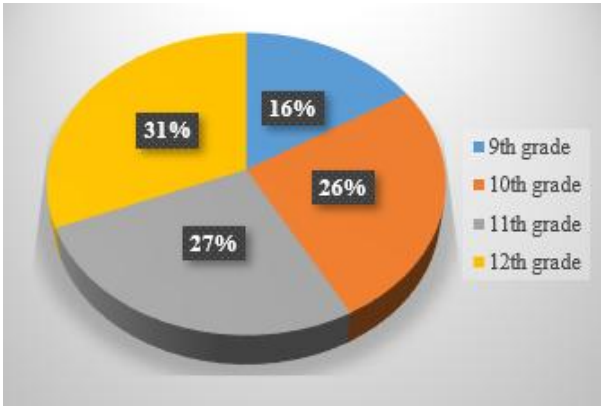


Fig. 1. Distribution of respondents by grade level
Source: own contribution.

Question 2: Students' gender

The distribution of respondents by gender indicates an almost balanced participation between male and female students, reflecting the representativeness of the sample. According to the collected data, 48% of respondents are male, 50% are female, and 2% chose the category "Other/Prefer not to say." This balanced distribution allows for the analysis of career motivation without being affected by a significant gender imbalance.

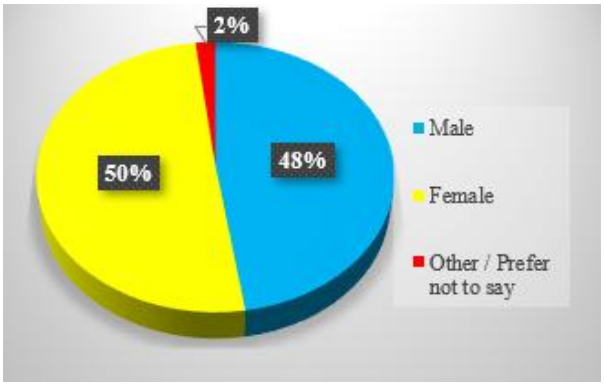


Fig. 2. Distribution of respondents by gender
Source: own contribution.

The presence of a small proportion of respondents who selected "Other/Prefer not to say" is relevant from the perspective of diversity and inclusion, providing a more comprehensive view of students' perceptions regarding careers, independent of social constraints related to gender. The balance between male and female students also suggests that the study can identify differences

and similarities in career motivation between genders if a segmented analysis is required.
This sample structure reinforces the validity of the research, providing a solid foundation for interpreting results related to intrinsic and extrinsic motivation, external influences, and perceptions of career-related obstacles.

Question 3: Area of origin

The distribution of students by area of origin shows a predominance of those from rural areas, with 61% of respondents being rural students, while 39% come from urban areas. This structure highlights that students from rural areas constitute the majority of respondents, which may influence the overall perception of access to educational resources, internship opportunities, and career-related information.

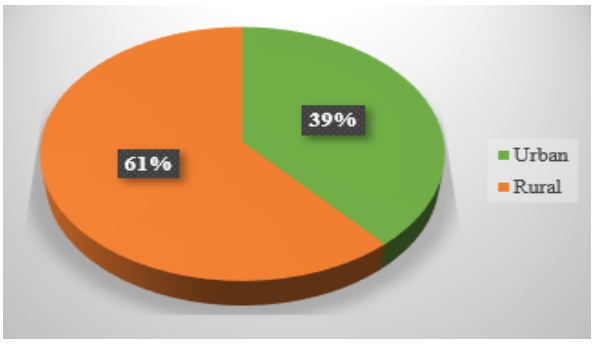


Fig. 3. Distribution of respondents by area of origin l
Source: own contribution.

The urban-rural difference can be relevant when interpreting results regarding career motivation, as access to modern laboratories, career counselling, and labor market information may be more limited in rural areas. At the same time, this distribution allows for highlighting the specific challenges faced by rural students and identifying factors that contribute to either enhancing or diminishing motivation within this group.
The sample structure, with significant representation of rural students, provides a realistic perspective on the socio-educational conditions and context of Ilfov County, thereby contributing to a detailed and applicable analysis of career motivation within vocational and technical education.

Question 4: Specialization of study

The analysis of students' distribution by field of study highlights a considerable diversity of vocational training domains among students in Ilfov County. The distribution on Table 1 reflects current trends in vocational and technical education in Ilfov County, highlighting students' preference for service- and commerce-related fields, while also showing a significant proportion of students choosing technical or agricultural specializations.

Table 1. Respondents' distribution based on enrolled specialization

Profile	No. of valid answers
Agriculture	71
Forestry	14
Commerce/ Trade	87
Economics	138
Tourism and food services	215
Environmental protection	26
Mechanics	58
Electronics and automation	34
Construction, installations, and public works	19
Other	9
Total respondents	**671**

Source: Own contribution.

The results suggest that career motivation may be influenced by the attractiveness of the field of study, employment prospects, and perceptions of professional benefits associated with each specialization.
Furthermore, the analysis of specializations provides a useful framework for interpreting data regarding intrinsic and extrinsic motivation, external influences, and perceived obstacles, allowing for the identification of differences between specialization groups and highlighting specific needs for support and career guidance within each field.

Section B – Career motivation

Question 5: How important is it for you to have a successful career in the field you are studying?

The results indicate that the majority of vocational and technical education students in Ilfov County assign high importance to professional success. The analysis indicates that 61% of respondents consider it "very important" to have a successful career, while 25% consider it "important," indicating that 86% of students attach significant value to their

own professional pathway. In contrast, a smaller proportion of students view this aspect as "slightly important" (12%) or "not important at all" (2%).

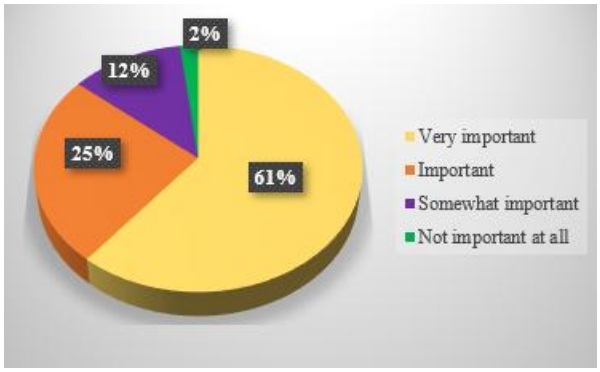


Fig. 4. Importance of a career in the field of specialization
Source: own contribution.

This distribution suggests that intrinsic motivation, related to the desire for self-fulfilment and professional success, predominates among students, serving as a central factor that can stimulate engagement in the educational process and active participation in professional training activities. The high importance placed on professional success also reflects students' concern for ensuring a stable future and leveraging the skills acquired within the technological track.

This finding is consistent with the specialized literature, which highlights that students in vocational and technical education display a strong orientation towards developing a solid career, being motivated both by intrinsic factors and by extrinsic benefits associated with professional success, such as financial stability and social recognition.

Question 6: What motivates you the most to choose a particular career?

The results indicate that extrinsic factors, particularly those related to financial rewards and economic stability, play a major role in motivating vocational and technical education students in Ilfov County. Findings from the survey indicate that 61% of respondents identified salary or financial stability as their primary motivating factor, reflecting a strong concern for securing a stable professional future and leveraging the skills acquired in the current economic context.

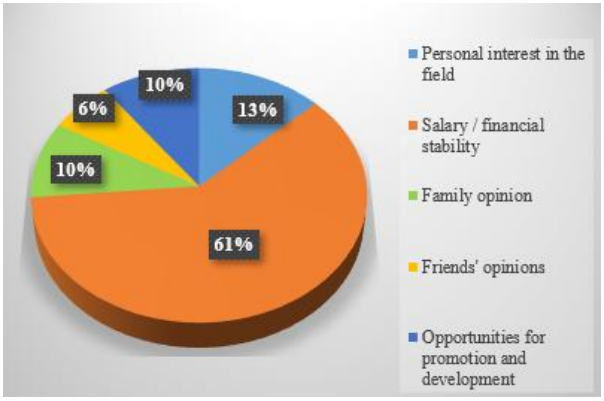


Fig. 5. Intrinsic motivation factors in career choice
Source: own contribution.

In contrast, 13% of students are primarily motivated by personal interest in their field of study, highlighting the presence of intrinsic motivation, albeit to a lesser extent compared to extrinsic factors. Social support, represented by family opinions (10%) and friends' views (6%), as well as opportunities for promotion and professional development (10%), were identified as less influential factors in career choice.

These results suggest that VTE students prioritize material aspects and professional security when making decisions about their career pathways, reflecting the importance of extrinsic factors in career orientation at the level of Ilfov County. At the same time, personal interest in the field, although less pronounced, indicates that intrinsic motivation contributes to students' engagement in educational activities and to the development of skills specific to the technological track.

These findings can guide educational strategies and career guidance programs, highlighting the need to combine counselling on career opportunities with support for skill development and intrinsic motivation.

Question 7: To what extent do you believe that school prepares you for choosing a career?

The results indicate that vocational and technical education students in Ilfov County perceive the preparation provided by school as moderate to high; however, a significant proportion consider this preparation insufficient. At the same time, only 18% of the respondents believe that school prepares them "very much" for career choice, while 48% consider that it prepares them "quite a lot,"

meaning that nearly two-thirds of students positively value the educational support provided for career guidance.

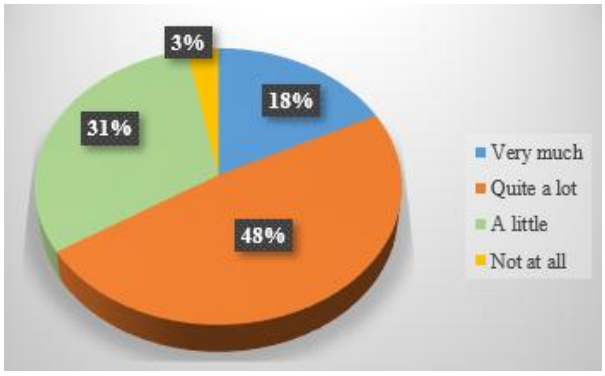


Fig. 6. Assessment of the school's contribution to preparing students for career choice
Source: Own contribution.

At the same time, 31% of respondents consider the preparation provided by school to be "slightly" satisfactory, and 3% believe it does not prepare them at all, indicating gaps in career guidance programs and practical activities. This distribution suggests that, although school contributes to the development of motivation and the provision of information to students, there is a need to strengthen the practical component and career counselling to facilitate more well-informed decisions regarding professional pathways.

The interpretation of these data highlights that school plays an important role in students' development and career orientation; however, the effectiveness of this support varies among students and may be influenced by factors such as access to resources, teacher involvement, and the availability of mentoring programs or internships. This observation confirms the importance of implementing integrated educational strategies that combine theoretical information with practical experiences, thereby enhancing students' motivation and preparation for their careers.

Section C – External Influences and Perceptions of the Labor Market

Question 8: Have you ever participated in activities that helped you discover your professional skills and interests?

The analysis of the responses shows that the majority of vocational and technical education students in Ilfov County have participated in career guidance activities, at least in some form. A majority of the respondents (58%) participated in such activities within the school, while 29% had similar experiences outside of school, through extracurricular programs, workshops, or internships. In contrast, 13% of students have never participated in such activities, indicating the presence of a segment of students who have not had opportunities to explore their professional skills and interests.

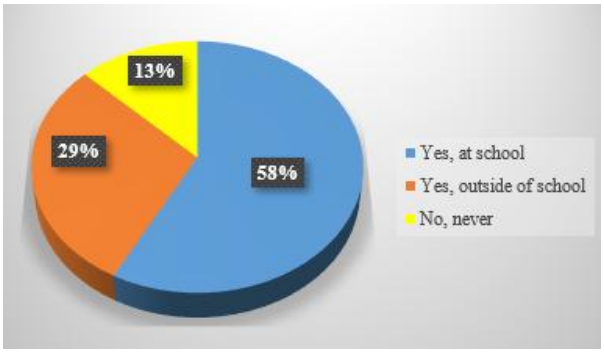


Fig. 7. Students' experience in activities for exploring professional skills and interests
Source: Own contribution.

These data suggest that, although the majority of students have been exposed to activities supporting career guidance, there is still a significant proportion who may be disadvantaged due to a lack of access to such experiences. Participation in activities that help discover professional skills and interests is essential for the development of intrinsic motivation, awareness of one's vocation, and the ability to make informed educational and career decisions.

The results highlight the role of both school-based and extracurricular activities in shaping career motivation and their relevance for VTE students. They also indicate the need to expand career guidance programs and internship opportunities to ensure comprehensive and equitable coverage for all students, so that each can systematically and practically explore their skills and interests.

Question 9: How easy do you think it is to find a job in the field you are studying?

Students' responses reflect a predominantly cautious perception of employment opportunities within their fields of specialization. The results indicate that 44% of

respondents consider finding a job in their field of study to be difficult, while 18% perceive it as very difficult. By contrast, only 21% of students believe that securing employment is easy, and 17% consider it very easy.

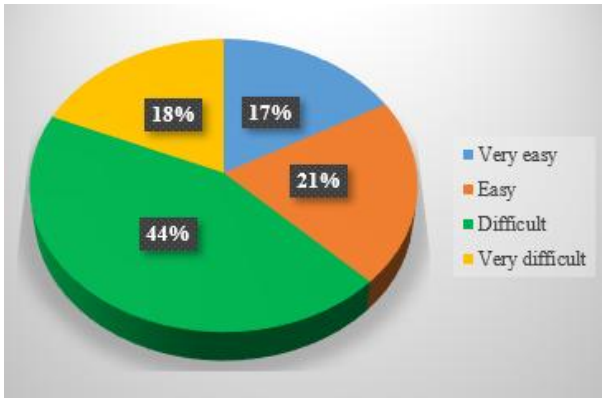


Fig. 8. Students' perception of the difficulty of finding a job in their field of study
Source: Own contribution.

This distribution suggests that students are aware of the challenges of the labor market and the competitiveness of the fields in which they intend to work, which may influence extrinsic motivation and career-related decisions. A high perception of employment difficulty may also stimulate the need to acquire practical skills and experience through internships, mentoring programs, or supplementary courses.

The results indicate the need for clearer communication between the educational environment and the labor market, as well as the strengthening of career guidance programs that inform students about the real requirements of employers and the opportunities available. This approach could reduce students' uncertainty and increase their motivation to develop the skills necessary for a successful career.

Section D – Personal Motivation and Perceived Obstacles

Question 10: How motivated are you to study to achieve your professional goals?

The results indicate a generally positive level of personal motivation among vocational and technical education students in Ilfov County, albeit with noticeable variation across motivation categories. The data show that 21% of respondents consider themselves very motivated, while 43% report being motivated, indicating that nearly two-thirds of students demonstrate a high level of motivation for learning and professional development. By contrast, 26% of students describe themselves as slightly motivated, and 10% report being not motivated at all, pointing to the existence of a subgroup with low motivation, which may be associated with reduced engagement in the educational process and potential difficulties in achieving professional goals.

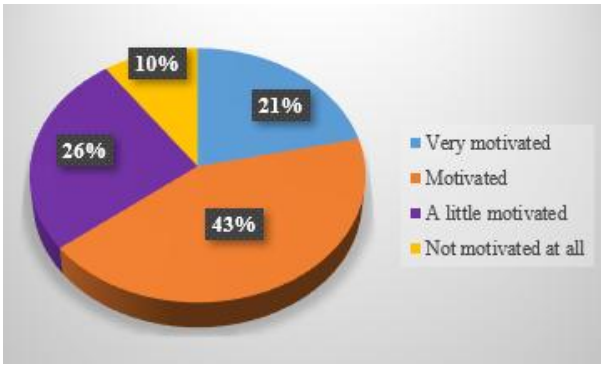


Fig. 9. Students' level of motivation to achieve their professional goals
Source: Own contribution.

This distribution suggests that, although the majority of students demonstrate positive motivation, there is a need for educational interventions that support the increase of intrinsic motivation and reduce the impact of perceived obstacles. Highly motivated students are more likely to actively participate in practical activities, pursue academic achievements, and strategically plan their professional pathways, whereas students with lower motivation may benefit from counselling, mentoring, and additional vocational guidance activities.

The analysis of personal motivation levels highlights the importance of combining intrinsic and extrinsic factors to stimulate student engagement and emphasizes the educational role of both the school and the family environment in fostering a proactive attitude toward one's career.

Question 11: What are the main obstacles that prevent you from achieving your career goals?

The analysis of students' responses indicates that they face a range of obstacles that may hinder the achievement of their professional goals. A lack of information about the field is

identified as the main obstacle by 26% of respondents, while 20% report limited school resources, such as inadequate laboratories and equipment. In addition, 21% of students point to the absence of mentors or career counselling as a significant barrier, whereas 14% cite a lack of family support, and a further 14% refer to financial difficulties. A smaller proportion, 5%, considers the lack of internship or practical opportunities to be the main obstacle.

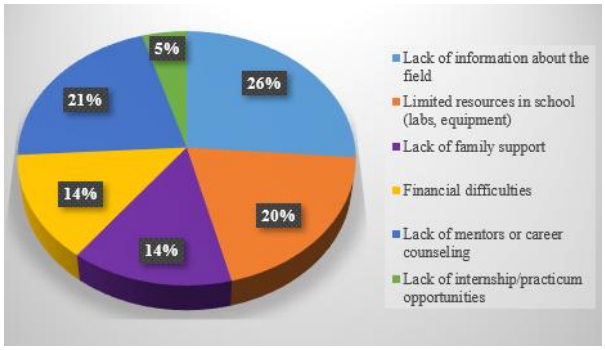


Fig. 10. Main obstacles perceived by students in achieving their professional goals
Source: Own contribution.

These data suggest that students perceive obstacles both at the individual and institutional levels. The lack of information and specialized counselling indicates the need for more effective career guidance programs that provide clear guidance and adequate resources for career planning. Material and infrastructural limitations in schools can affect the quality of practical training, while the absence of family support or financial difficulties may reduce students' motivation and engagement in educational activities.

Overall, the results highlight the importance of an integrated approach that combines information provision, career counselling, material resources, and social support to reduce the barriers perceived by students and increase their motivation in achieving professional goals. These findings provide relevant insights for educational authorities and for teachers involved in the guidance and career development of students in vocational and technical education.

The study's results indicate a predominantly positive motivation among vocational and technical education students in Ilfov County, both in terms of intrinsic and extrinsic motivation. Students show interest in professional success and economic stability, while school contributes to their career preparation to a moderate extent. These findings are consistent with the specialized literature, which emphasizes the importance of extrinsic factors, such as salary and financial security, in the motivation of VTE students, as well as the role of intrinsic motivation related to personal interest and self-fulfilment.

At the same time, the results confirm the observations of national studies regarding school resource limitations and the lack of adequate career counselling, factors that may reduce students' engagement and strategic career planning. Regarding labor market perceptions, students demonstrate a certain level of caution, considering that finding a job may be difficult, which aligns with trends observed in recent research on the labor market integration of vocational and technical education graduates.

However, the study presents several limitations that should be considered when interpreting the results:

Sample – Although the 671 responses provide a solid basis, the study focuses exclusively on students from Ilfov County and the technological track, which limits the generalization of the results to other counties or other types of vocational education.

Influence of external factors – Students' motivation may be affected by contextual or socio-economic factors that were not controlled in the study, such as family circumstances, income level, or the influence of the local environment on employment opportunities.

Measurement tools – The questionnaire, although well-structured and informally validated through piloting, relies on self-reported responses, which may introduce a certain degree of subjectivity or social desirability bias.

The results provide a detailed overview of career motivation among VTE students, identifying both positive aspects and challenges that may limit engagement and professional development. The analysis will be further elaborated in the discussion section,

where these results will be interpreted in relation to the specialized literature, practical implications for career guidance will be identified, and directions for educational interventions will be proposed. This approach will allow the formulation of relevant conclusions and concrete recommendations to support students in achieving their professional goals.

CONCLUSIONS

The study results regarding career motivation among vocational and technical education students in Ilfov County provide a clear overview of the factors influencing career choice and the level of student engagement in professional development. The data analysis shows that the majority of students assign high importance to professional success, highlighting the presence of significant intrinsic motivation associated with the desire for self-fulfilment and interest in their field of study. At the same time, extrinsic factors, such as salary and financial stability, are the most important determinants in career decision-making, confirming observations from the specialized literature regarding the influence of material rewards and economic security on the motivation of VTE students.

Students' motivation is also reflected in their level of engagement in the educational process. Most respondents consider themselves motivated or highly motivated to study in order to achieve their professional goals, suggesting that the level of engagement is directly linked to the perceived importance of their career and future benefits. However, there is a segment of students with lower motivation, who may be affected by factors such as a lack of information about their field, limited school resources, or insufficient family support. These observations align with studies emphasizing the role of a combination of intrinsic motivation and extrinsic support in strengthening student engagement in learning and in the development of professional skills.

A relevant aspect identified in this study is the influence of labor market perceptions on students' motivation. Almost half of the respondents consider finding a job in their field to be difficult or very difficult, which may create uncertainty and limit confidence in their own abilities. In the specialized literature, this perception is associated with the need to implement more consistent career guidance programs that provide up-to-date information on labor market requirements and employment opportunities. Additionally, students' participation in activities designed to explore professional skills and interests, conducted both inside and outside of school, contributes significantly to increasing intrinsic motivation and developing a proactive attitude toward their career.

The study results also highlight the obstacles perceived by students in achieving their professional goals. A lack of information about their field, limited school resources, the absence of career counselling and mentoring, as well as financial difficulties, are significant barriers that can reduce motivation and engagement. These findings underscore the need for integrated interventions that combine information provision, career counselling, material support, and family involvement to create an educational environment conducive to skill development and career guidance.

From a practical perspective, the study provides several concrete recommendations. First, career guidance programs in schools should be strengthened through the introduction of practical sessions, mentoring, internships, and workshops aimed at exploring students' skills and interests. Second, investment in educational infrastructure is necessary, ensuring modern laboratories, adequate equipment, and study materials specific to each specialization. Third, family involvement and social support should be enhanced through awareness campaigns and activities that facilitate dialogue between students, parents, and teachers. These measures can contribute to increasing both intrinsic and extrinsic motivation, reducing perceived obstacles, and improving students' preparedness for labor market integration.

Regarding suggestions for future research, several directions could enhance knowledge on career motivation among vocational and technical education students. First,

longitudinal studies could monitor the evolution of students' motivation throughout the entire high school cycle, allowing for the identification of changes and determinants over time. Second, expanding research to other regions of Romania would allow for comparisons of socio-economic contexts and infrastructure differences, providing a more comprehensive national picture of the phenomenon. Third, including additional motivational factors, such as the influence of the digital environment, international experiences, social media, and role models, could offer a broader and more complex understanding of the mechanisms shaping career choices.

The study demonstrates that career motivation among vocational and technical education students is strongly influenced by a combination of intrinsic and extrinsic factors, educational and family support, as well as perceptions of the labor market and available resources. The results confirm most observations from the specialized literature, while simultaneously providing information specific to the context of Ilfov County, highlighting particularities related to the distribution of specializations, access to information, and student involvement in career decision-making. Overall, the study's conclusions provide a solid foundation for developing educational strategies tailored to students' needs and for guiding interventions aimed at increasing motivation, engagement, and professional success.

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SOCIAL AND PROFESSIONAL INCLUSION OF STUDENTS WITH SPECIAL EDUCATIONAL NEEDS: TEACHERS' PERCEPTIONS IN TECHNOLOGICAL HIGH SCHOOLS IN ILFOV COUNTY, ROMANIA

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Abstract

This study examines teachers' perceptions of the social and professional inclusion of students with special educational needs (SEN) in technological high schools in Ilfov County, Romania, with a focus on identifying both the conditions that facilitate inclusive practices and the ongoing challenges that continue to limit their effective implementation. Data were collected through a structured online questionnaire administered to 216 teachers, covering socio-demographic and professional characteristics, perceptions of social inclusion, inclusive instructional practices, professional inclusion, and perceived constraints and support needs. Overall, respondents reported generally positive peer acceptance of SEN students, their participation in group activities, and the development of functional vocational competencies. Nevertheless, teachers highlighted major obstacles to effective inclusion, most notably large class sizes, limited access to specialized training, inadequate material resources, and insufficient collaboration with support professionals. Participants emphasized the need for sustained professional development, strengthened school counseling and specialist support, curriculum adaptation, and improved resources to enhance inclusive teaching and learning. The findings underscore the role of technological education in supporting the social participation and employability of SEN students and provide practice- and policy-relevant directions for schools and educational authorities to consolidate and scale inclusive approaches within vocational and technological settings.

Key words**:** *inclusion, technological education, social integration, vocational competencies, teaching strategies.*

INTRODUCTION

Inclusive education is widely recognized as a key priority of contemporary educational policies, being grounded in the principle of equal opportunities and the active participation of all students in the educational process, regardless of individual characteristics or the difficulties they may encounter. At the international level, key policy instruments such as the Salamanca Statement and the United Nations Convention on the Rights of Persons with Disabilities emphasize the need for education systems to adapt to the diverse learning needs of students. Within this broader policy context, the inclusion of learners with special educational needs is no longer viewed as an optional approach, but as a fundamental ethical, social, and professional responsibility of the education system [12] [21].

At the national level, Romanian legislation promotes inclusive education through a regulatory framework that supports the integration of students with special educational needs (SEN) into mainstream education, including technological high schools. The Preuniversity Education Law no. 198/2023, as well as subsequent educational strategies, emphasize the need for curriculum adaptation, differentiated assessment, and interdisciplinary collaboration to support these students. In Ilfov County, characterized by a dynamic socio-economic context and a highly diverse student population, technological high schools face specific challenges regarding the inclusion of SEN students, particularly in terms of developing vocational competencies and facilitating the transition to the labor market [13].

These students constitute a heterogeneous group, including students with disabilities, learning disorders, emotional or behavioral

difficulties, as well as those in educationally at-risk situations. The specialized literature emphasizes that these students require personalized educational interventions, based on the individual assessment of their needs and the implementation of adapted teaching strategies. Social inclusion aims at integrating SEN students into the school community, fostering interpersonal relationships, and promoting active participation in school life, while professional inclusion involves acquiring the competencies necessary for labor market integration and for living an independent adult life [9] [17] [22].

Technological education plays a strategic role in the social and professional inclusion of students with SEN, providing concrete opportunities for practical training and the development of functional competencies. The specific nature of this type of education, focused on hands-on activities, practical instruction, and partnerships with economic agents, can facilitate the adaptation of the educational process to the needs of SEN students and significantly contribute to increasing their chances of professional integration. However, the effectiveness of these efforts largely depends on the competencies of teachers, the institutional resources available, and the coherence of local educational policies [15] [23].

In the specialized literature, teachers are identified as key actors in the inclusion process, playing a decisive role in creating a supportive educational climate and in adapting teaching strategies to the needs of students with SEN. Teachers' attitudes toward inclusion, their level of psycho-pedagogical training, and access to support resources directly influence both the social integration of students and the effectiveness of vocational training. In technological education, these aspects become even more important, as practical activities and competency assessment require constant methodological adaptations and collaboration among teachers, practical instructors, and special education specialists [8].

Within this framework, the study focuses on examining the degree to which technological education facilitates the social and professional inclusion of students with special educational needs, while also identifying the key challenges encountered and the pedagogical strategies employed in this process.

The article aims to analyze the perceptions and practices of teachers in technological education regarding the inclusion of SEN students, with an emphasis on the social and professional dimensions of their integration. The specific objectives of the study are to identify the level of social inclusion of SEN students, to analyze the measures for adapting the vocational training process, and to highlight the needs and difficulties encountered by teachers in their educational practice.

MATERIALS AND METHODS

The concept of educational inclusion has evolved significantly over the past decades, moving beyond the paradigm of physical integration of students with SEN and focusing on the systemic adaptation of schools to the diversity of students' needs. In the specialized literature, inclusion is defined as a continuous process of identifying and removing barriers to participation and learning to maximize the potential of each student. From this perspective, inclusive education involves transformations at the curricular, methodological, and organizational levels, as well as changes in attitudes on the part of educational stakeholders [2].

At the international level, educational policies promote a human-rights-based model in which students with SEN have equal access to quality education. The Salamanca Statement, alongside later policy documents issued by UNESCO and the OECD, frames inclusive education as a fundamental element of social equity. Similarly, the United Nations Convention on the Rights of Persons with Disabilities affirms the right to inclusive education across all stages of learning, explicitly extending this principle to vocational and technical education and training [12] [21].

At the national level, the Romanian legislative framework aligns with these guidelines, promoting the integration of students with SEN into mainstream education and emphasizing the need to adapt the educational process to

their specific characteristics. According to Gherguț (2011), the success of inclusion depends on correlating educational interventions with psycho-pedagogical assessment and on implementing individualized educational plans that support both academic development and social integration [9].

Research highlights significant differences between technological and theoretical education regarding the inclusion of SEN students. Studies show that technological education, through its practical and applied focus, provides a more flexible framework for adapting learning activities and for leveraging students' functional competencies. Practical activities, workshop-based instruction, and internships allow the use of alternative teaching and assessment methods, which are particularly supportive for students experiencing academic difficulties [10] [14].

In contrast, theoretical high schools are more focused on academic performance and standardized cognitive assessment, which may limit the active participation of students with SEN and increase the risk of educational exclusion. However, the literature emphasizes that inclusion in technical schools is not without challenges, which are mainly related to the complexity of the vocational curriculum, safety requirements in practical activities, and the lack of adaptive resources [6] [7].

In Romania, studies on inclusion in technological education are relatively limited; however, existing research indicates that the success of integrating students with SEN is closely linked to the level of teacher training and the existence of partnerships with economic agents.

In this context, technological high schools have a significant role in mitigating the risk of early school leaving and in facilitating the transition of students with special educational needs into the labor market. [15].

Existing research identifies a range of effective approaches for enhancing the social and professional inclusion of students with special educational needs within technological education. Among these, curricular adaptation is particularly important, encompassing content simplification, differentiated learning activities, and the systematic use of formative assessment. Such measures support students with SEN in accessing learning processes more effectively and in developing relevant professional skills. [8].

Assistive technologies constitute a key element of inclusive education by enhancing access to information for students with special educational needs and by fostering greater autonomy within the learning process.

Studies show that the use of visual supports, digital applications, and adapted equipment contributes to increased motivation and performance of students in practical learning contexts. Additionally, mentoring and vocational counseling are considered essential practices for supporting the transition from school to professional life, particularly for SEN students at risk of social marginalization [3] [16] [18].

Overall, research emphasizes that the effective inclusion of SEN students in technological education requires an integrated approach that combines coherent educational policies, adapted teaching practices, and collaboration among the school, family, and community. These findings underpin the research approach of the present article, which focuses on analyzing the perceptions and practices of teachers in technological education [20].

This article is based on an empirical quantitative study conducted through a sociological survey to investigate the perceptions, practices, and challenges faced by teachers in technological education regarding the social and professional inclusion of students with SEN. The choice of a quantitative methodology allows for the systematic collection of data and comparative analysis of responses, providing an objective view of the perceived and implemented level of inclusion in technological schools.

The sample consisted of active teachers in technological high schools in Ilfov County who teach classes that include SEN learners. Participants were selected through a non-probabilistic convenience sampling method, based on the accessibility of teachers willing to participate in the research. The sample

included teachers with varying levels of seniority and professional rank to capture the diversity of professional experience.

Data were collected using a structured questionnaire, specifically designed to investigate the social and professional aspects of the inclusion of students with SEN. From a sociological methodology perspective, the questionnaire represents a standardized quantitative research instrument, intended to systematically and comparably collect direct information from respondents. It allows for the measurement of teachers' perceptions, attitudes, practices, and experiences, and is used to identify patterns, trends, and relationships among the variables of interest [4] [5].

The questionnaire was structured into five distinct sections to address multiple dimensions of inclusion: socio-demographic and professional aspects of teachers, their perceptions of social inclusion, applied teaching practices, the professional integration of SEN students, and the difficulties encountered, along with the identified needs for optimizing the educational process. This organization enables a detailed and systematic analysis of the data, as well as comparisons between different groups of teachers based on experience, professional rank, or curricular area [11] [19].

From a sociological standpoint, the structured questionnaire offers the advantage of standardized responses, which facilitates quantitative data processing and allows for inferences about the studied population. Additionally, combining closed, scaled, and open-ended questions allows both for an objective assessment of the phenomenon and the capture of qualitative nuances, thus providing a comprehensive understanding of how teachers contribute to the social and professional inclusion of students with SEN [1].

Section A – Socio-Demographic and Professional Data (Questions 1–5):

This section gathers information on teachers' gender, teaching context (urban or rural), professional experience in education, academic position, and area of specialization. The collected data enable an analytical linkage between teachers' professional profiles and their perceptions and practices related to inclusive education.

Section B – Perceptions of social inclusion (questions 6–9): this section investigates how teachers perceive the social integration of students with SEN within the school community. The items analyze peer acceptance, participation in group activities, the relational climate in the classroom, and the frequency of perceived discrimination. Responses were collected using a Likert scale from 1 (strongly disagree) to 5 (strongly agree), allowing the quantification of perceptions.

Section C – Inclusive teaching practices (questions 10–12): this section explores the concrete measures adopted by teachers to support the inclusion of SEN students. It examines the frequency of task adaptations, the types of adaptations used (simplification, extra time, visual support, etc.), and teachers' perceptions of their own competencies necessary to work effectively with SEN students.

Section D – Professional inclusion (questions 13–16): this section examines how SEN students acquire functional vocational skills and participate in practical training activities. It assesses teachers' perceptions regarding curriculum adaptability, student participation in practical activities, and their chances of entering the labor market.

Section E – Difficulties and needs (questions 17–18): the final section identifies the main difficulties faced by teachers when working with SEN students and the types of support considered necessary, including professional development, psycho-pedagogical counseling, and material resources.

The questionnaires were administered online, in accordance with the ethical standards specific to educational research. All participants received clear information regarding the purpose of the study, the confidentiality of their responses, and the voluntary nature of participation. Informed consent was obtained from the teachers, and the data were processed anonymously, without

identifying individual respondents. The results were analyzed in aggregate to highlight general trends, without compromising participant confidentiality. Data were processed using descriptive statistics and, where applicable, correlations between teacher characteristics (seniority, professional rank, curricular area) and reported perceptions or practices.
This approach enables the identification of the key factors influencing the effectiveness of social and professional inclusion for students with special educational needs in technological high schools in Ilfov County.

RESULTS AND DISCUSSIONS

This section of the paper presents the analysis of the data obtained through the structured questionnaire, aimed at investigating the perceptions, practices, and challenges of teachers in technological high schools regarding the social and professional inclusion of students with SEN. The survey was conducted online using a Google Forms questionnaire in January 2026, and responses were collected anonymously and voluntarily, in accordance with research ethics principles. A total of 216 valid responses were recorded, representing teachers from various disciplines and curricular areas in Ilfov County, thereby allowing a detailed and relevant analysis of the inclusion phenomenon in the context of technological education.
The data analysis is structured according to the five sections of the questionnaire, highlighting socio-demographic and professional aspects, teachers' perceptions, classroom practices, the level of professional inclusion of SEN students, and the main difficulties and needs identified.

Section A – Socio-demographic and professional data

Question 1: Teacher gender

Of the 216 respondents, 64% are female, 35% are male, and 1% preferred not to disclose their gender. This distribution indicates a slightly higher presence of female teachers in technological high schools in Ilfov County, reflecting general trends in pre-university education, where women slightly predominate across most disciplines, including technological contexts.
This gender composition is relevant for interpreting subsequent data, as perceptions and inclusion strategies may be influenced by professional experience and personal perspective, which, according to previous studies, can differ slightly between women and men in their approach to SEN students.

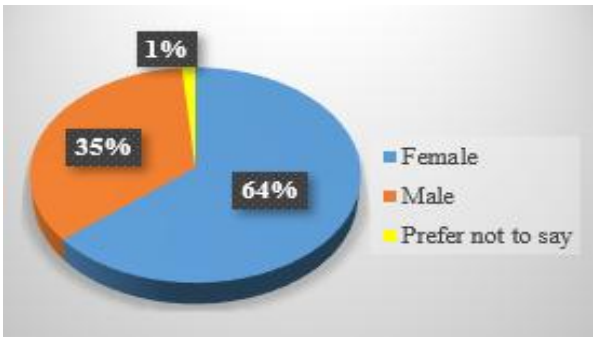


Fig. 1. Distribution of respondents by gender
Source: Own contribution.

Question 2: Teaching environment of the teacher

The data show that 38% of the teachers teach in urban areas, while 62% work in rural areas. This distribution indicates a predominance of rural teachers in the analyzed sample.

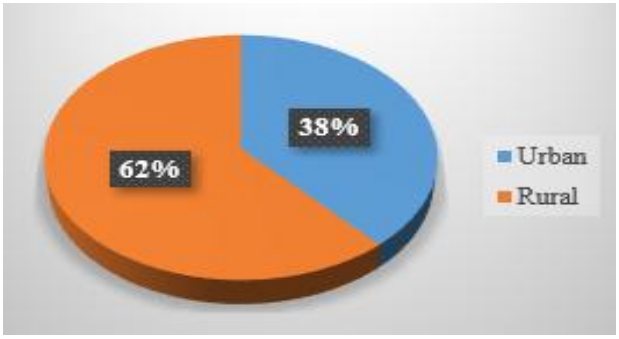


Fig. 2. Distribution of respondents by teaching environment
Source: own contribution.

Differences between urban and rural environments can influence access to resources, professional development opportunities, and the implementation of inclusive teaching strategies. For example, teachers in rural areas may face more limited material resources, larger class sizes, or reduced access to school counsellors and specialists, which can affect the

implementation of inclusion measures. At the same time, teachers in urban areas generally benefit from more diverse infrastructure and broader opportunities for collaboration with specialists, factors that can facilitate the integration of the SEN learners.

Question 3: Teaching experience

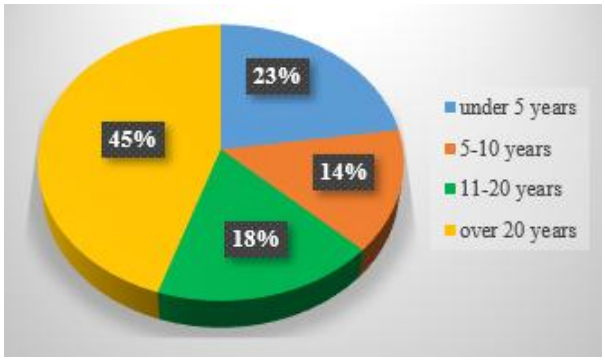


Fig. 3. Distribution of respondents by teaching experience
Source: own contribution.

The distribution of teachers in the sample according to teaching experience shows that 23% have less than 5 years of experience, 14% have between 5 and 10 years, 18% have between 11 and 20 years, and 45% of teachers have over 20 years of experience. This structure highlights that nearly half of the teachers involved in the study have extensive experience, which can positively influence the implementation of inclusive teaching strategies and the ability to adapt to the needs of students with SEN.

On the other hand, teachers with less than 10 years of experience represent 37% of the sample, and they are in a stage of accumulating practical experience and developing the specific competencies needed to work with SEN students. This combination of highly experienced and younger teachers can be beneficial for schools, allowing the integration of traditional methods with innovative and adaptive approaches necessary for the inclusion of SEN students.

Question 4: Teachers' professional rank

The analysis of responses indicates that 20% of the teachers are beginner (novice) teachers, 19% have passed the national tenure examination, 12% hold the second teaching degree, and 49% of the teachers hold the first teaching degree or a doctoral degree. This distribution shows that nearly half of the teachers in the sample are positioned at the highest professional level within the Romanian educational system, which may positively influence instructional quality and the implementation of inclusive teaching strategies for students with special educational needs.

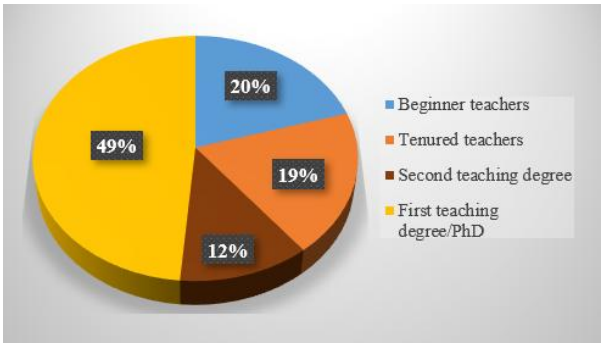


Fig. 4. Distribution of respondents by professional rank
Source: own contribution.

At the same time, the presence of beginner teachers and those who have achieved tenure, accounting for 39% of the sample, reflects a substantial group of educators who are still consolidating their professional experience and pedagogical competencies. This group can particularly benefit from mentoring, continuous professional development, and collaboration with more experienced colleagues. The coexistence of early-career and highly experienced teachers may facilitate the integration of established pedagogical expertise with innovative teaching approaches, thereby supporting more effective and inclusive educational practices.

Question 5: Teachers' curricular area

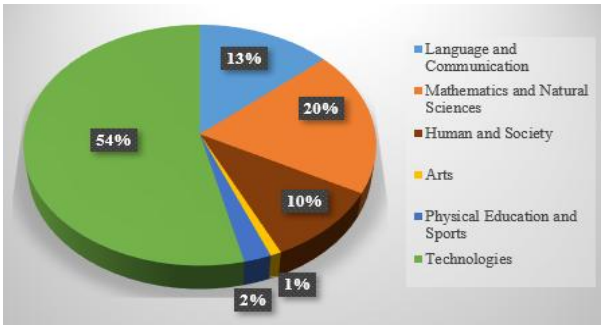


Fig. 5. Distribution of respondents by curricular area
Source: own contribution.

The distribution of teachers by curricular area shows that the majority are active in the field of Technologies (54%), followed by

Mathematics and Natural Sciences (20%), Language and Communication (13%), Human and Society (10%), Arts (2%), and Physical Education and Sports (1%). This structure reflects the predominantly technical nature of the sample, which is relevant for the study of the inclusion of students with SEN in technological education, as most of the teachers involved work in areas directly oriented toward the development of vocational competencies.

The involvement of teachers from both theoretical and artistic disciplines indicates an interdisciplinary perspective that can enhance the inclusion of students with special educational needs by integrating subject-specific instruction with strategies aimed at developing social and cognitive skills. At the same time, this configuration highlights the need for activity adaptation and inclusive practices to be aligned with the particular requirements of each discipline, so as to ensure the active engagement of students with SEN across all forms of educational activities.

Section B – Perceptions of social inclusion

Question 6: Are SEN students accepted by their peers?

The response analysis indicates that 26% of teachers fully agree that students with special educational needs are accepted by their peers, while 37% report a moderate level of agreement. In contrast, 6% of respondents adopt a neutral position. Lower levels of perceived acceptance are reflected by the 18% who express partial disagreement and the 13% who report complete disagreement.

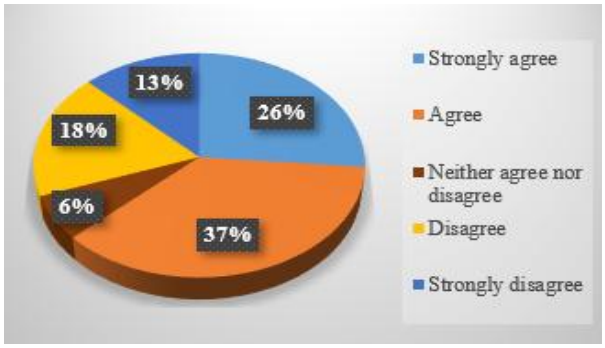


Fig. 6. Peer acceptance of students with SEN
Source: own contribution.

The findings suggest that while most teachers perceive students with special educational needs as being largely accepted within the classroom community, with a combined 63% expressing full or partial agreement, a substantial share of respondents (31%) continues to identify social challenges or peer-related resistance. This indicates that social integration is not uniform and that some SEN students may encounter obstacles in interpersonal relationships or in participation in group activities.

Question 7: Do students with SEN actively participate in group activities?

The analysis of teachers' responses reveals that 18% fully agree and 41% partially agree with the statement, resulting in a combined 59% of respondents who perceive students with special educational needs as demonstrating moderate to active participation in group activities. In contrast, 17% of teachers express a neutral position, while 24% report partial or complete disagreement, indicating that in certain contexts, students with SEN may experience limited integration or face challenges in achieving active participation.

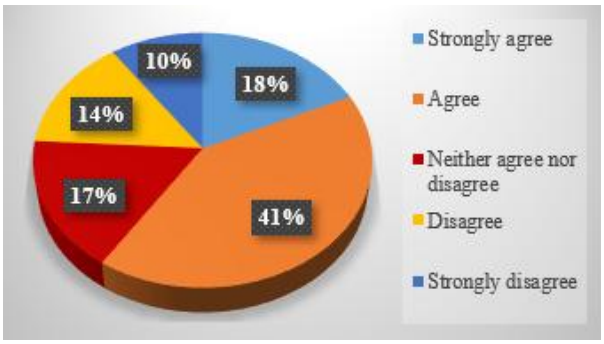


Fig. 7. Integration of students with SEN in group activities
Source: own contribution.

These results indicate that, although most SEN students are involved in group activities, the level of participation is not uniform, and teachers perceive significant differences between students. This highlights the need for teaching and social strategies that encourage the active involvement of all students, through adaptations of group activities and the creation of a relational climate conducive to inclusion.

Question 8: Is the relational climate in the classroom favorable to inclusion?

Responses indicated that 27% of teachers strongly agree, and 45% partially agree,

indicating that 72% of teachers perceive a relational climate favorable to the inclusion of students with SEN. A small percentage, 5% of respondents, neither agreed nor disagreed, while 23% indicated partial or total disagreement, suggesting that there are situations in which the classroom climate may be perceived as less supportive of social inclusion.

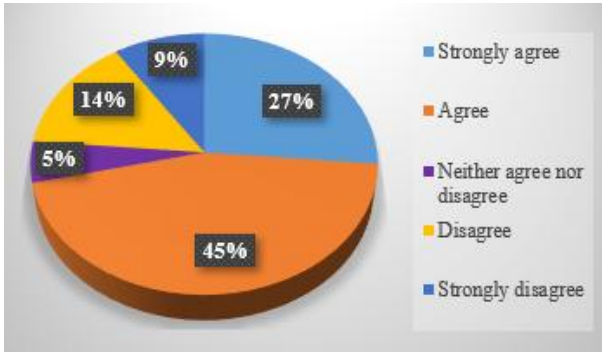


Fig. 8. Level of support for inclusion in student relationships
Source: own contribution.

These data suggest that, in general, teachers consider the relational environment in the classroom to support the social integration of SEN students; however, there remains a significant segment where additional interventions or pedagogical adaptations could strengthen inclusion. Maintaining a positive climate is essential for the active participation of students in group activities and for preventing social exclusion.

Question 9: Is discrimination against SEN students rare?

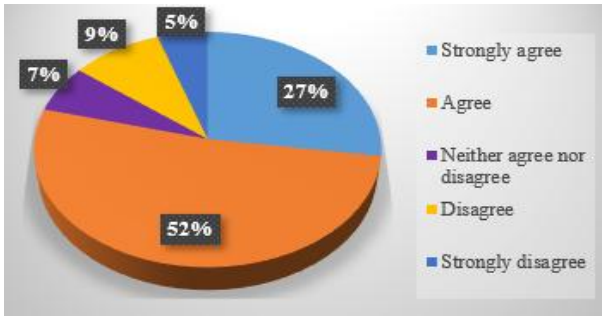


Fig. 9. Rate of discrimination against students with SEN
Source: own contribution.

The findings show that 27% of teachers strongly agreed and 52% partially agreed that discrimination against SEN students is rare in their classes, accounting for a total of 79% of respondents. However, 7% neither agreed nor disagreed, while 14% expressed partial or total disagreement, suggesting that instances of discrimination or exclusionary behaviour are still perceived to occur in some educational contexts.

These data suggest that, although most teachers perceive a low level of discrimination, continuous monitoring and socio-emotional education are needed to prevent marginalization and to promote the full social inclusion of SEN students. Overall, the results of Questions 6–9 indicate that teachers' perceptions are generally positive regarding the acceptance and social integration of SEN students, but there remains a minor segment where additional interventions could be beneficial.

Section C – Inclusive teaching practices

Question 10: Do you adapt learning tasks for students with SEN?

The findings show that 38% of teachers consistently adapt learning tasks for students with special educational needs, while 29% report doing so frequently. A further 28% indicate that task adaptation occurs only occasionally, whereas a small minority of respondents (5%) state that they do not adapt learning tasks at all.

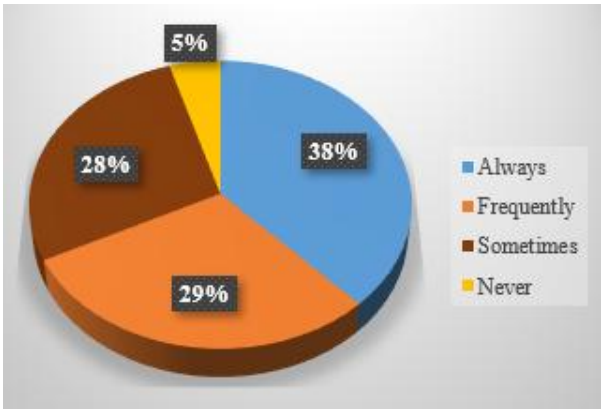


Fig. 10. Degree of task personalization for students with SEN
Source: own contribution.

The results indicate that a clear majority of teachers implement adaptations to learning tasks, with 95% reporting that they do so always, frequently, or occasionally, which reflects a general commitment to practical inclusion and to supporting students with

special educational needs throughout the learning process. At the same time, the contrast between teachers who consistently adapt tasks and those who do so only sporadically points to variability in the application of instructional strategies, potentially shaped by factors such as professional experience, academic position, curricular specialization, or the availability of institutional resources.

Question 11: What types of adaptations do you use most frequently?

The responses indicate that the most frequently used adaptation strategies are task simplification (30%), providing extra time (27%), differentiated work (24%), and the use of visual supports (19%). This distribution shows that teachers employ a variety of methods to support SEN learners, adapting the learning process according to individual needs.

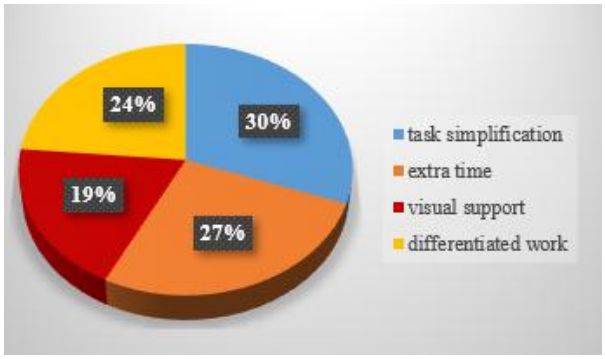


Fig. 11. Types of pedagogical interventions to support students with SEN
Source: Own contribution.

The preference for task simplification and extra time suggests that teachers focus on ensuring access to content and reducing cognitive or time-related difficulties encountered by students. At the same time, differentiated work and visual support reflect more diverse approaches aimed at stimulating active participation and supporting the learning process through visual and individualized methods.

Question 12: Do you consider that you have the necessary competencies to work with students with SEN?

The analysis shows that only 4% of teachers consider themselves to possess the necessary competencies to a very great extent, while an additional 27% report a high level of competence. By contrast, most respondents (52%) perceive their competencies as limited, and 17% indicate that they do not possess the required competencies at all.

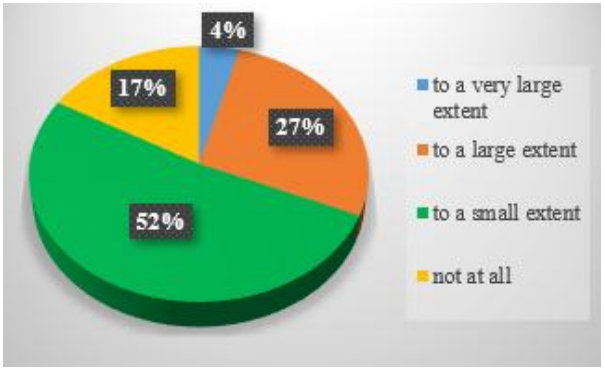


Fig. 12. Teachers' self-assessment of competencies for working with students with SEN
Source: own contribution.

Overall, this pattern indicates that, despite the frequent implementation of instructional adaptations for students with SEN, many teachers feel insufficiently prepared to address their specific educational requirements. This reinforces the need for ongoing professional development and access to specialized support to strengthen competencies in inclusive education and to improve the effectiveness of classroom practices.

Section D – Professional inclusion

Question 13: Can students with SEN acquire functional vocational competencies?

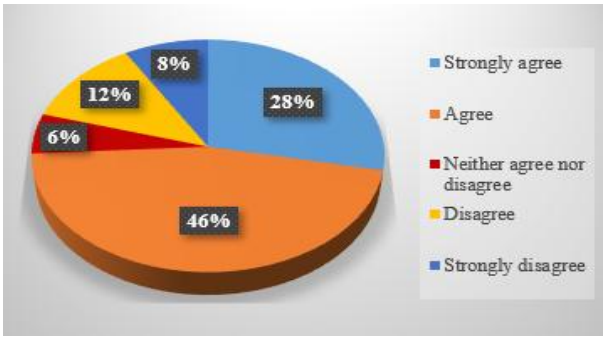


Fig. 13. Acquisition of vocational competencies among students with SEN
Source: own contribution.

The results indicate that 28% of teachers strongly agree, and 46% partially agree, suggesting that 74% of respondents believe that SEN students can acquire functional vocational competencies. Meanwhile, 6% chose "neither agree nor disagree," and 20%

(12% partial disagreement and 8% total disagreement) are not fully convinced of this possibility.

These data suggest that, in general, teachers believe in the potential of SEN students to engage in professional activities, but there is a significant segment that perceives certain limitations, possibly related to the complexity of the technological curriculum, practical requirements, or the resources available for training. This perception highlights the need for adaptations and additional support in vocational training to increase teachers' confidence and students' success in acquiring functional competencies.

Question 14: Does the technological high school curriculum allow for meaningful adaptations?

Teachers' responses reveal a mixed assessment of curricular flexibility. While 21% strongly agreed and 36% partially agreed that the technological high school curriculum enables meaningful adaptations for students with SEN, amounting to 57% of respondents, a notable share expressed reservations. Specifically, 18% remained neutral, and 25% disagreed to some extent, suggesting that a considerable proportion of teachers view the curriculum as insufficiently flexible or adaptable to fully support SEN students.

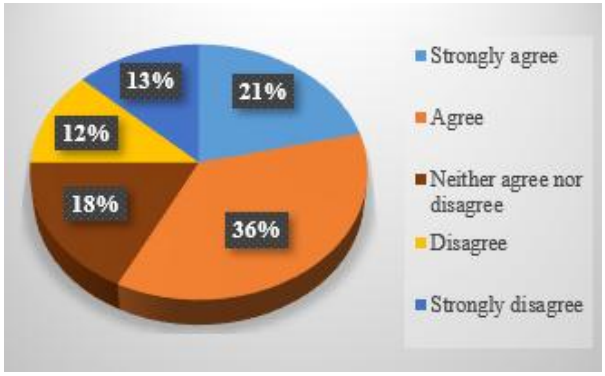


Fig. 14. The capacity of the technological curriculum to support didactic adaptations
Source: own contribution.

This distribution highlights that, although there is a relatively positive consensus regarding the possibility of curriculum adaptation, perceived obstacles still exist, which may include the rigid structure of programs, the lack of adapted teaching resources, or difficulties in implementing differentiated instructional strategies. These aspects underscore the need to review and make the technological curriculum more flexible so that it is more accessible and effective for the inclusion of students with SEN.

Question 15: Are students with SEN involved in practical training?

These findings point out that 36% of teachers strongly agree and 52% partially agree, indicating that 88% of respondents perceive active involvement of such students in practical training activities. Only 5% responded "neither agree nor disagree," and 7% indicated partial or total disagreement, suggesting that there are a small number of cases in which SEN students are not fully integrated into practical activities.

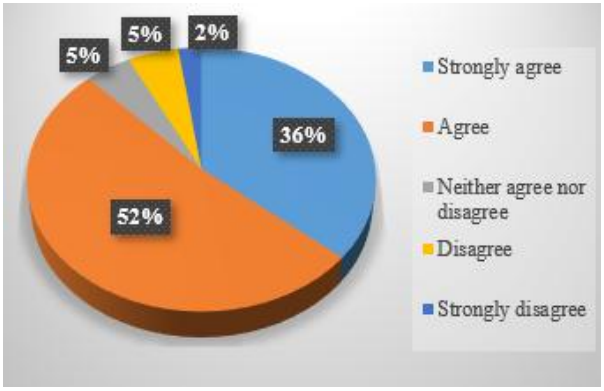


Fig. 15. Level of involvement of students with SEN in practical training
Source: own contribution.

These data indicate a high level of practical participation among SEN students, which is essential for acquiring functional vocational competencies and for their integration into the labor market. However, the small percentage of teachers who perceive a lack of involvement highlights the need for continuous monitoring of practical training and the provision of additional support to ensure the full inclusion of all students.

Question 16: Are there real opportunities for labor market integration?

The data show that 45% of teachers strongly agreed and 41% partially agreed that students with SEN have real opportunities for professional integration after completing their studies at a technological high school, resulting in a combined total of 86% of respondents.

Only 7% responded "neither agree nor disagree," and 7% indicated partial or total disagreement, suggesting that a small segment of teachers perceives obstacles or limitations in the professional integration of SEN students.

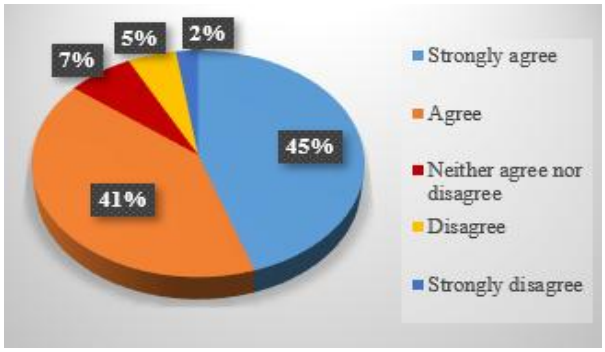


Fig. 16. Professional integration prospects for students with SEN
Source: own contribution.

These data reflect a generally positive perception of the professional opportunities for SEN students, highlighting the effectiveness of practical training programs and the relevance of the competencies acquired in technological high schools. At the same time, the minor percentage of negative responses suggests that external factors, such as labor market demands or lack of support from employers, may constitute barriers to full professional integration.

Section E – Difficulties and needs

Question 17: What are the main difficulties encountered when working with students with SEN?

A notable proportion of teachers (54%) consider class size to be the main difficulty when working with learners with specific educational support needs. Other reported difficulties include lack of specialized training (14%), insufficient collaboration with specialists (12%), lack of time (10%), and lack of adapted materials (10%).

These data indicate that organizational factors and limited resources represent the primary obstacles to providing an inclusive and effective educational process. Large classes can hinder the implementation of differentiated instruction strategies and the active engagement of students with SEN, while the lack of training and collaboration with specialists reduces teachers' capacity to adequately meet individual needs. This underscores the necessity of better class organization, provision of adapted materials, and the development of teachers' competencies through continuous professional development.

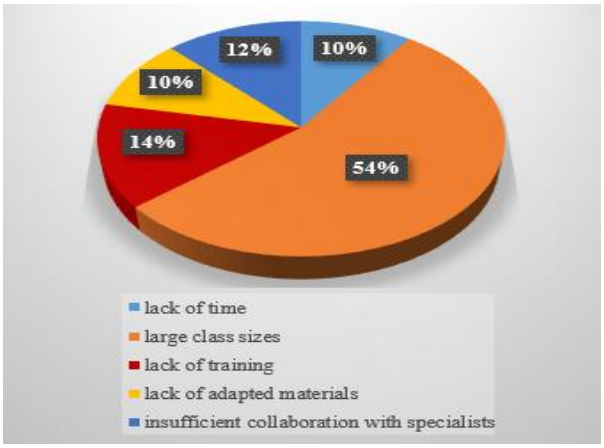


Fig. 17. Obstacles in implementing educational activities for students with SEN
Source: own contribution.

Question 18: What type of support do you consider necessary?

Overall, respondents identified the most important forms of support for working with students with SEN as school counselling (32%), continuous professional development (27%), adapted teaching materials (22%), and curriculum adaptation (19%). These data highlight that, to ensure effective social and professional inclusion, teachers need not only additional knowledge and competencies but also institutional support and adequate resources.

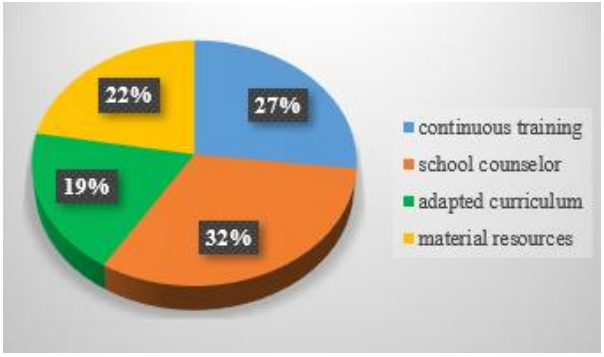


Fig. 18. Educational and social support needs for students with SEN
Source: own contribution.

School counselling is perceived as essential for managing interpersonal relationships and

supporting students in the learning process, while continuous professional development and adapted resources enable the practical application of inclusive strategies. Although less frequently mentioned, curriculum adaptation remains important for making the educational process flexible according to the individual needs of students with SEN.

The analysis of data collected through the structured questionnaire reveals both the advances achieved and the ongoing challenges related to the social and professional inclusion of students with special educational needs in technological high schools in Ilfov County. The results indicate a generally positive perception among teachers regarding the acceptance and participation of SEN students in group activities, practical training, and the acquisition of functional vocational competencies. At the same time, most teachers frequently adapt tasks and employ various inclusive teaching strategies, although there are significant differences in perceived competence in managing specific educational situations. Simultaneously, the analysis identifies a range of specific challenges and needs: large class sizes, lack of specialized training, limited resources, and insufficient collaboration with specialists are perceived as factors that may limit effective inclusion. Teachers emphasize the importance of institutional and professional support through continuous training, school counselling, curriculum adaptation, and adequate teaching materials. The interpretation of these results suggests that school inclusion does not depend solely on the individual commitment of teachers but also on the organizational framework and available resources. Moreover, the data confirm that positive perceptions regarding social and professional inclusion coexist with areas where additional interventions are needed to ensure the full participation of all SEN students. This complex picture provides a solid foundation for developing concrete recommendations and for formulating conclusions, which will be addressed in the following section of the article.

CONCLUSIONS

The present study offers an evidence-based overview of the social and professional inclusion of students with SEN in technological high schools in Ilfov County, capturing both encouraging developments and persistent constraints. Teachers' responses suggest that SEN students are generally accepted by peers and are perceived to participate actively in group activities and practical training; respondents also expressed confidence in SEN students' capacity to develop functional vocational skills and access employment opportunities after graduation.

At the same time, the findings point to structural and capacity-related barriers that may hinder consistent implementation of inclusive practice, particularly large class sizes, limited access to specialized training, insufficient adapted materials, and weak collaboration with support professionals (e.g., psychologists, school counsellors, therapists). Although many teachers report using adaptive strategies, a substantial proportion indicate a need for stronger competencies and more systematic institutional support.

Overall, the results reinforce that inclusion in technological education has implications that extend beyond academic attainment, supporting social participation and employability and reducing risks of marginalisation. Strengthening professional support, resources, and school-level conditions can further consolidate inclusive climates and facilitate the transfer of effective practices to comparable educational settings.

Based on the study's findings, the following recommendations can be outlined for policymakers, educational institutions, and teachers:

- ✓ Continuous professional development and teacher competency building – specialized programs in inclusive education, training on curriculum adaptations, and the use of assistive technologies.
- ✓ Reducing class sizes – to allow for differentiated instruction and individualized monitoring of SEN students' progress.
- ✓ Improving collaboration with specialists – involving school counsellors,

psychologists, and therapists in the educational process to support both students and teachers.

✓ Adapting and flexibilizing the technological curriculum – including modules or materials that allow for personalized learning and the development of functional professional competencies.

✓ Access to material and technological resources – providing visual supports, adapted teaching materials, and assistive technologies to facilitate the learning process.

✓ Creating an inclusive school climate – promoting group activities, collaborative projects, and extracurricular programs that foster acceptance and cooperation among students.

Overall, the study confirms that technological high schools can serve as an effective environment for the social and professional inclusion of students with special educational needs, but success depends on teacher training, available resources, and institutional support. Implementing the recommendations outlined above could contribute to improving the quality of inclusive education and preparing SEN students for real integration into society and the labor market, thus reinforcing the role of vocational training as a driver of inclusion and sustainable social development.

This research underscores both the strong potential of technological education to support the socio-professional integration of these students and the structural challenges faced by teachers in translating inclusive principles into practice. The findings highlight the importance of coherent organizational frameworks, adequate material and human resources, and well-developed professional competencies among teachers as key conditions for the effectiveness and sustainability of inclusive education.

Beyond its educational implications, the study demonstrates clear social and professional relevance, showing that inclusive school environments promote acceptance, community participation, and the development of competencies essential for labour market integration. In this respect, technological high schools can play a decisive role in preparing SEN students for active social and professional life, provided that differentiated instructional approaches, curriculum flexibility, and ongoing institutional support are consistently ensured.

By articulating targeted recommendations such as continuous teacher training, enhanced collaboration with specialists, improved access to adapted resources, and reduced class sizes, the article offers a practice and policy-oriented framework for strengthening inclusive education. Consequently, the study contributes not only to understanding the current state of inclusion in technological high schools but also to informing concrete interventions aimed at improving educational quality and expanding socio-professional opportunities for students with SEN.

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STATISTICAL ANALYSIS OF MILK AND DAIRY PRODUCT PRODUCTION IN ROMANIA (2020–2024)

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Abstract

The study analyzes the evolution of milk and dairy product production in Romania during the period 2020–2024, focusing on the main product categories: fluid milk, cream, fermented dairy products, cheese, butter, and powdered milk. The research highlights the overall stability of production for fluid milk and cream, steady growth for cheese and powdered milk, as well as minor variations for butter and fermented products, influenced by consumer preferences and market factors. The application of statistical methods (time series analysis, growth indices, coefficient of variation, and CAGR) allowed the identification of trends and fluctuations, while the SWOT analysis emphasized the nutritional strengths, product diversity, risks related to perishability and competition from plant-based alternatives, as well as opportunities for innovation and market expansion. The results suggest that the dairy sector remains strategic, with stable demand and development potential, and the recommendations focus on maintaining the stability of core production, developing value-added products, and adapting marketing strategies to enhance competitiveness and capitalize on domestic and international opportunities..

Key words: *dairy sector, milk production, fermented dairy products, dynamics analysis, CAGR, coefficient of variation, swot analysis, market trends*

INTRODUCTION

The dairy sector in Romania has undergone significant changes since 1990, including a reduction in livestock number and an increase in production per animal [2].

Milk production is influenced by a multitude of factors, especially environmental and climatic ones. Milk and dairy products provide essential nutrients, such as proteins and calcium, and may offer therapeutic benefits [5]. Despite the visible progress in the national dairy market, producers face challenges caused by market liberalization, rising production costs, and issues related to milk collection [6,11]. These aspects indicate that the sector is undergoing a period of transition or crisis, requiring improvements in efficiency and strategic adaptation.

Dairy products, including fluid milk, cream, fermented dairy products (yogurt, buttermilk, and other fermented preparations), powdered milk, butter, and cheese, represent a fundamental food category both from a nutritional perspective and within the food industry. These products are characterized by a high density of essential nutrients, such as high-quality proteins, vitamins (A, D, B2, B12), and minerals (particularly calcium and phosphorus), playing a crucial role in preventing nutritional deficiencies and maintaining bone health and cardiovascular system function [3,18].

Fluid milk is considered a functional food due to its complex composition, which provides not only essential nutrients but also bioactive effects on the good microbiota and lipid metabolism [21]. Fermented dairy products, such as yogurt and buttermilk, obtained through controlled lactic fermentation, have the added benefit of contributing to the balance of gut microbiota and enhancing the bioavailability of certain minerals and vitamins [4]. Butter and cheese, although higher in fat, provide essential fatty acids and fat-soluble vitamins and can be included in a balanced diet without compromising the lipid profile if consumed in moderate amounts [19, 20]. Powdered milk, through the concentration and dehydration of milk, allows the long-term

preservation of its nutritional value and facilitates its distribution and use across various food industries, from bakery products to pediatric or sports nutrition products [9]. The importance of these products also extends to public health, as regular consumption of dairy is associated with a reduced risk of chronic diseases, including hypertension, obesity, and type 2 diabetes, according to evidence from recent epidemiological studies and meta-analyses [22, 18]. At the same time, the quality of dairy products is determined not only by the initial composition of the milk but also by the technological processes applied, such as pasteurization, homogenization, ripening, and controlled fermentation, which influence microbiological stability, sensory properties, and final nutritional values [20]. Thus, milk and dairy products constitute multifunctional foods, combining nutritional value, bioactive benefits, and appealing sensory properties, and are strategically integrated into diet and industry. Recent studies emphasize the need to approach the dairy matrix as a complex system, in which interactions between components (proteins, lipids, minerals) determine nutrient bioavailability and functional effects on the body, highlighting the importance of a holistic analysis of these products' role in modern nutrition [21].

The aim of this study is to analyze the evolution of milk and dairy product production in Romania during the period 2020–2024, identifying general trends, fluctuations, and variability in production for the main product categories (fluid milk, cream, fermented dairy products, cheese, butter, and powdered milk). The study also seeks to assess the impact of economic, seasonal, and market factors on production, apply specific statistical methods (time series analysis, growth indices, coefficient of variation, CAGR), and conduct a SWOT analysis to highlight the strengths, weaknesses, opportunities, and threats of the dairy sector. Ultimately, the study aims to provide strategic recommendations for maintaining production stability, developing value-added segments, and enhancing the sector's competitiveness in domestic and international markets.

MATERIALS AND METHODS

The data used in this study were obtained from official statistical sources, specifically from the publications of the National Institute of Statistics (INS) entitled 'Production of Meat, Milk, and Dairy Products from Industrial Units' for the years 2020, 2021, 2022, 2023, and 2024, published in Bucharest.These reports provide annual information on milk and dairy product production in Romania. The analysis focused on the main product categories, namely: fluid milk, fermented milk products, cream, cheese, powdered milk, and butter. The period 2020–2024 was analyzed for these products, allowing the identification of sectoral trends as well as fluctuations in production levels during this interval.

For the statistical interpretation and processing of the collected data, the following methods and analytical tools were applied:

Time Series Analysis

The evolution of milk and dairy product production for each product category was analyzed using time series analysis, with the aim of highlighting short- and medium-term changes in production levels. The analysis included:calculation of annual growth rates; determination of variation indices.

This approach allowed the identification of both general trends and annual fluctuations in production [7]. To interpret the collected data, the following statistical methods were applied:

Growth Index (%)

To evaluate the annual changes in milk and dairy product production, the growth index was calculated using the following formula:

$$I_t = \frac{X_t}{X_{t-1}} \times 100 \quad \text{.....(1)}$$

where:

I_t= growth index for year t,

X_t = indicator value in year t,

X_{t-1} = indicator value in the previous year.

This method is widely applied in the statistical analysis of socio-economic dynamics [17].

The coefficient of variation (CV).
To assess the stability or volatility of milk and dairy product production over the analyzed period, the coefficient of variation (CV) was applied, calculated as follows:

$$CV=\sigma/\mu \quad \text{.....(2)}$$

where:
σ = standard deviation,
μ= arithmetic mean of the data series.
A CV below 0.2 indicates low variability, and a CV above 0.5 indicates high variability[16, 10],
The Compound Annual Growth Rate (CAGR)
The CAGR was calculated to analyze the long-term trends in the production of milk and dairy products. CAGR is a valuable tool in long-term analysis because it enables the comparison of growth or decline over different periods, accounting for market or production fluctuations. It is useful for:
• Evaluating sector performance – providing a clear picture of how milk and dairy production has developed over time.
• Estimating long-term growth – using historical data to help forecast the future development of the dairy sector.
• Comparing product categories or regions – allowing comparison of growth rates across different dairy products or geographic areas [22,7]

$$CAGR = \left(\frac{V_f}{V_i}\right)^{\frac{1}{n}} - 1 \text{.....(3)}$$

where:
V_f= the final value of the indicator,
V_i = theinitialvalue of the indicator,
n = thenumber of yearsunderreview.
The SWOT analysis was applied to provide a clear overview of Romania's milk and dairy products sector, highlighting its strengths and weaknesses, as well as existing opportunities and threats. This approach allows for a comprehensive assessment of the internal and external factors influencing production and market dynamics, offering a valuable tool for strategic planning and decision-making [8].

RESULTS AND DISCUSSIONS

The analysis of milk and dairy product production allows for monitoring trends, optimizing production, and adapting to market demands, supporting the competitiveness and sustainability of the sector.
Analyzing fluid milk production during 2020–2024, according to Fig 1, it is observed that production showed slight variations, increasing from 357,313 tons in 2020 to 387,231 tons in 2021 (+8.4%), followed by a decline in 2022 and 2023, returning to 375,548 tons in 2024. This suggests stable demand, with potential influences from seasonal and market factors.

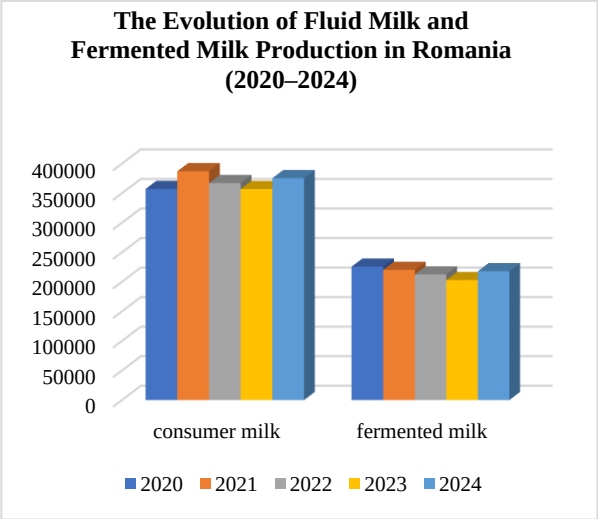


Fig. 1. The Evolution of Fluid Milk and Fermented Milk Production
Source: [12,13,14,15, 16].

According to Fig. 1, the production of fermented milk products (including yogurt, buttermilk, and other fermented products) shows a downward trend until 2023, decreasing from 225,730 tons in 2020 to 202,954 tons in 2023 (-10.1%), followed by a recovery in 2024 to 218,070 tons. This may reflect changes in consumer preferences or marketing strategies.
Analyzing the evolution of cream and cheese production in Romania during 2020–2024, according to Fig. 2, cream production remained relatively constant, around 65–70 thousand tons, with a slight increase in 2024, indicating stable consumption.

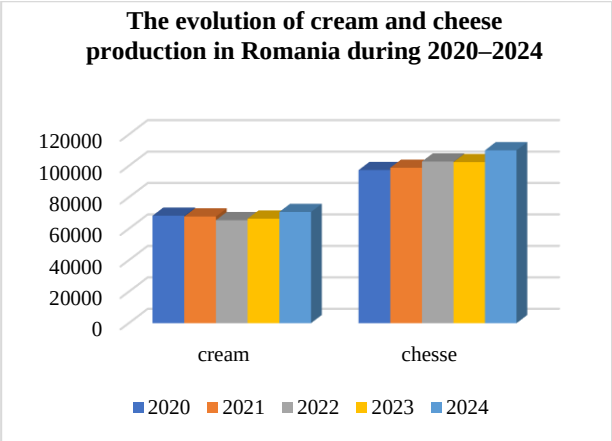


Fig. 2. The Evolution of cream and cheese production
Source: [12,13,14,15, 16].

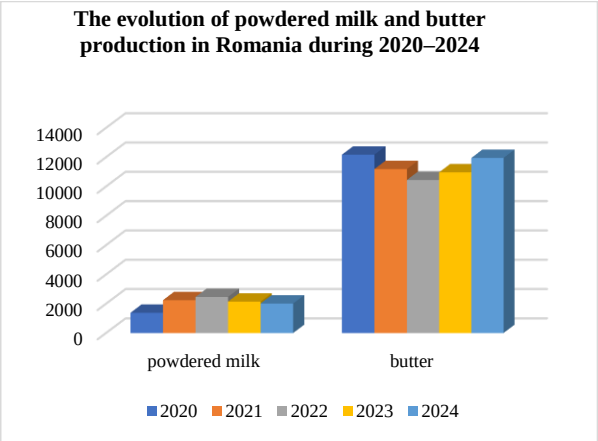


Fig. 3. The Evolution of powder milk and butter production
Source: [12,13,14,15, 16].

Cheese production showed a steady increase, from 97,356 tons in 2020 to 109,952 tons in 2024 (+12.9%), reflecting growing demand for cheese and traditional dairy products.
Analyzing the evolution of cream and cheese production in Romania during 2020–2024, according to Fig. 3, milk powder production remains low compared to liquid milk, fluctuating between 1,379 and 2,464 tons, with a slight decrease in 2024, indicating more stable and limited demand, possibly oriented toward exports. Butter production decreased between 2020 and 2022, followed by an increase in 2023–2024, returning nearly to its initial level.

This may reflect variability in domestic demand or the effects of raw material prices.
Statistical indicators for production of dairy products, 2020-2024 in Romania are shown in Table 1.
Fluid milk shows relatively low variability (CV = 0.03), indicating stable and predictable production over the 2020–2024 period.
The cumulative increase of 5.1% between 2020 and 2024 reflects a steady and consistent demand, supported by the importance of milk in the daily diet and its contribution of high-quality calcium and proteins.

Table 1. Statistical indicators for production of dairy products, 2020-2024 in Romania

	Standard deviation	Mean	Coefficient of variation	2023/2019 (%)
Fluid milk	11,474.7	368,860.4	0.03	105.1
Cream	1,784.4	67,745.6	0.03	103.5
Fermented milk	7,739.4	215,943.2	0.04	96.6
Milkpowder	365.8	2,049.0	0.18	146.0
Butter	635.9	11,347.6	0.06	98.2
Cheese	4,366.9	102,271.0	0.04	112.9

Source: own calculations based on data collected from NIS [12,13,14,15, 16].

The modest annual growth rate (1.3%) confirms that fluid milk remains a staple product, with limited adjustments depending on market fluctuations and seasonality (Table 1).
Cream also demonstrates high production stability, similar to fluid milk, reflecting the constant and traditional consumption of this product in the Romanian diet. The cumulative increase of 3.5% over the analyzed period and an annual growth rate of 0.9% suggest a mature market with stable consumption and limited influence from seasonal or economic factors (Table 1).
Fermented milk products show slightly higher variability compared to fluid milk and cream (CV = 0.04), which may reflect consumer preferences and market trends. The cumulative

decrease of 3.4% between 2020 and 2024, with a negative annual rate (-0.9%), indicates a slight decline in consumption or production adjustments, possibly due to market competition or alternative products (Table 1).

Milk powder shows the highest relative variability among the analyzed products (CV = 0.18), indicating volatile production, likely driven by fluctuating export demand and industrial use (Jakubowska et al., 2024).

The cumulative growth of 46% and an annual rate of 9.9% show significant expansion, likely reflecting storage policies and the development of the food and pharmaceutical industries, wheremilkpowderis an important ingredient (Table 1).

Butter has relatively good stability (CV = 0.06), but shows a slight long-term decrease (2024/2020 ratio<100%), which can be attributed to variability in fat consumption, prices, and substitutes. The negative annual rate (-0.5%) suggests a stable but slightly declining market, in line with global trends toward reduced saturated fat intake (Table 1).

Cheese production recorded a steady and consistent increase (+12.9% cumulative) with moderate variability (CV = 0.04). This reflects the growing demand for traditional and processed cheeses, as well as their role in the Romanian dietand in dairy product exports. The positive annual growth rate (3.1%) confirms the development of this sector, supported by product diversification and consumer preferences (Table 1).

SWOT analysis of dairy products

Strengths

Nutritional value and health benefits

Dairy products are recognized for their rich content of essential nutrients, high-quality proteins, calcium, phosphorus, and vitamins which contribute to bone health, metabolism, and overall biological functions. Studies show that milk and dairy products can be associated with a reduced risk of cardiovascular diseases and diabetes, especially fermented dairy products (yogurt), which have a protective effect on human health.

A comparative study on the Romanian market indicates that dairy products (milk, cream, cheese) are balanced sources of macronutrients and micronutrients necessary for the diet [1],

Diverse product segments

The dairy sector includes a wide range of products: milk, cream, cheese, butter, fermented products (yogurt, kefir), and powdered milk, providing portfolio diversification and reducing dependence on a single product type. This diversification helps adapt to consumer demand and increases revenue across multiple segments.

Stable and traditional demand

Dairy products remain staple foods, consumed daily in many cultures, including Romania, where they are part of traditional dietary habits. This stable demand provides a solid foundation for producers and distribution chains.

Weaknesses

Perishability and logistics

Dairy products are generally perishable, requiring a continuous cold chain and significant infrastructure investments (e.g., refrigeration, transport logistics), which increase operational costs.

Dependence on raw materials and seasonality

Milk production and its derivatives depend on the quality and volume of raw milk collected from farms. This can be affected by seasonal production, climatic conditions, and animal health, causing supply variability.

Price sensitivityandcompetition

Dairy faces fluctuations in raw material prices and competition from alternative products such as plant-based drinks or lactose-free products, which can affect market share, especially among price-sensitive consumers or those with lactose intolerance.

Opportunities

Food innovation and functional products

There is growing interest in functional dairy products — for example, probiotic-enriched yogurts, protein-fortified products, or organic dairy which can increase added value and attract a premium consumer segment.

Rising demand for protein and health

Market reports indicate significant growth in the dairy protein segment, including whey and casein protein ingredients, which can stimulate

innovation and revenue growth in related sectors (protein snacks, sports drinks, etc.).

Expansion of exports and external markets

High-quality traditional dairy products can be integrated into export strategies, especially in markets where demand for premium dairy is increasing (e.g., European and North American markets).

Preference for ethical and sustainable products

Consumers increasingly value ethical attributes and animal welfare, creating opportunities for responsibly produced dairy (ethical, animal-friendly), leading to premium prices and increased customer loyalty.

Threats

Environmental conditions and resources

The dairy sector is vulnerable to climate change, access to pasture land, and rising feed costs. Ecosystem changes can affect milk production and, consequently, raw material availability.

Global competitiveness

International players (Lactalis, Danone, Nestlé, andArla Foods) use advanced marketing strategies and modern processing technologies, putting pressure on smaller local producers to continuously adapt or risk losing market share.

Changes in consumer behavior

Growing preference for vegan products or plant-based alternatives (soy, almond, oatmilk) poses a threat to traditional dairydemand, especially among younger generations and consumers concerned with sustainability and health.

CONCLUSIONS

The analysis of milk and dairy product production during 2020–2024 shows overall stability, with modest increases for fluid milk and cream and positive trends for cheese and powdered milk. Fermented products and butter experienced slight variations, influenced by consumer preferences and market factors. The low variability of most products indicates predictable production, while powdered milk shows higher volatility due to industrial and export demand. The SWOT analysis highlights the nutritional strengths and product diversity, as well as risks related to perishability, seasonality, and competition from plant-based alternatives. Key opportunities focus on innovation, functional products, and expansion into foreign markets, while challenges include climate change, rising raw material costs, and international competition.

It is recommended to maintain the stability of core production (fluid milk, cream), develop value-added products (premium cheeses, functional fermented products, powdered milk), and adapt marketing strategies to respond to consumer preferences and leverage opportunities in external markets. Investments in sustainability and optimization of the supply chain can support long-term competitiveness.

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SHIFTS IN TOURIST BEHAVIOR IN THE DIGITAL ERA: THE INFLUENCE OF ONLINE BOOKING PLATFORMS ON ACCOMMODATION CHOICE

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Abstract

The rapid digitalization of the tourism industry has fundamentally transformed how travelers plan, select, and book accommodation. This study investigates the influence of online booking platforms (OBPs) on tourists' decision-making, with a focus on the role of online reviews, ratings, interface design, and price sensitivity. Drawing on a quantitative survey of 104 respondents in Romania, the results indicate that reputational and visual elements—such as user-generated reviews, photographs, and detailed descriptions—are the most influential factors guiding accommodation choice, surpassing traditional considerations like cancellation policies or payment methods. Negative reviews were found to exert a disproportionate impact on consumer decisions, underscoring the persistent weight of informational asymmetry in digital contexts. While discounts and interface features shape immediate choices, long-term loyalty appears to be driven more by travel frequency and entrenched habits. From a managerial perspective, the findings emphasize the need for active online reputation management, high-quality visual presentation, and transparent communication in order to maintain competitiveness in the digital marketplace.

Key words: *online booking platforms, tourist behavior, online reviews, accommodation choice, digitalization in tourism*

INTRODUCTION

The evolution of tourism in the digital context

Digitalization has profoundly reshaped the tourism industry, influencing every stage of the traveler's decision-making process (Bathla et al., 2025; Bilan et al., 2024) [3, 4]. Over the past two decades, technological transformations have not only altered the way trips are planned and booked but have also redefined the dynamics between service providers and consumers. The Internet, mobile technologies, and online platforms have enabled fast, comparative, and highly personalized access to tourism offers, particularly accommodation (Zhang & Szabó, 2024) [34]. This transition to digital ecosystems has fundamentally shifted patterns of tourist consumption, giving rise to a more informed, demanding, and autonomous traveler (Wu et al., 2024) [31].

The literature consistently highlights tourism as one of the first sectors to adopt digitalization on a global scale (Gutierriz et al., 2023) [13]. The shift from face-to-face interactions with travel agents to self-service online bookings through platforms such as Booking.com, Expedia, Airbnb, or TripAdvisor radically altered the balance of power between providers and consumers. These platforms evolved from mere booking channels into spaces of social validation, comparative information, and trust-building (Gretzel & Yoo, 2008; Xiang & Gretzel, 2010) [11, 32].

Within this new digital ecosystem, the decision to choose a specific accommodation unit no longer depends exclusively on price or location. Instead, it is guided by a complex set of factors such as user-generated scores, detailed reviews, transparency of offers, visual content, and the degree of personalization provided (Sánchez-Franco & Rey-Tienda, 2024) [27]. Research shows that the opinions of fellow travelers are often perceived as more trustworthy and persuasive than official advertising messages (Casaló et al., 2019; Sciarelli et al., 2018) [5, 28]. This phenomenon

is further supported by Halkiopoulos et al. (2020) [14], who argue that online reviews act as a substitute for direct experience, offering consumers a sense of security and social validation prior to purchase. This evolution has been enabled by advances in digital infrastructure: high-speed mobile networks, intuitive applications, secure payment systems, and the integration of artificial intelligence into the booking process (Kim & Kim, 2017) [17]. Since the early 2000s, tourism has entered a new era characterized by the "disintermediation" of traditional channels and the rise of "do-it-yourself" consumer behavior (Tse, 2003) [30]. Tourists have gained direct control over the planning, booking, and evaluation of travel services. The emergence of peer-to-peer platforms such as Airbnb further disrupted tourism distribution models, enabling individuals to act as direct providers of accommodation. This collaborative model not only expanded the range of available options but also introduced new criteria for selection, including authenticity of the experience and host–guest interaction (Moon et al., 2019) [22].

Globally, studies show that more than 80% of tourists use the Internet to plan and book their trips, and over 70% consult online reviews before making a decision (Statista Research Department, 2025) [29]. As such, online platforms play an essential role in both facilitating bookings and shaping tourist expectations and perceptions. They operate as aggregators of content and symbolic mediators between supply and demand.

The rise of OBPs must also be understood in relation to the diversification of accommodation supply, particularly in rural and alternative tourism segments. Recent studies on the Romanian agri-tourism sector indicate a steady growth in the number of guesthouses and available beds over the past decade, reflecting both the increasing demand for authentic experiences and the expansion of rural destinations in the national tourism landscape (Popescu, 2021) [26]. This evolution highlights the growing relevance of digital platforms not only for urban hotels but also for small-scale rural providers, who increasingly rely on OBPs to reach wider markets and compete in an environment where visibility, online reputation, and accessibility are decisive factors. From the service provider's perspective, digitalization has required a strategic shift in marketing and distribution. Accommodation units must optimize their online presence, actively manage digital reputation, and respond dynamically to market demands by adjusting prices, images, descriptions, and replies to reviews (Yerbolatqyzy, 2025) [33]. At the same time, user-generated data provide opportunities for detailed analyses of consumer behavior and increasingly tailored offers.

Consequently, digital tourism has reshaped the provider–tourist relationship into one that is interactive, transparent, and accountable. This transformation is not only technological but also cultural, with trust, user experience, and online reputation functioning as currencies in the decision-making process (Elshaer et al., 2024) [8]. Recent studies (Halkiopoulos et al. (2020) [14] also demonstrate that these decisions are strongly shaped by emotional components, even in contexts that appear rational—particularly when platform interactions are rapid and driven by visual stimuli. The present study seeks to explore these dynamics by focusing on the factors that shape tourists' decisions to book online, within the broader context of digital platforms and evolving consumption behavior. Central to this analysis is the process of consumer decision-making in tourism, with particular attention to accommodation choices. Tourism consumption decisions are inherently complex, shaped by economic, social, psychological, and technological dimensions. Because travel is associated with strong emotions, it is perceived not merely as the consumption of services but as a deeply personal experience, laden with symbolic a6d affective meaning (Hosany et al., 2020) [17]. In the digital environment, this process is further amplified by access to abundant information, social influence, and exposure to reviews and visual content.

Online booking platforms have fundamentally transformed how tourists choose their

accommodation. Whereas travelers once relied on personal recommendations and printed brochures, consumer behavior has shifted toward an analytical model based on comparing prices, evaluating ratings, and reviewing facilities. Studies consistently show that travelers prefer sources of information that provide transparency and allow direct comparisons across options (Filieri & McLeay, 2013) [10].

Accordingly, examining the factors that determine accommodation choice is critical for understanding how online platforms shape consumer behavior. These factors encompass both tangible elements—such as price, location, and facilities—and intangible dimensions, including online reputation, personalized services, and perceptions of safety (Kolesárová et al., 2024) [18].

At the same time, a comprehensive understanding of the decision-making process requires attention to its stages: recognizing a need, searching for information, evaluating alternatives, making the final decision, and engaging in post-purchase evaluation. The model proposed by Middleton & Clarke (2001) [21] provides a relevant analytical framework that can be adapted to the specifics of digital tourism decision-making.

Study objectives

Building on this context, the present study aims to: ***i)*** identify and analyze the key determinants influencing tourists' accommodation choices; ***ii)*** explore how online booking platforms affect consumer decision-making processes; ***iii)*** assess the impact of reviews, ratings, and user-generated content on perceptions and trust in accommodation services; ***iv)*** analyze the behavior of the modern tourist consumer within a dynamic digital ecosystem.

MATERIALS AND METHODS

This study employed a quantitative approach with both descriptive and explanatory purposes, using an online questionnaire as the primary research instrument. This method was selected for its ability to collect data rapidly from a relatively large pool of respondents, as well as for its appropriateness in examining consumer behavior within a digital context.

The questionnaire, designed in Google Forms, comprised 27 questions organized into four main sections: ***i)*** demographic information (age, gender, education level, income); ***ii)*** travel behaviors and habits (frequency of trips, preferred type of accommodation, reasons for booking online); ***iii)*** decision-making criteria in choosing accommodation (price, location, reviews, images, facilities, cancellation policy, payment methods); ***iv)*** use of online booking platforms (frequency, preferred platforms, influence of reviews, trust in ratings).

The survey included both closed-ended questions (single-choice and multiple-choice) and Likert-scale items (five-point scale), allowing for a nuanced examination of the factors shaping booking decisions (Annex 1).

Prior to full deployment, the questionnaire was pre-tested with a pilot group of 10 participants to ensure clarity of wording and logical coherence. Data collection took place between March and May 2025. The survey was distributed via social media channels and through direct invitations in online travel and tourism groups in Romania. A total of 104 valid responses were obtained, all from individuals who had used an online booking platform at least once to select accommodation.

Data were processed and analyzed using Microsoft Excel (Microsoft Corporation, 2023) [20]. Descriptive statistics (frequencies, percentages, means) and simple correlations between variables were employed to highlight significant relationships between respondents' profiles and booking behaviors. The analysis also examined behavioral patterns related to variables such as frequency of platform use, trust in online reviews, and the impact of ratings on purchasing decisions.

The interpretation of results was conducted in relation to the existing body of literature on consumer behavior in the digital tourism environment (Pinto & Castro, 2019) [25], with the aim of embedding empirical findings within a solid theoretical framework.

RESULTS AND DISCUSSIONS

Socio-demographic profile of respondents and travel behaviors

Socio-demographic profile

The sample of 104 respondents reflects a profile that is typical for OBPs users. In terms of age (**Q1**), the 26–35 group is dominant (48.1%), followed by 36–45 (26.9%) and 18–25 (17.3%), while individuals over 45 account for only 7.6%. Gender distribution (**Q2**) is notably uneven, with women representing 73.1% of the sample and men only 26.9%. Educational attainment (**Q3**) is relatively high: 44.2% hold a bachelor's degree, 40.4% a master's degree, and 15.4% completed secondary school, with no respondents lacking at least high school education (Table 1).

This profile suggests a respondent pool with a higher-than-average capacity to critically evaluate digital information. This distribution is consistent with previous findings, which show that OBP adoption tends to be higher among younger, digitally literate, and highly educated consumers (Hien et al., 2024) [15].

Table 1. Socio-demographic distribution of respondents

Variable	Category	N	%
Age	18–25	18	17.3
	26–35	50	48.1
	36–45	28	26.9
	46–55	4	3.85
	Over 55	4	3.85
Gender	Women	76	73.1
	Men	28	26.9
Education	Highschool	16	15.4
	Bachelor's	46	44.2
	Master's	42	40.4

Source: own calculations based on online survey.

Travel behaviour

Respondents are active travelers (**Q4**), with 75% traveling two to three times per year, while 17.3% travel only once annually. A smaller proportion (7.7%) travel monthly or more frequently, indicating that the sample is skewed toward moderately active tourists rather than frequent travelers.

Use of online booking platforms and reasons for booking

Use of online booking platforms

OBPs usage (**Q5**) is widespread, with most respondents accessing platforms two to three times per year or more often (Table 2). This confirms the integration of OBPs into routine travel behavior, a trend also emphasized in the literature (Amaro & Duarte, 2015) [1].

Table 2. Frequency of OBP use

Frequency of use	N	%
2–3 times per year	72	69.2
Monthly	10	9.6
Several times per month+	6	5.8
Once per year	16	15.4

Source: online survey, own processing.

In terms of platform preferences (**Q6**), Booking.com overwhelmingly dominates with 86.5% of responses, followed by the direct websites of accommodation providers (11.5%) and Airbnb (1.9%). Regarding preferred types of accommodation (**Q7**), hotels are the most popular (50%), but a notable share opts for apartments (26.9%) or guesthouses (19.2%).

Reasons for booking online

When asked about their primary reasons for booking online (**Q8**), most respondents highlight convenience and efficiency of the process, alongside access to better prices and discounts, as the central drivers of platform use. Secondary motivations include user reviews and the diversity of available options, pointing to the dual importance of economic benefits and informational capital in shaping decisions (Table 3).

Table 3. Main reasons for booking online

Reason	N	%
Convenience and speed	34	32.7
Better prices and discounts	28	26.9
Variety of options	22	21.1
Other users' reviews	14	13.5
Payment security	4	3.9
Free cancellation option	2	1.9

Source: own calculations based on online survey.

These findings suggest that while economic rationality (price) and functional ease (convenience) remain critical, reputational cues (reviews) also hold a meaningful role, echoing the broader literature on digitally mediated consumer trust (Li et al., 2025) [19].

Online booking platform usage patterns

Regarding the main steps followed in the accommodation selection process (**Q9**), most respondents mention searching for the desired location and filtering by price (40.4%), followed by checking reviews and ratings

(32.7%), and comparing properties based on facilities (17.3%). The analysis of photographs and detailed descriptions is considered a priority by only 9.6% of respondents (Table 4). These findings confirm that price and online reputation represent the initial and most influential decision filters.

Table 4. Main steps in selecting accommodation on online platforms

Step	N	%
Search location and filter by price	42	40.4
Check reviews and ratings	34	32.7
Compare units by facilities	18	17.3
Analyze photos and descriptions	10	9.6

Source: own calculations based on online survey.

When asked about the use of advanced platform features (**Q10**), 57.7% of respondents reported having used interactive maps or virtual tours at least once to support their accommodation choice, while 42.3% stated they had never relied on such tools. This relatively high proportion of users engaging with advanced functionalities highlights the growing importance of visual and interactive elements in the booking experience. However, other research suggests that the overall impact of these tools on final booking decisions is often secondary to more traditional factors, such as price, reviews, and location. In this sense, the findings of our study point to a partial shift in user behavior, where interactive features act less as primary determinants of choice and more as confidence-enhancing mechanisms that complement other decision drivers.

In terms of cross-checking offers (**Q11**), 61.5% of respondents report that they usually compare prices and booking conditions directly on accommodation websites, while 38.5% prefer to finalize reservations exclusively through OBPs. This behavior suggests a cautious attitude among travelers, who seek validation before confirming a purchase, but it also highlights an opportunity for hoteliers to attract customers via their own channels when price differences or added benefits are visible.

In **Q12**, many respondents (61.5%) stated that they usually contact the accommodation after booking, to reconfirm details such as check-in, additional services, or payment validation (Table 5). This practice indicates a residual level of mistrust toward OBPs, suggesting that for a considerable share of users, reassurance is still sought directly from the accommodation provider. Such behavior highlights the persistence of traditional trust-building practices, even in the context of highly digitalized booking environments.

Table 5. Reasons for contacting the accommodation after booking

Response	N	%
Do not contact the accommodation	40	38.5
Reconfirm check-in time	22	21.1
Ask about additional services	18	17.3
Confirm that the booking was made	14	13.5
Confirm that the payment was recorded	10	9.6

Source: own calculations based on online survey.

Determinants of booking decisions and the role of reviews

Decision-making criteria

The analysis of decision-making criteria (**Q13**) reveals that location (M = 4.54), user reviews (M = 4.46), and images/descriptions of the accommodation (M = 4.40) emerge as the most influential factors guiding tourists' choices. Secondary considerations include the facilities provided by the accommodation (M = 4.29) and the available payment options (M = 3.92), while the cancellation policy appears to carry the least weight (M = 3.65) (Table 6).

Table 6. Importance of decision-making factors in online booking (means on a 1–5 scale)

Factor	Mean
Location	4.54
User reviews	4.46
Images and descriptions	4.40
Facilities	4.29
Payment options	3.92
Cancellation policy	3.65

Source: own calculations based on online survey.

This ranking diverges from much of the international literature, where cancellation policies are often emphasized as a critical determinant of trust and booking security (Chen et al., 2011) [6]. The relatively lower importance of this factor in our study may be attributed to the dominance of platforms such as Booking.com, which are perceived to

guarantee sufficient flexibility and contractual safeguards by default. In such contexts, the decision process shifts away from risk-mitigation strategies toward a greater reliance on visual cues (photographs and descriptions) and reputational capital (reviews and ratings).

These findings reinforce the idea that in digitally mature markets, online travel OBPs act as trust brokers, absorbing much of the perceived risk that would otherwise make cancellation policies decisive. In addition, consumers evaluate recency, credibility, style, and consistency when interpreting online reviews, which gives weight to reputational signals over more technical contractual factors (Filieri, 2016) [9].

Influence of reviews

Regarding reviews, 50% of respondents stated that they had chosen accommodation exclusively based on reviews or ratings from the platforms (**Q14**), which confirms the conclusions of the literature on the social power of online ratings (Gu et al., 2023; Park et al., 2021) [12, 23]. However, the influence of negative reviews is also significant: 48.1% of respondents reported that these influenced their decision "strongly" or "very strongly" (**Q15**) (Fig. 1). This shows that, in some cases, negative feedback carries more weight than positive feedback, as emphasized by the theory of informational asymmetry (Park & Nicolau, 2015) [24]. When faced with mixed reviews (**Q16**), respondents adopt selective strategies: some focus on recent or detailed reviews (53.8%), while others look for alternative options (17.3%). This shows that OBP users do not relate passively to ratings but rather develop their own mechanisms for filtering information (Fig. 2).

With regard to the negative aspects in reviews that lead to avoiding an accommodation (**Q17**), cleanliness was most frequently mentioned (80.7%), followed by unsatisfactory facilities (38.5%) and staff attitude (26.9%) (Fig. 3).

The question on the level of trust in online reviews (**Q18**) shows that most respondents position themselves at intermediate or high values on the 1–5 scale, indicating a cautious but optimistic attitude: 32.7% rated it 4, while 25.0% gave the maximum score.

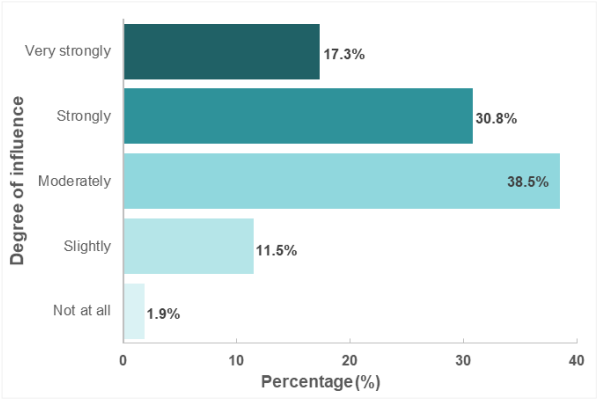


Fig. 1. Degree of influence of negative reviews on accommodation choice
Source: own elaboration based on online survey.

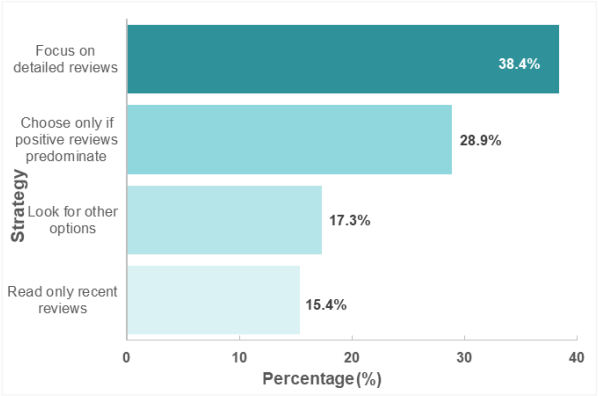


Fig. 2. User strategies when facing mixed reviews
Source: own elaboration based on online survey.

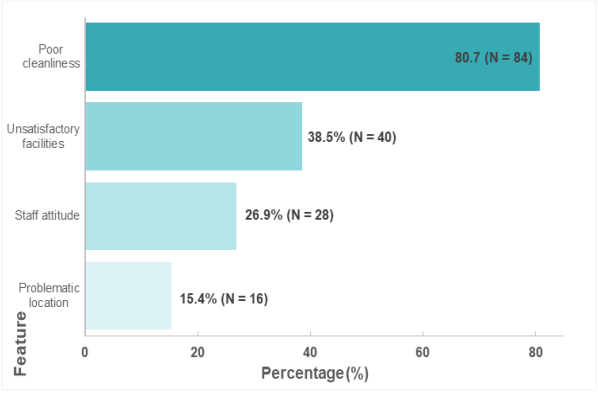


Fig. 3. Negative review aspects leading to accommodation avoidance
Source: own elaboration based on online survey.

Prices, discounts, and the digital interface

Question **Q19** highlights the impact of discounts and special offers: nearly half of the respondents reported being influenced "strongly" or "very strongly", confirming that price sensitivity remains a constant in tourist behavior. However, when compared with the results of **Q8**, it becomes clear that price is not

always the main factor, but rather functions in combination with reviews and the convenience of the booking process.

Perceptions of the booking interface are reflected in **Q20–Q22**. Respondents favor intuitive platforms (32.7%), fast ones (28.8%), and reliable ones (23.1%), while design is considered "important" (40.4%) or "very important" (21.2%). These results align with **Q9** and **Q13**, where visual and interactive elements were frequently mentioned as supports in the decision-making process. The most requested mandatory features are high-quality photographs (65.4%), a user-friendly interface (51.9%), and a clear review section (44.2%), confirming that visual experience and ease of use are critical factors (Fig. 4).

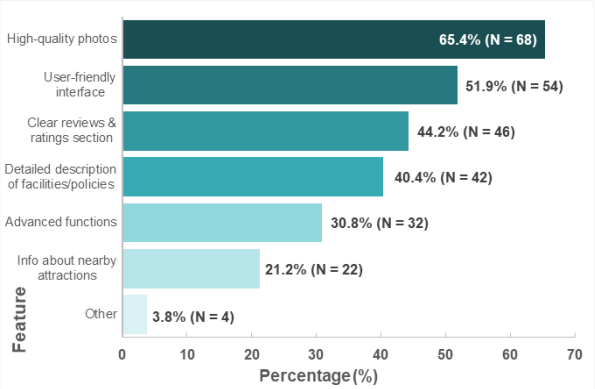


Fig. 4. Essential features of an online booking website
Source: own elaboration based on online survey.

Question **Q23** illustrates the consequences of poor design: more than half of respondents (51.9%) reported that they immediately switch to another platform, while others complete the booking but retain a negative perception. This finding supports the idea that user experience directly influences both trust and customer loyalty (Dabrowski et al., 2014) [7].

Negative experiences and future intentions

Negative experiences when using OBPs

With regard to technical difficulties (**Q24**), only a minority (33%) reported significant problems, suggesting that booking platforms are generally perceived as reliable. However, **Q25** highlights notable negative experiences: the most frequent are discrepancies between images and reality (40.4%) and hidden fees (21.2%), followed by check-in issues (7.7%) or unexplained cancellations. These results resonate with the findings from **Q17**, where cleanliness and facilities were decisive, indicating that informational transparency and visual accuracy remain critical vulnerabilities.

Future usage intentions

As for future intentions (**Q26**), the vast majority of respondents (82.7%) declared that it is "very likely" they will continue to use OBPs, with only a small minority expressing reservations. This strong intention aligns with the observations from **Q6** and **Q9**, where platforms were shown to be deeply integrated into tourist behavior, and parallel checks or occasional negative experiences did not substantially diminish loyalty toward digital channels. Nevertheless, **Q27** reveals that 25% of respondents noted a lack of trust in reviews or previous negative experiences as potential reasons to discontinue using platforms. This finding underscores the centrality of trust in the effective functioning of OBPs, as consistently highlighted in the literature (Ardani et al., 2019) [2].

Inferential statistical analyses

Inferential analyses were employed to move beyond a simple description of distributions and to test hypotheses regarding associations between variables and differences across groups.

The choice of statistical tests followed the logic of the data type: Spearman correlations (ρ) were applied to assess relationships between ordinal variables (e.g., travel frequency, OBP usage, future intention, influence of negative reviews); χ^2 tests of independence were used to examine associations between categorical variables (e.g., age × platform, parallel checking × platform); and t-tests and ANOVA were conducted to verify mean differences between groups (e.g., trust in reviews by gender or age).

The correlation results highlight several clear and robust relationships. Travel frequency is strongly associated with OBP usage ($\rho = 0.719$, $p < 0.001$): the more frequently respondents travel, the more likely they are to rely on online booking platforms. This finding suggests that OBPs are not merely an occasional substitute for direct bookings but rather an integrated component of tourism practices among highly

mobile users. Moreover, travel frequency also emerges as a significant predictor of future intention to use OBPs (ρ = 0.334, p = 0.018), confirming that loyalty to digital platforms is fueled primarily by travel experience rather than strictly by demographic variables (Table 7).

Table 7. Spearman correlations between travel behaviors and OBP usage

Variable pair	ρ (Spearman)	p	Interpretation
Travel frequency× OBP usage	0.719	<0.001	strong, significant
Travel frequency × Future intention	0.334	0.018	positive, significant

Source: own calculations based on online survey.

With respect to online reviews, the analysis revealed that sensitivity to negative feedback is significantly correlated with the overall level of trust in reviews (ρ = 0.496, p = 0.002). In other words, respondents who place greater trust in reviews are also those most influenced by negative comments. At the same time, t-tests and ANOVA showed that trust in reviews does not vary significantly across gender or age groups (p > 0.3), indicating that attitudes toward online reviews are relatively homogeneous within the sample. Furthermore, trust in reviews was not correlated with the intention to continue using OBPs in the future (ρ = –0.008, p = 0.950), suggesting that while reviews shape the selection of specific accommodations, they do not influence the broader reliance on digital booking platforms (Table 8).

The χ^2 analyses confirmed that the choice of booking platform does not vary significantly by age (p = 0.225), nor does the practice of cross-checking offers depend on the platform used (p = 0.241). However, some interesting tendencies emerged: negative experiences were reported more frequently by women (p = 0.079), while younger respondents appeared more likely to encounter technical difficulties (p = 0.090) (Table 9). Although these effects did not reach statistical significance, they may point to subtle differences in risk perception, which could be further explored using larger and more diverse samples.

Table 8. Results of statistical tests on online reviews and intentions to use OBPs

Variable pair	Test	Value	p	Conclusion
Negative reviews × trust	Spearman ρ	0.496	0.002	significant
Trust × gender	t-test	0.56	0.582	no differences
Trust × age	ANOVA	1.19	0.327	no differences
Trust × future intention	Spearman ρ	-0.008	0.950	null

Source: own calculations based on online survey.

Another relevant finding concerns discounts and platform design. The correlations indicate that neither the influence of discounts nor the perception of the interface shows a significant relationship with the intention to continue using OBPs (p > 0.4) (Table 10). This suggests that while discounts and user experience play a crucial role in the immediate selection of accommodation, long-term loyalty to OBPs is driven more by travel habits than by transactional or interface-related factors.

Table 9. Results of χ^2 tests on associations between socio-demographic variables and tourist behaviors

Pair of variables	χ^2	df	p	Conclusion
Age × platform used	10.6	8	0.225	not significant
Cross-checking offers × platform	2.85	2	0.241	not significant
Age × technical difficulties	8.04	4	0.090	tendency
Gender × negative experiences	14.1	8	0.079	tendency

Source: own calculations based on online survey.

Finally, the analysis of the internal consistency of the items related to the choice factors yielded a Cronbach's α of 0.52, suggesting a multidimensional structure of the decision-making process. Respondents simultaneously considered reputational factors (reviews), visual elements (photographs), economic aspects (prices), and contractual dimensions (cancellation policy), without these converging into a single, unified construct.

Table 10. Spearman correlations between discounts, platform design, and future intention to use OBP

Pair of variables	ρ	p	Interpretation
Discounts × future intention	0.108	0.562	not significant
Design × future intention	0.144	0.401	not significant

Source: own calculations based on online survey.

CONCLUSIONS

The findings of this study confirm the pivotal role that online booking platforms play in shaping contemporary tourist behavior. For most respondents, the decision-making process when choosing accommodation is primarily driven by reputational and visual factors—such as user reviews, photographs, and detailed descriptions—alongside traditional criteria like location and price. Notably, negative reviews exert a disproportionate influence on purchasing decisions, supporting the literature that highlights the asymmetric impact of negative information in online environments. At the same time, our analysis reveals that loyalty toward online platforms is not determined by discounts or interface design but is instead shaped by travel frequency and entrenched usage habits. This underscores the idea that OBPs have evolved beyond mere booking tools, becoming part of a broader ”tourist habitus” embedded within consumers’ mobility routines.

At the same time, the study highlights several critical nuances. For instance, while international research often regards cancellation policies as essential, within our sample this factor was assigned relatively low importance. This discrepancy may be explained by the high level of trust placed in dominant platforms, which are perceived as guarantors of transaction security and contractual flexibility. Moreover, the fact that a significant number of respondents reported contacting the accommodation provider even after completing their booking suggests that, despite the trust vested in platforms, there remains a residual need for direct confirmation and personal reassurance. These findings reflect an ambivalence in consumer behavior: on the one hand, reliance on the digital interface; on the other, a persistent caution toward perceived risks.

From a managerial perspective, the findings underscore the critical importance of actively managing online reputation. Given that negative reviews exert a substantial influence on purchasing decisions, accommodation providers must devote greater attention to monitoring feedback and responding promptly and transparently in order to rebuild consumer trust. Furthermore, elements such as high-quality images, user-friendly interfaces, and clear information about facilities are confirmed as non-negotiable features for maintaining both attractiveness and competitiveness in the digital environment.

Nonetheless, several limitations of this study must be acknowledged. First, the relatively small sample size and its non-representative structure—skewed toward women, younger individuals, and respondents with higher education—restrict the generalizability of the findings to the broader population. Second, the data collection method, based on self-reported responses to an online questionnaire, may introduce both selection and response biases. Third, the cross-sectional design of the study does not allow for capturing the long-term dynamics between past experiences and future intentions to use booking platforms. Finally, the modest internal consistency of the items related to selection criteria confirms the multidimensional nature of decision-making but also points to the need for more refined measurement instruments.

Future research directions should include expanding the sample to encompass more diverse population segments, as well as conducting comparative studies across national and international markets. Employing mixed-methods approaches—combining quantitative data with qualitative interviews or content analysis of real reviews—would provide richer insights into consumer behavior. Furthermore, the application of structural models or longitudinal analyses would allow for assessing how negative experiences, platform design, or pricing strategies shape trust and loyalty over time. In this way, future studies could contribute to a more nuanced understanding of the interplay between the

technological and psychological dimensions of the tourist decision-making process.

Annex

Questionnaire

Questions

1. What is your age?
• 18–25 years
• 26–35 years
• 36–45 years
• 46–55 years
• Over 55 years

2. What is your gender?
• Woman
• Man

3. What is your highest level of education?
• Primary school
• High school
• Bachelor's degree
• Master's degree
• Doctorate

4. How often do you travel for tourism purposes?
• Once a year
• 2–3 times a year
• Monthly
• More frequently

5. Which online booking platforms do you use most frequently?
• Booking.com
• Airbnb
• Expedia
• TripAdvisor
• Agoda
• Hotels.com
• Accommodation providers' own websites
• The one offering the best price
• Other

6. How often do you use these platforms?
• Once a year
• 2–3 times a year
• Monthly
• Several times a month or more

7. What type of accommodation do you usually prefer?
• Hotel
• Apartment
• Guesthouse
• Other

8. What is the main reason you choose to book accommodation online?
• Convenience and speed of the process
• Better prices and discounts
• Wide range of options
• Other travelers' reviews
• Payment security
• Free cancellation option

9. What are the main steps you follow when choosing accommodation online?
• Search location and filter by price
• Check reviews and ratings
• Compare facilities
• Review photos and detailed descriptions
• Other

10. Have you ever used advanced features (e.g., interactive maps, virtual tours) when choosing accommodation?
• Yes
• No

11. Do you usually check in parallel whether accommodation providers offer better conditions than online platforms?
• Yes
• No

12.After booking, do you contact the accommodation unit?
• I do not contact
• Check if the booking is confirmed
• Check if the payment is confirmed
• Reconfirm check-in time
• Ask about additional services

13. How important are the following aspects?
(1 = Not important, 5 = Very important)
• Price
• Location
• Reviews
• Images/description
• Cancellation policy
• Facilities
• Payment options

14. Have you ever chosen accommodation solely based on reviews?
• Yes
• No

15. How much do negative reviews influence your decision?
• Very strongly
• Strongly
• Moderately
• Slightly
• Not at all

16. What do you do if you find mixed reviews?
• Read only recent reviews
• Focus on detailed reviews
• Look for other options
• Choose only if positive reviews predominate
• Other

17. What negative aspects make you avoid accommodation?
• Poor cleanliness
• Staff attitude
• Unsatisfactory facilities
• Poor location
• Other

18. On a scale from 1–5, how much do you trust online reviews?
• 1 Not at all
• 2
• 3
• 4
• 5 Very much

19. How much do discounts and special offers influence your decision?
• Very much
• Much
• Moderately
• Little
• Not at all

20. How would you like the booking interface to be?
• Reliable
• Fast
• Intuitive
• User-friendly/**e**mpathetic
• Information-rich

21. How important is the platform's design to you?

- Very important
- Important
- Moderate
- Slightly important
- Not important

22. Which features should be mandatory?
- High-quality photos
- User-friendly interface
- Detailed description of facilities/cancellation policies
- Clear review section
- Interactive maps
- Nearby attractions info
- Other

23. How do you react to a poorly designed booking website?
- I adapt and finalize booking
- Switch to another platform
- Contact the accommodation directly
- Other

24. Have you ever encountered difficulties when booking online?
- Yes
- No

25. What were your most unpleasant experiences with online booking?
- Accommodation did not match photos
- Check-in problems
- Hidden fees
- Cancellation without explanation
- None
- Other

26. How likely are you to continue booking online in the future?
- Very likely
- Likely
- Neutral
- Unlikely
- Very unlikely

27. What would make you stop using booking platforms?
- Lack of trust in reviews
- Higher prices than other channels
- Negative past experiences
- I only use online platforms
- Other

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NEONICOTINOIDS IN THE ROMANIAN AGRICULTURE: BETWEEN NECESSITY AND RISKS

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Abstract

Neonicotinoids are systemic insecticides used in agriculture to treat corn, sunflower and rapeseed seeds, due to their high efficacy against soil pests in the early stages of growth. In the European Union, the use of the main active substances in this class was gradually restricted and subsequently banned for outdoor applications, following the identification of risks to pollinators and biodiversity.In this context, Romania has repeatedly resorted to granting temporary derogations, citing specific agronomic needs and the lack of alternatives with comparable efficacy.This article analyses the use of neonicotinoids in Romanian agriculture from an agronomic, ecological, and legislative perspective to evaluate their benefits and risks, as well as the implications of their elimination for agricultural productivity and farm competitiveness. The study is based on an analysis of scientific publications in the field, statistical data provided by the National Institute of Statistics and official documents issued by European and national authorities. The results indicate a discord between environmental protection objectives and the phytosanitary needs of Romanian farmers, as well as the risks associated with the application of use restrictions in the absence of effective alternative solutions. At the same time, the analysis highlights the importance of specific support measures to facilitate the transition to more sustainable agricultural systems, in line with the objectives of the European Green Deal.

***Key words*:** *Neonicotinoids, environmental protection, sustainability*

INTRODUCTION

In Romania, neonicotinoid use in agriculture expanded after 2007, following the country's accession to the European Union and the subsequent alignment of national phytosanitary regulations with the EU legislative framework. During this period, neonicotinoids were introduced as modern solutions for the protection of crops, especially in the form of seed treatment, being considered effective in combating pests in the early stages of plant development.

Initially, these systemic insecticides were promoted due to their high efficacy and the application method that allowed for the reduction of the number of subsequent treatments in vegetation [16]. Subsequently, their widespread use became a subject of controversy, following the results of studies that highlighted negative effects on pollinating insects and other non-target organisms [13]. These findings led the European Union to adopt, starting in 2013, progressively restrictive measures regarding the use of the main active substances in this class [8].

In general, neonicotinoids are a class of neuroactive insecticides developed in the second half of the 20th century, whose use has rapidly expanded in modern agriculture due to their effectiveness against a wide range of insect pests [9]. Their systemic nature allows the protection of plants in the early stages of vegetation, an aspect considered essential for the stability of crops under conditions of high pest pressure [11].

In Romanian agriculture, neonicotinoids have been used mainly for seed treatment before sowing, especially in spring and autumn crops of major economic importance. The specific pedoclimatic conditions and the constant presence of soil pests have contributed to a high dependence on this type of treatment, which has influenced the position of farmers towards the restrictions imposed at the European level.

Seed treatment for sunflower and corn crops is very important because it provides them with

increased protection against a certain soil pest, considered aggressive for plants in the first days of emergence, namely *Tanymecus Dilacotillis* (Photo 1 - 4). This pest can cause significant damage to crops, reaching the point of reseeding.



Photo 1. *Tanymescus Dilacotillis* on sunflower
Source: Original.



Photo 2.*Tanymescus Dilacotillis* on sunflower
Source: Original.



Photo 3. Corn crop affected by *Tanymecus Dilacotillis*
Source: Original.

In the cultivation of straw cereals, the main pests combated by seed treatment are Delia coarctata (cereal fly),Agriotes spp. (wireworms) and Zabrus teneobriotes (humpback beetle) (Photo 4)



Photo 4. Larva of *Zabrus teneobriotes*
Source: Original.

For rapeseed and corn, researchers from major pesticide companies have now found an alternative for seed treatment, namely cyantraniliprole. The approved commercial product is known as Lumiposa 625 FS.

The new substance has a different mechanism of action than neonicotinoids, affecting receptors involved in the muscle function of insects, which causes an uncontrolled release of calcium and inhibition of muscle contraction, with a direct effect on their feeding capacity. Cyantraniliprole was developed to replace neonicotinoid treatment in the main crops.

In practice, for Romanian farmers, the use of neonicotinoids represents a difficult compromise between the need to ensure effective phytosanitary protection and compliance with European requirements regarding environmental protection and biodiversity conservation [6,14].

This article aims to examine the use of neonicotinoids in Romanian agriculture from an agronomic, ecological and legislative point of view, with a focus on the effects of their restriction on agricultural productivity and the challenges generated by the transition to more sustainable solutions.

MATERIALS AND METHODS

The research was conducted with the aim of interpreting data and information on the use of neonicotinoids and highlighting the impact of their use on the environment and the economic and agronomic implications of their restriction. The analysis also uses sources from specialized scientific literature, reports and opinions of the European Food Safety Authority (EFSA), as well as official documents of the European Commission on risk assessment and the European legislative framework applicable to the use of neonicotinoids.

Official statistical data provided by the National Institute of Statistics, regarding the structure of crops and the dynamics of the beekeeping sector in the period 2020–2024, were also used, along with relevant national legislative and administrative documents. Sources from the specialized agricultural press were used complementary, exclusively to contextualize the public debate and the positions of the main actors involved.

The analysis of the information was done by comparing the European legislative framework and the way it was applied in Romania, especially on the accumulation of temporary derogations that Romania offered to farmers. At the same time, the correlation between the use of neonicotinoids, agricultural productivity and the impact on the environment and biodiversity was also used by analyzing statistical data on cultivated areas and the evolution of the beekeeping sector during the periods of use and restriction of neonicotinoids.

RESULTS AND DISCUSSIONS

In Romanian agriculture, seeds treated with neonicotinoids have been associated with better crop emergence. Under these conditions, farmers report fewer reseeding interventions, which helps to limit production costs, while providing predictability regarding the yields potentially obtained. In practice, this stability is appreciated, especially in medium and large-sized farms.

According to Fig. 1, the areas planted with corn and sunflower remained fairly constant between 2020 and 2024, highlighting the strategic role of these crops in the national agricultural landscape. Maintaining cultivation on extensive areas reinforces the need for specific plant protection measures, especially to mitigate pest attacks shortly after emergence.

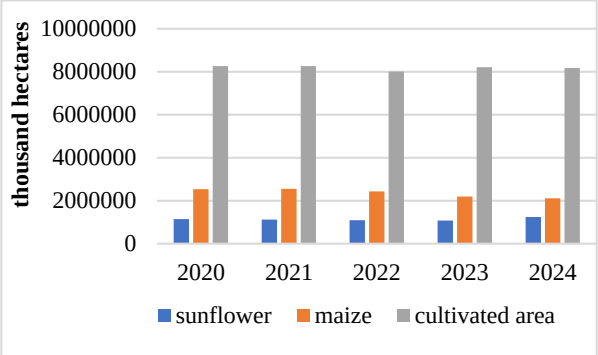


Fig. 1. Corn and sunflower areas cultivated in Romania, in the period 2020 – 2024
Source: INSSE, Tempo online [7].

At the same time, attention to the consequences of the use of neonicotinoids on the environment has been constantly increasing [3,13]. Active compounds such as imidacloprid, thiamethoxam and clothianidin have been used worldwide for over two decades [10]. Although the European Union has imposed restrictions on their use, seed treatments with these substances remain authorised in many countries outside the EU, where they are generally considered safe for human health and the environment when applied according to recommended procedures [2].

These assessments are supported by both regulatory authorities and independent scientific studies. In contrast, a significant number of studies conducted in the European context have reported possible adverse effects of neonicotinoids on pollinating insects, in particular on honeybees. Reported effects include disruptions in orientation, foraging behaviour and homing, which may indirectly influence colony dynamics and viability [6]. These findings were the basis for the European Union's decisions to restrict and subsequently

ban the outdoor use of the main active substances in this class.

In Romania, the beekeeping sector has consistently expressed concerns about the use of neonicotinoids, with beekeepers reporting losses in both bee populations and honey production [2]. However, the statistical data presented in Fig. 2 and 3 indicate fluctuations in the number of bee colonies and the amount of honey produced during the period 2020–2024, variations that can be attributed to a combination of factors, including climatic conditions, diseases specific to the beekeeping sector, agricultural practices and the use of plant protection products. These results highlight the complexity of the relationship between agricultural activities and pollinator population dynamics, making it difficult to directly attribute causality to a single factor.

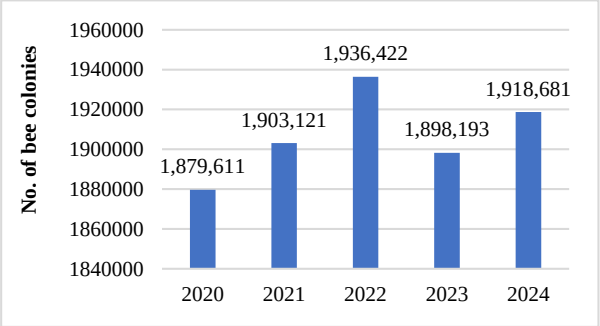


Fig. 2 Number of bee colonies declared between 2020 and 2024
Source: INSSE, Tempo online [7].

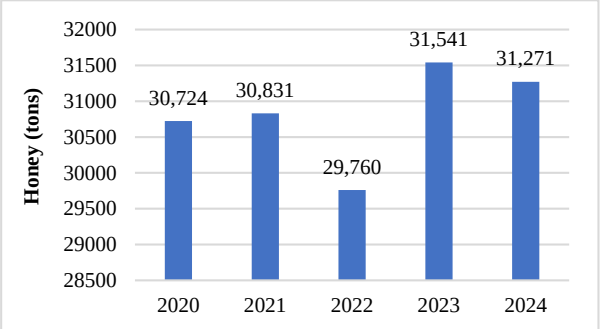


Fig. 3. Quantity of honey produced in Romania between 2020 and 2024 (tons)
Source: INSSE, Tempo online [7].

Another relevant aspect in assessing the impact of neonicotinoids is soil and water contamination [12]. Due to their systemic nature and high persistence, these substances can remain in the soil for long periods, depending on soil and climatic conditions. Repeated application of neonicotinoids can have a long-term effect of accumulating residues in the soil, with an impact on soil microbial communities and, at the same time, on soil fertility and the functioning of agroecosystems. On the other hand, because these compounds are water-soluble, they can move through leaching or surface runoff, increasing the risk of contamination of both groundwater and surface waters. Field studies have found neonicotinoids in surface waters in agricultural regions, sometimes at concentrations that can become harmful to existing fish populations. These observations highlight the importance of monitoring residues and the obligation to adopt sustainable agricultural practices that reduce their dispersion in the environment [10].

At the European Union level, assessments carried out by the European Food Safety Authority (EFSA) have led to the imposition of stricter regulations on the use of neonicotinoids [4,5]. The ban on outdoor application of neonicotinoid active substances reflects the precautionary principle, in order to protect pollinators, biodiversity and ecosystem health. In this regard, the 2013 EU regulations, which were strengthened in 2018, have considerably limited their use in the Member States. In this context, of the European regulation of neonicotinoids, Romania has occasionally granted temporary derogations to protect crops from soil pests when there are no equally effective alternatives [10].

The divergent positions of the actors involved – farmers, beekeepers, national authorities, and European institutions – highlight the difficulty of striking a balance between environmental protection and the competitiveness of the agricultural sector [15]. While some national-level studies suggest that neonicotinoid seed treatments have no significant effects on bees, other research supports the need for an accelerated transition to alternative solutions.

Alternatives to the use of neonicotinoids include a wide range of agronomic and biological practices, such as integrated pest management, crop rotation, the use of cover crops, biological methods and biopesticides. However, the implementation of these

solutions requires additional investments, the adaptation of crop technologies and the accumulation of technical knowledge, which currently limits their widespread application.
From the farmers' point of view, since there are no comparable alternatives to neonicotinoids, especially for corn and sunflower crops, banning their use poses a major challenge. This situation highlights the need for an integrated approach, supported by coherent public policies, applied research and support measures, that would enable a sustainable transition to more environmentally friendly agricultural systems, without compromising the security of agricultural production.

CONCLUSIONS

The final phasing out of the exemptions granted for the use of neonicotinoids in Romanian agriculture represents a major structural change, with significant implications for both agricultural production and environmental protection. This transition has a particular impact on medium and large farms, especially those cultivating maize and sunflower on extensive areas, where soil pest pressure is high and effective short-term phytosanitary protection options are limited.
When chemical alternatives with at least similar efficacy are not available, and pest management systems are not fully developed or widely applied, farmers risk losing their competitiveness through substantial production losses or higher costs for pest control. These effects are important for farms with limited financial or technical capacity, where adapting to new practices is a real challenge.
The transition to neonicotinoid-free agriculture requires technical expertise as well as higher investments in pest surveillance in the context of crop management. In this situation, the absence of coherent support and advisory services can further increase the economic vulnerability of farmers during the transition period.
On the other hand, if we look at it from an environmental and biodiversity perspective, restricting the use of neonicotinoids offers clear benefits, including reduced risks for pollinators (especially bees) and lower contamination of soils and groundwater and surface water (for fish). These improvements support the functioning of agricultural ecosystems and increase their sustainability over time.
At the same time, the elimination of neonicotinoids can encourage the adoption of more sustainable practices, such as diversified crop rotations, the use of organic inputs, and the application of integrated pest management strategies. Such practices can contribute to aligning Romanian agriculture with the European Green Deal and the Farm to Fork strategy. Although this transition involves short-term costs and uncertainties, the long-term benefits - in particular the protection of biodiversity - can form the basis of a more sustainable agricultural system.

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ECOLOGICAL FOOTPRINT - AGROECOLOGICAL PRACTICES AND INNOVATIONS TO LIMIT IT

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Abstract

The ecological footprint is a pressing issue for every sector of activity in modern society. The ever-increasing industrialisation and exploitation of natural resources have a negative impact on the environment and human health. In the domain of agriculture, the implementation of agroecological practices and innovations has emerged as a pivotal strategy for achieving unconventional but effective solutions across various levels. The application of agroecological practices and innovations is considered from the perspective of the ecological footprint. The present study explores the rationales underpinning the adoption of agroecological practices within agricultural holdings. Examples are given of agroecological practices that could minimize the ecological footprint of agriculture. Based on the results of a survey conducted among 150 Bulgarian farmers, it can be concluded that agroecological practices and innovations are being implemented consciously and their popularity among farmers is growing gradually but steadily. They have a positive impact on the agricultural sector, making it sustainable and competitive.

Key words**:** *ecological footprint, agriculture, environmental benefits, sustainable development*

INTRODUCTION

The more modern and technological the world becomes the faster climate change accelerates. All industrial activities generate large amounts of greenhouse gases [1] [18]. The agricultural sector is one of the main sources of greenhouse gas emissions. It is widely believed that the sector contributes significantly to the generation of harmful emissions (carbon dioxide, methane, and nitrogen oxide). For this reason, it is extremely important to work towards reducing pollution and cleaning up the sector through appropriate environmental methods [23].

Agriculture has a major impact on the ecological footprint because the sector is in symbiosis with the environment and dependent on natural resources. Work in the sector involves intensive use of land, water, and energy and generates large amounts of harmful waste [13].

Food production affects climate change, biodiversity loss, and soil degradation, so the need for emission reduction strategies is extremely urgent. [12]. Monitoring and quantifying the ecological footprint of agriculture are important elements in achieving carbon neutrality targets in line with the European Green Deal. Accurate measurement of harmful emissions from agriculture is a major challenge due to the incompleteness and quality of data, inconsistencies in emission factors, and the complexity of supply chains involving multiple stakeholders [19].

Minimizing the negative impact of agriculture on the environment can be achieved by combining several strategies:

-developing standards for sustainable agricultural practices;

-conducting awareness campaigns targeting consumers and producers;

-using financial incentives;

-creating educational programs. [22].

A change and improvement of the practices applied in agriculture is necessary in order for the sector to become sustainable and meet the modern requirements for reducing the ecological footprint [9].

Various studies examine the interaction between agriculture and the ecological footprint and the problems it causes [8] [24]. Some authors believe that sustainable agriculture contributes to reducing the negative impact of the sector on the environment, and meets the food needs of the Earth's growing

population in the context of urbanization and energy transition [7].

The integration of digital solutions, methodologies, and regulatory incentives is crucial to improving the accuracy of carbon emissions reporting. Strengthening consumer engagement and implementing eco-labeling strategies can further stimulate demand for low-carbon food products, supporting the transition to sustainable agriculture. [6]. By reducing emissions and increasing ecosystem capacity, agriculture can contribute to a balanced and sustainable environment. [10] [21]. Economic constraints also have a major impact, as small and medium-sized enterprises typically lack the financial resources and expertise to carry out comprehensive ecological footprint assessments [28].

The exchange of know-how and good practices between stakeholders helps to make agriculture a sustainable and innovative sector. It is important to hold information seminars on possible innovations that farmers in different regions can benefit from. [20] [32].

There are practices that minimize the negative impact of agricultural industrialization on the environment. Agroecology, for example, applies ecosystem concepts to agricultural management and includes practices such as polyculture, agroforestry, and crop-livestock interactions to increase sector revenues by improving the health of agroecosystems [4]. Other approaches and techniques for sustainable agriculture include no-till farming, crop rotation, and appropriate planting times. These methods protect the soil from compaction and control erosion, while its water retention capacity improves agricultural productivity [31].

Some technological practices include precision farming, such as the creation of cold- or drought-resistant seeds, which is associated with increased agricultural resilience [5] [17].

Organic farming uses fewer synthetic chemicals to grow crops and improves soil health and biodiversity, while regenerative farming aims specifically to improve soil health, increase biodiversity, and eliminate the ecological footprint. In livestock farming, various strategies have been introduced to promote resource conservation, such as the implementation of rotational grazing systems and better methods for the disposal and use of animal manure, which is a major source of methane emissions when decomposed. [3] [11] [15].

Smart farming is defined as the implementation of contemporary technologies to optimize the allocation of resources, ensuring their judicious use in the appropriate location and at the optimal moment, thereby reducing losses. The goal is to improve the efficiency of the resources used; for example, water shortages can be limited by introducing efficient irrigation and management methods and appropriate crop selection. [16] [26] [30].

Tree planting and carbon sequestration in soils are important techniques for removing carbon from the atmosphere, which helps combat climate change while promoting ecosystem health. These are some of the main effective agroecological practices, which are necessary to minimize the environmental impact of agricultural production and to balance the production capacity of agriculture with the conservation of natural resources [25] [27].

Changes in consumer behavior are another factor in environmental change. Consumers need to change their habits and educate themselves about healthy eating so that they buy food products that are produced in a safe and environmentally friendly way [2] [14]. There is a change in people's behavior regarding how their food choices affect the environment. This leads to an increase in demand for sustainably produced products, which encourages more producers to use agroecological practices. [29].

MATERIALS AND METHODS

The goal of this article is to assess the effectiveness of agroecological practices and innovations in agriculture in reducing the ecological footprint of such activities.

A review of various agricultural practices that contribute to reducing the ecological footprint is provided. The economic, environmental, and social benefits of applying agroecological practices and innovations are examined, and

problems and options for solving them are identified. The article we are reviewing here makes an analysis of the questions from the author's study, which included 150 Bulgarian farmers who were invited to comment on 54 questions linked to agroecological practices and innovations in agriculture. The study mainly examines the methods farmers use to limit the environmental footprint of the sector.
Table 1 presents the main characteristics of the farmers participating in the survey. The majority of them are male (62.3%), mainly between 31-45 (36.9%) and 46-60 (33.6%) years of age. In terms of education, only 5.7% have a specific university degree in agriculture. Professional experience in the sector is divided almost equally between the four groups, but if a comparison is to be made, farmers with less than five years' experience are in the majority (27.9%).

Table 1. Socio-demographic characteristics of farmers participating in the survey

Sex			
Male		Female	
62.3%		37.7%	
Age			
up to 30	31 – 45	46 – 60	over 60
16.4%	36.9%	33.6%	13.1%
Education			
High school	Bachelor's /Master`s Degree	Master's degree in agriculture	
45.9%	48.4%	5.7%	
Professional experience in the sector			
up to 5 years	6 – 10 years	11 – 20 years	over 20 years
27.9%	22.1%	25.4%	24.6%

Source: Calculations based on data from own survey.

The data in Table 2 describe the farms surveyed. Crop farms predominate (73%), located in the South Central Region (40.2%) and the Northeast Region (36.9%). The standard output of the holding is mainly 8,000 - 15,000 (31.1%) and 15,000 - 25,000 (22.1%). In terms of the labor force employed, it is clear that 93.4% of the farms employ up to five people.

Table 2. Main characteristics of the agricultural holdings participating in the survey

Region of activity in Bulgaria							
North Central		Northeast		Southwest		South Central	
0.8%		36.9%		22.1%		40.2%	
Specialization							
Crop farming		Livestock farming		Mixed			
73%		8.2%		18.9%			
Standard output of the holding (SO)							
2,000 - 4,000	4,000 - 8,000	8,000 - 15, 000	15, 000 - 25, 000	25, 000 - 50, 000	50, 000 - 100, 000	100, 000 - 250, 000	over 250, 000
3.3%	19.7%	31.1%	22.1%	11.5%	7.4%	2.5%	2.5%
Number of employees in the holding							
up to 5		6 – 20		21 – 40		over 40	
93.4%		4.9%		0.8%		0.8%	

Source: Calculations based on data from own survey.

RESULTS AND DISCUSSIONS

Although the study does not include measurements of specific economic parameters (costs, revenues, profitability), farmers' responses allow for informed conclusions to be drawn about the perceived economic impact.
Over a third of respondents (34.4%) link the use of agroecological practices to lower operating costs, like saving water, fertilizers, fuel, and pesticides. 30.3% of respondents indicate that their yields have increased as a result of the implementation of sustainable agricultural practices such as composting, cover crops, or precision irrigation. This is an indirect indicator of improved farm profitability.
There are also signs of increased competitiveness – farmers report improved product quality, which enables them to achieve better market outcomes, especially on local markets and in the organic segment. Although only 13.9% of respondents cited subsidies as a motive, it is precisely independently implemented innovations and environmental solutions that are perceived as a path to long-term sustainability and independence from external funding.
Therefore, from the farmers' point of view, the economic effects of agroecological practices are not only environmental, but also have a

positive impact on the structure of costs, yields, and market stability.

Agroecological practices are gradually but steadily establishing themselves as an effective and modern solution in Bulgarian agriculture. More and more farmers are placing their trust in these methods of farm management and operation. The most common reasons for using agroecological practices are presented in Table 3.

It is significant that environmental protection (which includes minimizing the ecological footprint) is the most important reason for using agroecological practices – 74,6%. This may be due to farmers' greater awareness of the harmful effects of agricultural production and the realization that flora and fauna are closely interrelated and that if one is polluted, the other will inevitably suffer. The return of young and educated people to the sector is also having a positive impact.

The share of agroecological practices for improving soil quality and composition is also high – 68.9%. It is a well-known fact that fertile soil produces rich harvests, which is economically beneficial and the goal of anyone involved in agricultural production, including Bulgarian farmers.

Relatively equal attention is paid to reducing costs and improving product quality, with 34.4% and 33.6% of the farmers surveyed citing these reasons as factors for using agroecological practices on their farms.

Higher yields were also reported by about 30% of farmers in response to the question. The relatively low percentage can be explained by the fact that many farmers consider soil improvement and high yields to be complementary factors and have chosen the more general answer, namely soil improvement.

The least common reason for implementing agroecological practices on the farm is support from programs – 13.9%. It should be noted that additional funding and subsidies for organic production, etc., are not a driving force for the use of agroecological practices. Care for the environment, the quality of the products produced, food security, and the health of the population are a matter of conviction and principles rather than financial opportunity.

Financial support is an additional bonus for organic production, not a primary goal, because a farm that cannot function independently is not competitive in today's demanding market and, in that sense, is better off not operating.

Table 3. Reasons for implementing agroecological practices

Agroecological practices	**% of implementation**
Environmental protection	74.6
Soil improvement	68.9
Cost reduction	34.4
Quality improvement	34.4
Higher yields	30.3
Support from programs	13.9

Source: Calculations based on data from own survey.

The analysis of empirical data from a survey of 150 farmers reveals interesting trends regarding the degree of implementation and perceived benefits of agroecological practices. Of the farmers who participated in the survey, 68% of respondents use at least one sustainable agroecological practice. Around 41% of respondents have introduced more than two parallel practices, with the most common combination being waste recycling, crop rotation, and optimized irrigation. Farmers who apply a wider range of practices report better production efficiency and sustainability, especially for crops such as cereals and vegetables.

Over 70% of respondents say they plan to expand the application of agroecological practices, confirming their positive assessment of the impact of the measures already implemented.

The most common agroecological practices used by Bulgarian farmers to minimize their ecological footprint are:

-Recycling farm waste (48%),

-Reducing uncontrolled use of water resources from water sources (47%), which shows that farmers perceive these measures as directly related to their daily activities and the possibility of a quick effect.

Less commonly used are crop rotation (3%), use of biological plant protection products (1%), and measures for prevention and control of the production process, which may be due to the need for higher investments and/or lack of sufficient information.

Farmers who implement these combined practices report:

-A reduction in fertilizer and pesticide costs of 12–15% on average;

-A 5–8% increase in yields for crops such as tomatoes, wheat, and sunflowers due to improved soil structure;

-Improved long-term sustainability of cultivated areas by preventing erosion and salinization;

-Better use of labor—farmers report an average 9% reduction in labor costs as a result of technological optimization and precision farming.

There is a positive relationship between the number of agroecological practices implemented and farmers' satisfaction with the results, with over 70% of them planning to expand the environmental measures they apply over the next three years.

Other agroecological practices include the use of biological products for plant protection, crop rotation, and prevention and control of production (Fig. 1).

Figure 1 shows that the last three agroecological practices are implemented to a very limited extent compared to recycling and proper use of water resources. A possible explanation for these results may be the fact that agricultural waste is generated daily and in large quantities, so farmers are forced to find ways to eliminate it, and recycling is one of the best options for this because it allows something that is no longer needed to be reused and have a positive impact on the farm.

The application of agroecological practices leads to a multifaceted economic effect at the micro and macro levels:

-At farm level: farmers who have implemented precision irrigation reduce their water costs by up to 20% per year, while the use of biological products reduces chemical costs by 15–18%.

-Market value: products produced to environmental standards are sold at prices 10–25% higher on local markets and in organic shops, especially for fruit and vegetables.

-Economic sustainability: practices such as crop rotation and organic fertilization reduce the long-term risk of soil degradation and ensure more sustainable yields, increasing farm income by up to 12% over a five-year period.

-Indirect savings: through reduced fuel use, optimized waste management, and fewer plant diseases, farmers reduce their overall operating costs by about 8–10%.

The implementation of agroecological practices has been demonstrated to yield macroeconomic benefits, including the creation of sustainable employment opportunities, the reduction of health expenditures associated with pesticide exposure, and the promotion of the development of sustainable local markets.

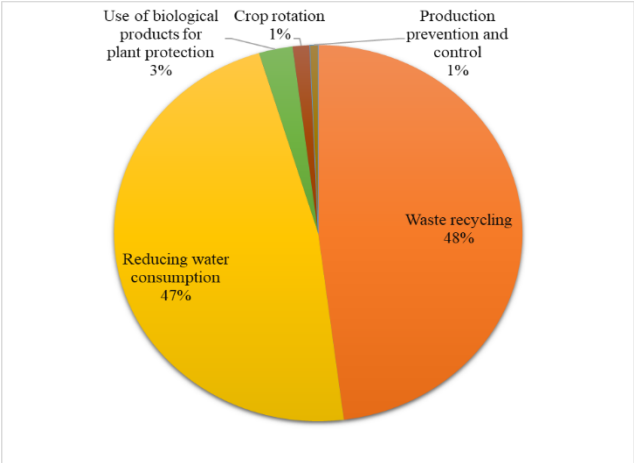


Fig. 1. Agroecological practices to minimize the ecological footprint
Source: Results from field survey.

Farmers apply the selected agroecological practices simultaneously or in stages, continuously or cyclically, depending on the specific characteristics and financial capabilities of each individual farm.

It has been observed that farmers who combine more than one practice - such as waste management, water-saving technologies, and biological agents - often report improved soil quality, healthier crops, and better control over production costs. Although the study did not collect quantitative economic indicators, 34.4% of respondents directly linked the

implementation of agroecological practices to reduced costs, and 30.3% to higher yields, indicating a positive economic impact as assessed by the farmers themselves. This perception is particularly strong among younger and more educated farmers, as well as among those who have access to additional training or information campaigns.

However, farmers have a positive attitude towards agroecological practices and innovations. They also recognize the importance of environmental protection measures and sustainable agriculture, because the quality of food produced can improve or worsen people's health. Over 70% of respondents stated their intention to expand the application of environmental measures, confirming that the practices introduced are perceived as sustainable and effective in the long term. This is an important prerequisite for the development of green and competitive agriculture in Bulgaria.

The need for food security is an extremely important issue that concerns the agricultural sectors and policies of every country.

CONCLUSIONS

Climate change and environmental protection are pressing issues, and special policies and measures are being developed worldwide to address them. Agriculture, as a sector of every country's economy, is also seeking solutions to these problems.

Within this framework, the focus is on agroecological practices and innovations. These are establishing themselves as effective means of achieving sustainable, profitable, and environmentally responsible agriculture. The results of a survey of 150 Bulgarian farmers confirm that there is a real and growing commitment to the application of environmentally friendly management methods. Over two-thirds of those surveyed use agroecological practices, and more than 70% plan to expand them. The practices implemented - including waste recycling, rational use of water resources, and crop rotation - not only reduce the ecological footprint but are also perceived by farmers as economically beneficial. Respondents report improved soil quality, higher yields, and lower production costs, showing that sustainable practices can be a competitive advantage, not just a moral choice.

Although external funding (in the form of subsidies or programs) is not a primary motivation, farmers expect more stable and adequate support mechanisms. This includes guarantees for market access for organic products, protection from unfair competition from imported products, and access to education and information.

A good approach would be to direct most of the subsidies towards activities involving agroecological practices, thereby giving small farms and young farmers an additional incentive to take advantage of scientific advances in environmental protection.

In this regard, it is advisable to develop targeted policies that:

-Stimulate the introduction of agro-environmental innovations through linked support;

-Encourage young farmers to adopt sustainable practices;

-Support digitization and access to modern technologies;

-Build active networks for the exchange of good practices between farms;

-Strengthen the link between scientific research and the real agricultural sector.

Farmers need to be given greater guarantees when participating in agri-environmental measures. Mechanisms should be put in place to protect their organic or biological production from imported products, so that local producers have an incentive to continue farming.

Agroecology should not be seen merely as an alternative to conventional agriculture, but as a logical development towards a sustainable model that takes into account the limited nature of natural resources, the need for high-quality food, and the preservation of biodiversity.

Agroecological practices are a means for more farmers to switch to more environmentally friendly and efficient methods of growing crops and farm management, which is a

prerequisite for building a circular economy and a sustainable future for agriculture.

A very important aspect in reducing the ecological footprint is raising awareness and discussing the issue among a wide range of stakeholders, including governments, public administrations, scientific organizations, research centers, independent organizations, foundations, cooperatives, startups, etc.

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ANALYSIS METHODS AND MODELS OF GRAPEVINE YIELD VARIATION AS DECISIONS SUPPORT TOOLS IN VINEYARD MANAGEMENT

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Abstract

The specifics of the vineyard, and the large amount of information, require the identification of methods and models that can efficiently evaluate the contribution of productivity parameters to yield formation for the sustainability of vineyard plantations. The study comparatively analyzed the productivity elements and yield of 15 local grapevine cultivars for red wines (RWC1 to RWC5), for white wines (WWC1 to WWC5), and for fresh consumption (FCC1 to FCC5). The study was conducted in Alba County, Romania. The average grape berry weight (GBW, g), the number of grapes per bunch (GNB, number), the average weight of a grape bunch (GBuW, g), and the yield per plant (Y, kg plt^{-1}) were evaluated. Based on PCA, the first two components explained 93.225% of the total variance. The analyzed parameters showed differentiated action, in sense and intensity, in relation to the principal components (e.g. GBW positive action in PC2, r = 0.820; Yplt positive action in PC3, r = 0.812. Cluster analysis grouped the cultivars into two distinct clusters, based on Euclidean distances (Coph.corr = 0.869). Regression analysis generated mathematical and graphical models (3D, isoquants) that described the variation in yield (Yplt) in relation to the considered parameters (e.g. R^2 = 0.795, P = 0.006 in relation to GBW and GNB; R^2 = 0.789, P = 0.0071 in relation to GBW and GbuW; R^2 = 0.802, P = 0.0053 in relation to GNB and GBuW). The results obtained provide valuable scientific and practical information for optimizing technologies and can represent decision support tools in vineyard management.

Key words: *grapevine, horticultural ecosystems, mathematical models, multivariate analysis, vineyard management, yield*

INTRODUCTION

The wine sector is of particular importance in the global, European and Romanian economy, through specific wine products and its high market share [9, 23, 31, 35].
Grapevine (*Vitis vinifera* L.) comprises a great diversity of genotypes (varieties, cultivars, local populations), with high ecological plasticity [5, 36]. Numerous grape varieties are cultivated in the world for red wines, for white wines, for fresh consumption, for raisins, etc., in different cropping systems and with specific quality indices of grapes and wine products [1, 4, 7, 20, 27].
The wine sector also represents an important component in the preservation of local traditions, with a positive impact on tourism and agro tourism [14].
Technological practices in wine vineyards are adapted to the type of plantations, the cropping system, the specifics of the varieties, the morphology of the land, the soil conditions and the climate in the wine-growing area, in order to increase the yield and quality of wine products [3, 33, 34, 39].
Grapevine productivity parameters were analyzed in relation to biological material, crop system, soil conditions, climatic conditions, technology elements [18, 37]. Viticultural technologies ensure a balance between productivity parameters and vegetative growth in the vine, to ensure the yield and quality of grapes, for the sustainability of vineyard plantations [13, 17, 26].
The yield and quality indices of the vine are

important for wine products, for the profitability of wine farms and winegrowers [1, 12, 19, 22].
Vineyard management analyzes and adjusts viticultural technologies to optimize yield, quality products, and the market for wine products [6, 8, 28, 32].
Different methods, models and indicators have been promoted in studies and analyses in viticulture, grape production, and the quality of wine products to explain the formation and quality of grape production in relation to natural and technological factors [2, 11, 24, 30].
The study analyzed fifteen local grape cultivars for red wines, white wines and fresh consumption, based on productivity and yield parameters to evaluate analysis methods and yield variation models, useful as support tools in vineyard management decisions.

MATERIALS AND METHODS

The study was conducted in Alba County, Romania (Figure 1), between 2020 and 2022. Fifteen local grapevine cultivars were considered in the study: red wine cultivars - RWC ('Pleoapa' – RWC1, 'Vechi de Ighiu' – RWC2, 'Izabela de Ighiu' – RWC3, 'Rosu rezistent' – RWC4, 'Cabernet Sauvignon' – RWC5); white wine cultivars - WWC ('Sard I' – WWC1, 'Ruginiu de Alba' – WWC2, 'Busuioaca de Ighiu' – WWC3, 'Aromat alb' – WWC4, 'Feteasca Regala' – WWC5); fresc concumption cultivars - FCC ('Mare timpuriu' – FCC1, 'Precupeasca' – FCC2, 'Butuc alb' – FCC3, 'Fragă' – FCC4, 'Chasselas doré' – FCC5).

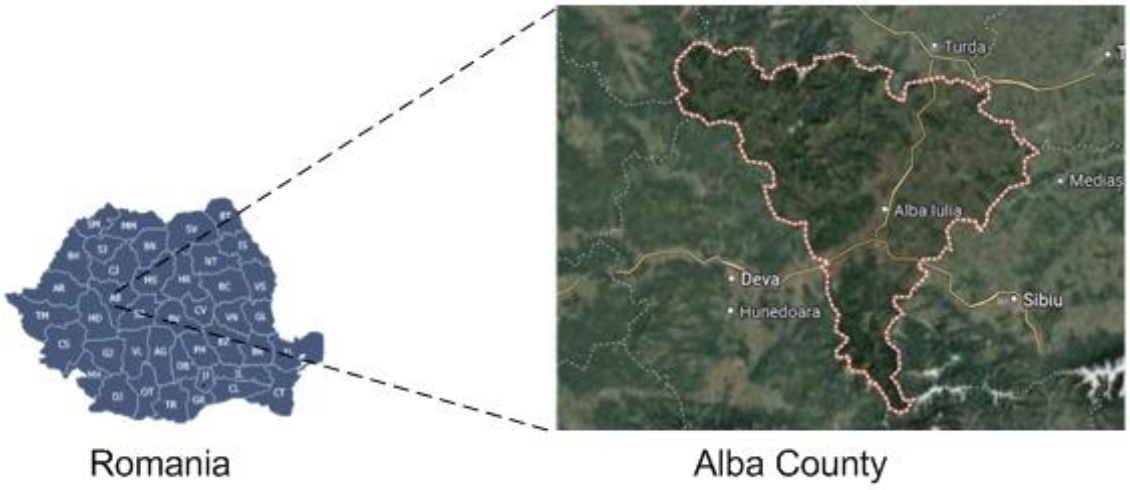


Fig. 1. Study location, Alba County, Romania [40]
Source: Original figure.

The plantation system was high trellis management, Guyot pruning type with raised head. The vine plants were spaced 2 m between rows, and 1 m between plants per row, with a density of 5,000 plants ha^{-1}.
A conventional cultivation technology was used, with a minimum level of intervention. Soil maintenance was done by milling and mowing, alternatively.
A plant protection system was applied with three treatments: treatment I (period 15 – 20 May, product Champ 77 WG, 2 kg ha^{-1}, concentration 0.2%); treatment II (period 15 – 20 June, product Armetil Cobre, 2.5 kg ha^{-1}, concentration 0.25%); treatment III (period 15 – 20 July, product Kumulus, concentration 0.3%).
During the vegetation period, manual work was carried out to maintain the shoots by tying and pinching, end of BBCH stage 7 - beginning of BBCH stage 8 [25].
The climatic conditions during the study period, in terms of thermal and rainfall regime, are presented in Table 1.
Grape samples were harvested at full maturity, 89 BBCH code (Lorenz et al., 1995), for all three categories of grape cultivars.
The mean grape berry weight (GBW, g), the

number of grapes in the bunch (GNB, no), the mean weight of a grapes bunch (GBuW, g), and the yield per plant (Y, kg plt^{-1}) were evaluated. Grape weighing was done with a technical laboratory balance, accuracy ±0.02 g. To determine grape berry weight (GBW, g), the berries were weighed with an analytical balance, Kern ABT 320-4NM (±0.0001 g).

Table 1. Climatic conditions during the study period

Year	Month	Temperature variation interval				Mean of minimum temperature	Mean of maximum temperature	Mean temperature	Rainfall
		Minimum temperature		Maximum temperature					
		Low	High	Low	High				
		(°C)							(mm)
2020	January	-10	0	-3	9	-4.16	3.00	-0.58	3.90
	February	-8	8	4	16	-0.13	10.45	5.16	19.20
	March	-6	9	2	22	1.52	13.52	7.52	17.40
	April	-7	13	10	26	1.90	19.93	10.92	6.20
	May	3	13	6	29	7.74	21.22	14.48	28.80
	June	6	18	20	33	14.70	26.23	20.47	145.10
	Iuly	8	19	24	33	14.90	28.61	21.76	52.20
	August	12	20	28	34	16.32	30.42	23.37	90.40
	September	9	16	15	32	12.13	26.77	19.45	15.80
	Octomber	1	18	11	27	8.36	18.06	13.21	70.00
	Nvember	-3	11	1	17	2.67	8.87	5.77	14.50
	December	-6	6	4	17	1.51	7.78	4.65	19.40
2021	January	-9	6	-0.77	14	-1.00	5.23	2.22	48.20
	February	-12	2	-4	20	-0.62	9.69	4.54	43.20
	March	-7	5	5	19	-1.23	10.97	4.87	34.50
	April	-6	12	7	22	3.00	14.53	8.77	34.20
	May	3	13	16	28	8.13	21.13	14.63	59.40
	June	6	20	21	37	13.30	29.45	21.38	16.40
	Iuly	14	21	27	38	18.16	32.71	25.44	55.90
	August	8	22	18	38	14.94	29.77	22.36	49.10
	September	2	17	14	30	10.40	24.60	17.50	19.20
	Octomber	-1	12	11	25	4.74	17.22	10.98	22.40
	Nvember	-3	12	7	25	1.93	12.37	7.15	61.90
	December	-7	4	1	14	-0.79	5.59	2.40	74.30
2022	January	-16	4	-1	14	-4.32	3.74	-0.29	278.90
	February	-4	4	3	15	-0.32	9.71	4.70	14.00
	March	-9	8	4	22	-2.51	12.00	4.74	5.50
	April	-3	9	8	24	2.87	16.57	9.72	44.60
	May	2	14	17	30	9.58	24.61	17.10	34.00
	June	9	18	28	38	14.40	30.67	22.53	16.40
	Iuly	8	21	25	40	15.87	32.52	24.19	9.80
	August	13	21	24	37	16.90	31.68	24.29	59.50
	September	4	19	12	30	11.97	21.93	16.95	169.10
	Octomber	0	14	15	25	8.03	19.29	13.66	18.70
	Nvember	-2	11	6	21	3.87	11.97	7.92	46.60
	December	-5	10	1	15	0.11	8.41	4.26	55.70

Source: Alba Iulia weather station [41].

The workflow, in relation to the purpose of the research, was designed by the authors according to the diagram in Figure 2.

Multivariate analysis (PCA) was used to find out the level of correlation of grapevine cultivars with productivity parameters and yield, as biplot.

Multivariate analysis also explained the level of variance in the experimental data, based on principal components, and component loadings.

Cluster analysis was used to find out the cluster association of genotypes based on productivity and yield parameters. SDI (Similarity and Distance Indices) values were calculated to find out the value expression of the level of similarity between grapevine cultivars.

Regression analysis was applied in order to find out the contribution of productivity parameters, as a direct and interaction effect, to the formation of yield.

For the analysis and statistical processing of experimental data, dedicated software [15, 16, 38] were used.

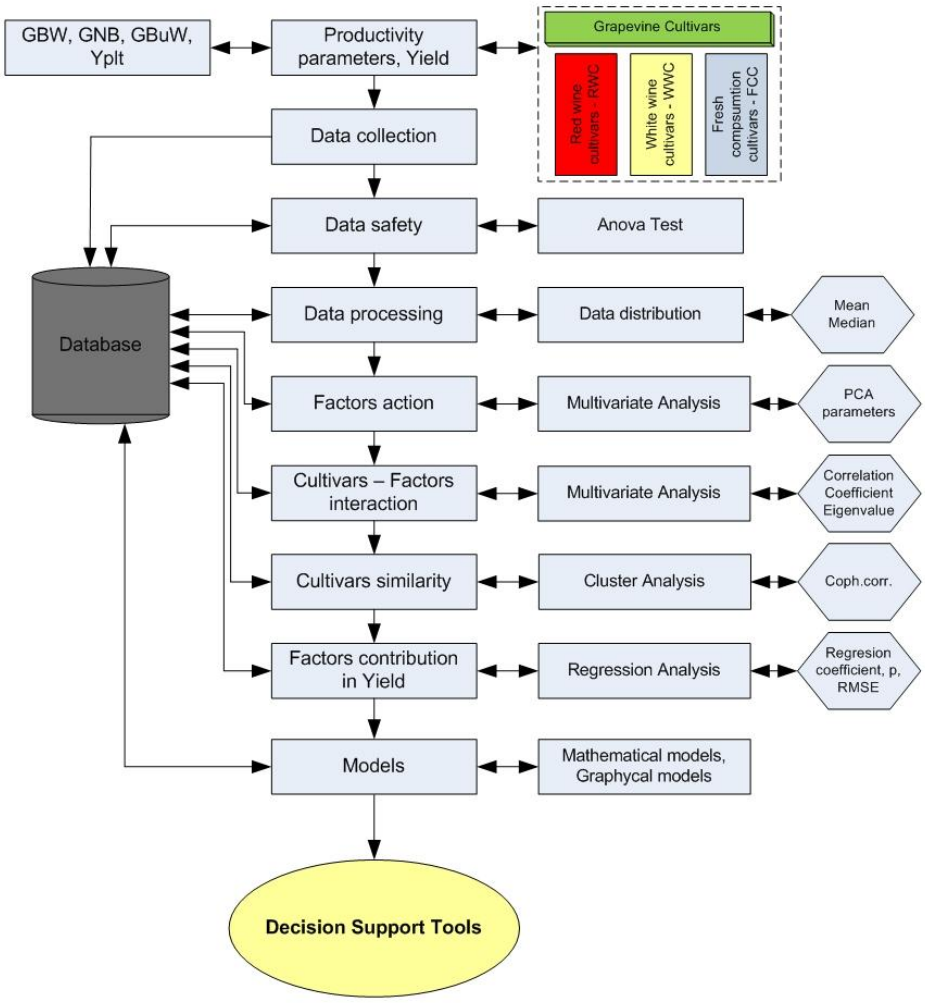


Fig. 2. Flowchart diagram
Source: Original.

RESULTS AND DISCUSSIONS

Fifteen local grape cultivars were comparatively analyzed in this study. The cultivars were grouped into three categories, red wine cultivars (RWC1 to RWC5), white wine cultivars (WWC1 to WWC5), and fresh consumption cultivars (FCC1 to FCC5). The values of the productivity parameters (GBW, GNB, GBuW), and the yield per plant (Yplt), recorded in the experiment, are presented in Table 2.

The experimental data presented statistical reliability, according to the results of the ANOVA Test, Alpha = 0.05 (Table 3).

The GBW parameter showed values between 1.15±0.17 g (RWC5) and 3.13±0.17 g (RWC3). The GNB parameter showed values between 23.30±8.70 grains (RWC2) and 145.21±8.70 grape berries (WWC2).

Table 2. Parameter values for local grapevine cultivars

Cultivars	Cultivar Code	GBW	GNB	GBuW	Yplt
		(g)	(no)	(g)	(kg plt^{-1})
'Pleoapa'	RWC1	3.12	35.61	101.10	2.31
'Vechi de Ighiu'	RWC2	3.01	23.30	70.07	1.36
'Izabela de Ighiu'	RWC3	3.13	33.91	105.20	1.74
'Rosu rezistent'	RWC4	1.72	56.90	98.07	2.35
'Cabernet Sauvignon'	RWC5	1.19	96.61	115.20	2.22
'Sard I'	WWC1	1.91	96.80	185.30	2.88
'Ruginiu de Alba'	WWC2	1.35	145.21	196.08	3.10
'Busuioaca de Ighiu'	WWC3	2.13	51.60	110.20	2.26
'Aromat alb'	WWC4	1.42	79.57	113.07	2.68
'Feteasca Regala'	WWC5	1.57	80.90	127.10	2.76
'Mare timpuriu'	FCC1	2.30	106.51	245.02	2.97
'Precupeasca'	FCC2	1.81	38.90	70.20	2.43
'Butuc alb'	FCC3	1.52	42.71	64.08	2.05
'Fragă'	FCC4	1.32	66.13	85.10	2.52
'Chasselas doré'	FCC5	2.11	89.50	189.03	2.69

Source: Original data.

Table 3. ANOVA Test results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	158,666.2	3	52,888.76	52.3434	2.96E-16	2.7694
Within Groups	56,583.49	56	1,010.42			
Total	215,249.7	59				

Source: Original data.

The GBuW parameter showed values between 64.08±13.92 g (FCC3) and 245.02±13.92 g (FCC1). The yield, Yplt, showed values between 1.36±0.12 kg plt^{-1} (RWC2) and 3.10±0.12 kg plt^{-1} (WWC2).

According to the multivariate analysis, the main two components explained 94.23% of the total variance. The component loadings are presented in Table 4, and the PCA diagram (Figure 3) presented the distribution of grape cultivars in relation to the determined parameters.

Table 4. Component loadings

	PC 1	PC 2	PC 3	PC 4
GBW	-0.353	0.820	0.153	0.425
GNB	0.574	0.023	-0.531	0.623
GBuW	0.487	0.572	-0.190	-0.632
Yplt	0.556	-0.005	0.812	0.179

Source: Original data

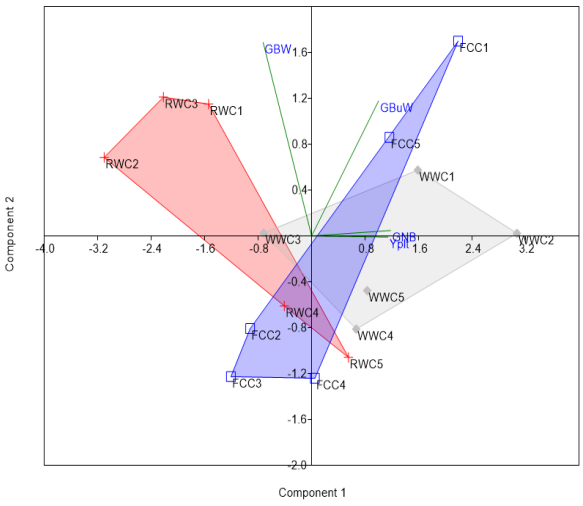


Fig. 3. PCA diagram regarding the distribution of grape cultivars in relation to determined parameters
Source: Original figure.

In relation to PC1, the GBW parameter showed negative action (r = -0.353), and the other parameters showed positive action. In relation to PC2, the yield (Yplt) showed negative, negligible action (r = -0.005), and the other parameters showed positive action. In relation to PC3, two parameters showed negative action, GBN (r = -0.531) and GBuW (r = -0.190), and the other parameters showed positive action. In relation to PC4, the GBuW parameter showed negative action (r = -0.632), and the other parameters showed positive action.

In the group of red wine cultivars (red field in Figure 3), RWC3 and RWC1 presented a correlated positioning with the GBW parameter, and the others were positioned independently of the determined parameters. Within the group of white wine cultivars (white-gray field in Figure 3), WWC2 presented a close correlation with the GNB parameter. The other cultivars presented an intermediate positioning between certain parameters (e.g. WWC1) or an independent position.

Within the group of fresh consumption cultivars (blue field in Figure 3), FCC1 was positioned closely correlated with the GBuW parameter, followed by the FCC5 cultivar. The other cultivars were positioned independently of the considered parameters.

The cluster analysis generated the clustering dendrogram of the cultivars based on Euclidean distances, Coph.corr. = 0.869 (Figure 4).

The studied grape cultivars were grouped into two distinct clusters, with several sub-clusters. The local grape cultivars were associated in different cluster combinations, in relation to the classification category (cultivars for red wines, white wines, or for fresh consumption). The highest level of similarity was recorded between RWC1 and RWC3 (SDI = 4.47).

In relation to the analyzed parameters, two clusters resulted, one cluster that included GNB and GBuW parameters, and the other cluster included the GBW parameter and yield (Yplt), with a high level of similarity.

In the general analysis of the data, a high level of similarity was recorded between RWC1 and RWC3 (SDI = 4.47), both cultivars for red wines. In the analysis by cultivar groups, at the level of the group of red wines cultivars, a high level of similarity was recorded between

RWC1 and RWC3. At the level of the group of white wines cultivars, a high level of similarity was recorded between WWC4 and WWC5, SDI = 14.09. At the level of the group of fresh consumption cultivars, a high level of similarity was recorded between FCC2 and FCC3, SDI = 7.22.

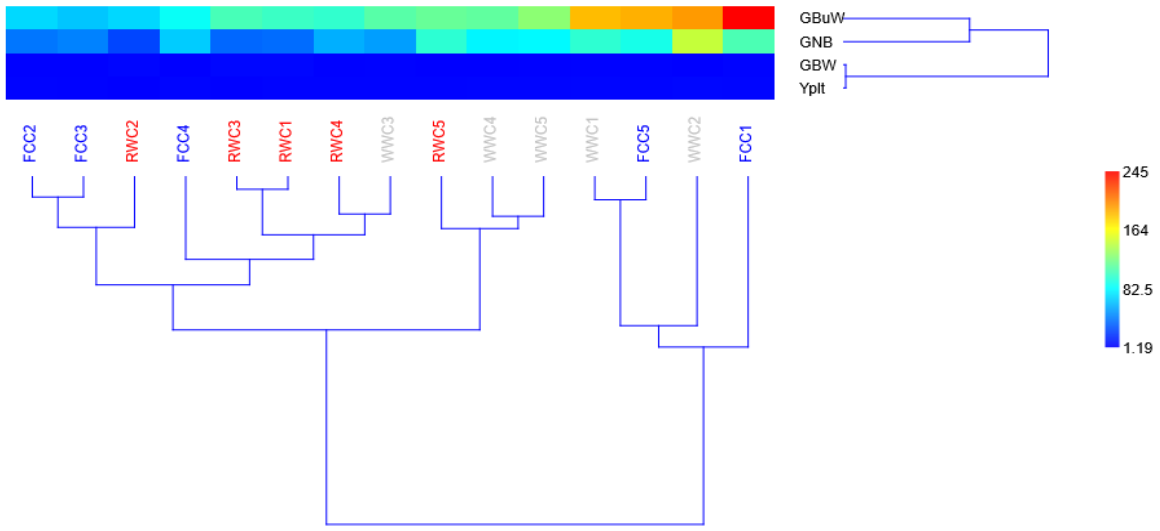
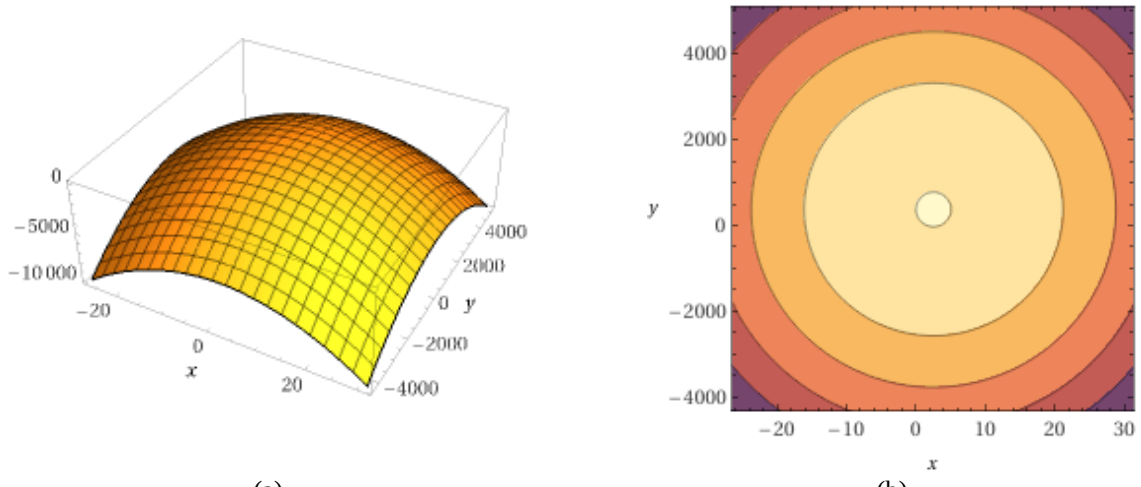


Fig. 4. Cluster dendrogram of local grape cultivars and parameters
Source: Original figure.

Regression analysis was used to evaluate the contribution of the parameters, as direct and interaction an effect, to the mean weight of grape bunches and yield per plant. The variation of the GBuW parameter in relation to GBW and GNB was described by equation (1) under conditions of $R^2 = 0.998$, F = 1342.674, P<0.001, RMSE = 1.905, Figure 5.

$$GBuW = a\,x^2 + b\,y^2 + c\,x + d\,y + e\,xy + f \qquad (1)$$

where: GBuW – mean weight of a grapes bunch; x – GBW; y – GNB; a, b, c, d, e, f – parameter of equation (1); a = -5.87417204; b = -0.000234; c = 28.290093; d = 0.184511; e = 0.920650; f = -32.894182



(a) (b)

Fig. 5. Variation of the GBuW parameter in grapevine cultivars, in relation to GBW (x – axis), and GNB (y – axes); (a) – 3D model; (b) model in isoquants format
Source: Original figure.

Regression analysis showed the variation of yield (Yplt) in relation to determined productivity parameters. The variation of Yplt in relation to GBW and GNB was described by

equation (2) under conditions of $R^2 = 0.795$, F = 6.9998, P = 0.0062, RMSE = 0.2039, Figure 6.

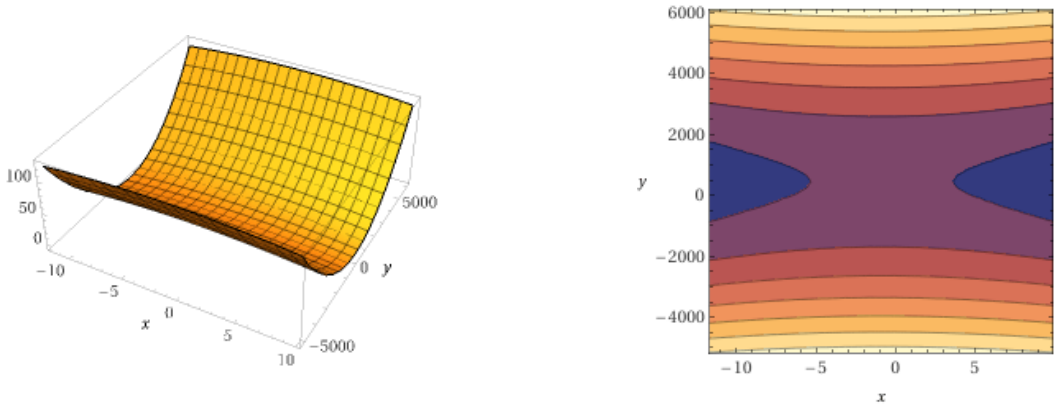
$$Yplt = a\,x^2 + b\,y^2 + c\,x + d\,y + e\,xy + f \qquad (2)$$

where: Yplt – yield on plant; x – GBW; y – GNB; a, b, c, d, e, f – parameter of equation (2); a = -0.072108; b = 0.000004; c = -0.129980; d = -0.003802; e = 0.007589; f = 2.273972

The variation of Yplt in grapevine local cultivars, in relation to GBW and GBuW was described by equation (3) under conditions of $R^2 = 0.789$, F = 6.7297, P = 0.0071, RMSE = 0.2071, Figure 7.

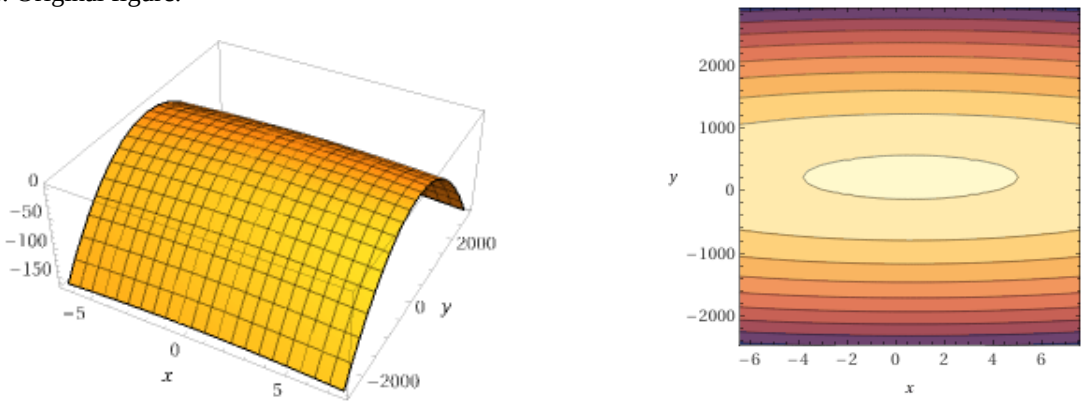
$$Yplt = a\,x^2 + b\,y^2 + c\,x + d\,y + e\,xy + f \qquad (3)$$

where: Yplt – yield on plant; x – GBW; y – GBuW; a, b, c, d, e, f – parameter of equation (3); a = -0.140604; b = -0.000022; c = 0.164042; d = 0.009988; e = 0.001143; f = 1.581796



(a) (b)

Fig. 6. Grapevine yield (Yplt) variation in relation to GBW (x – axis), and GNB (y – axes); (a) – 3D model; (b) model in isoquants format
Soure: Original figure.



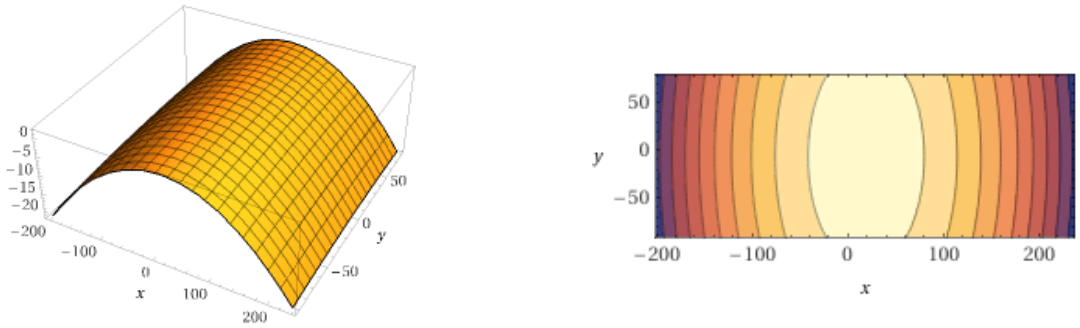
(a) (b)

Fig. 7. Grapevine yield (Yplt) variation in relation to GBW (x – axis), and GBuW (y – axes); (a) – 3D model; (b) model in isoquants format
Source: Original figure.

The variation of Yplt in grapevine local cultivars, in relation to GNB and GBuW was described by equation (4) under conditions of $R^2 = 0.802$, F = 7.3086, P = 0.0053, RMSE = 0.2004, Figure 8.

$$Yplt = a\,x^2 + b\,y^2 + c\,x + d\,y + e\,xy + f \qquad (4)$$

where: Yplt – yield on plant; x – GNB; y – GBuW; a, b, c, d, e, f – parameter of equation (4); a = -0.000466; b = -0.000127; c = 0.017022; d = -0.001513; e = 0.000491; f = 1.56646



(a) (b)

Fig. 8. Grapevine yield (Yplt) variation in relation to GNB (x – axis), and GBuW (y – axes); (a) – 3D model; (b) model in isoquants format
Source: Original figure.

Technological works in vineyard plantations have certain common elements, but also differentiated elements in relation to the assortment of varieties, the destination of grape production [32]. The adjustment of technological work is constantly made in relation to the biology and phenology of the vine, the growing system, the soil conditions and the climate, in order to optimize the yields and quality of the grapes [33]. The results recorded in the present study showed the differentiated positioning of genotypes in relation to productivity and yield parameters. In the group of red wine cultivars, higher values of the GBW parameter were recorded (RWC3 cultivar), in the group of white wine cultivars a high value was recorded for the GNB parameter (WWC2 cultivar), and in the group of fresh consumption cultivars a high value was recorded for GbuW (FCC1 cultivar). In each grape group, cultivars with high yield levels (Yplt) were recorded.

Studies on the analysis of grapevine plant vigor, modeling and optimization have been communicated within other studies [2, 6, 18]. Multivariate analysis facilitated an objective visualization of the experimental data and a better perspective on how grape cultivars were positioned in relation to productivity parameters and yield. Productivity parameters, as factors, presented differentiated action in terms of direction (positive / negative) and intensity (correlation coefficient value) in relation to the principal components. Thus, the GBW parameter presented positive action (PC2, PC3, PC4), with strong intensity in component PC2, and negative action in PC1. The GNB parameter showed positive action (PC1, PC2, PC4), with weak intensity, and negative action in PC3. The BguW parameter showed positive action in PC1 and PC2, and negative action in PC3 and PC4, with weak intensity. The Yplt parameter showed positive action (PC1, PC3, PC4), with strong intensity in PC3, and negative action in PC2. PCA analysis has been used to describe morphological characteristics in grapevines [21], grapevine plant status [29], grapevine yield [12], or grapevine quality indices [10].

The regression analysis described the variation of yield (Yplt) in relation to productivity parameters, as a direct and interaction effect. According to the regression coefficient (R^2), of the statistical safety parameters associated with equations (1), (2), and (3), it resulted that equation (3) ensured a high level of yield estimation ($R^2 = 0.802$). The RMSE parameter confirmed that the yield estimation model given by equation (3) presented a high level of reliability; RMSE = 0.2039 in the case of equation (1), RMSE = 0.2071 in the case of equation (2), RMSE = 0.2004 in the case of equation (3). Similar studies have communicated the importance of grapevine yield estimation in relation to productivity parameters [6, 22, 28].

The results recorded are consistent with research in the field, and the methods used and the models obtained provided information that can be useful in the management of vineyard plantations.

CONCLUSIONS

The grape cultivars analyzed were positioned differently in relation to productivity and yield parameters, according to the multivariate analysis. Therefore, a first set of information regarding fruiting prunings resulted, for optimizing productivity and yield parameters, useful for plantation management. The results of the Cluster analysis showed the degree of similarity between the studied grape cultivars. These results can be useful in harmonizing technologies for each grape group, in order to obtain similar results, in terms of yield in relation to productivity parameters. Regression analysis led to yield estimation models, in the form of quadratic polynomial equations and graphical models (3D, isoquants). Divergent action was recorded in the case of GBW and GNB parameters, according to equation (1). These parameters require a differentiated, balanced approach to optimize the yield under the study conditions. Convergent action was recorded in the case of the parameters GBW and GBuW, respectively GNB and GBuW, analyzed by equations (2) and (3). High level of confidence for yield estimation was recorded for GNB and GbuW parameters. The analysis model can be extended to other grape cultivars. Also, the analysis model can be developed by including a larger number of parameters, as variables with influence on yield, in order to improve management decisions for vineyard plantations.

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ECONOMIC EFFICIENCY OF MAIZE HYBRIDS CULTIVATION WITH THE USE OF BIOLOGICAL PRODUCTS IN THE STEPPE OF UKRAINE

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Abstract

The aim of the research was to determine the technical and economic efficiency of modern biological products in protecting maize hybrids from fungal diseases and pests in the steppe zone of Ukraine. It was found that growing maize hybrids in the FAO group 190-420 was characterized by an increase in net profit when using the biopreparations Biospectr BT and Biplan M. The use of the biological preparation Biospectr BT increased the conditional net profit by 0.67–3.50 thousand UAH/ha in hybrids of different FAO, while treatment with Biplan M increased profit by 3.18–3.51 thousand UAH/ha. The positive effect of biological preparations on grain yield in corn hybrids of different FAO groups has been proven. The technical efficiency of using the biological preparation Biplan M to protect corn plants from the European corn borer (Ostrinia nubilalis Scheld.) varied from 21.8% to 32.6% in different FAO groups of hybrids. The biological preparation Biospectr BT recorded technical efficiency at the level of 18.5% - 25.2%. Biplan M demonstrated technical efficiency against corn smut (Ustilago zeae Beckm.) ranging from 34.3% to 48.7%, while Biospectr BT ranged from 27.3% to 37.8%. The grain yield of corn hybrids of different FAO groups varied over the years of research within the range of 6.15 to 8.51 t/ha. The increase in grain yield from the use of biopreparations ranged from 0.47 to 0.79 t/ha. The highest yield increase was recorded with the use of Biplan M (0.61–0.79 t/ha). The highest grain productivity was achieved by the hybrid Oleshkivskyi (FAO 280) when using the biopreparation Biplan M – 8.51 t/ha. Increasing the FAO group of hybrids negatively affected grain yield.

Key words**:** *maize, grain, agritechnology, biopreparations, net profit, profitability, cost, yield*

INTRODUCTION

In the complex of agrotechnological and organizational-economic measures that create conditions for stabilizing maize grain production volumes and increasing its competitiveness, the rational use of the genetic potential of varietal resources and the use of

biopreparations play an important role. The process of intensifying maize grain production is closely related to the use of the latest achievements in hybrid breeding. The use of modern breeding and genetic developments to create innovative, more productive, resistant biotic and abiotic factors of damage in the conditions of climate change, adverse natural and climatic conditions and diseases of corn hybrids, as well as the use of biologically active preparations with a protective and growth-stimulating effect, allows to increase the grain yield of this crop by 20–25% [7, 8, 24, 25, 26, 27]. In modern global agricultural production, there is a rapidly growing trend towards agrotechnologies aimed at ecological farming. The biological method of plant protection (biological control or biocontrol) in its narrow classical sense is a means of controlling pests, weeds, and plant diseases using natural enemies. It is based on natural mechanisms ("predator-prey," "parasite-host") with active human intervention in the process of regulating and suppressing pests and pathogenic organisms [10, 13].

Among biopreparations, the fungus *Trichoderma* spp. is one of the most studied genera due to its wide application in agricultural production as a natural means of protecting plants from pathogenic fungi and bacteria. Various species of this fungus can act against 18 genera and 29 species of harmful organisms. The mechanisms of action of *Trichoderma* spp. mainly involve aggression and fungicidal parasitism, which is accompanied by increased plant resistance, production of antifungal metabolites, stimulation of plant growth, and stimulation of immunity [9].

Brazilian researchers [16] have found that biological control of plant pathogens is a promising direction in the protection of fruit crops. Studies have been conducted to identify specific compounds isolated from *Trichoderma* spp. for in vitro control.

Numerous scientific studies by Palenychak O. [14] and Mishchenko S. V. et al. [12] have proven that modern biopreparations can significantly increase the productivity and quality of agricultural crops. The use of biological approaches in agricultural production offers prospects for effective control of disease pathogens, pests, and weeds, which aligns with the development directions of the European Union.

As Dean A. N. et al. [3] points out, a significant problem for agricultural production is the parallel evolution of pests and the breeding and genetic achievements in creating pest-resistant genotypes. In Iowa, pests are adapting to pesticides due to their systematic use on maize crops, especially with continuous maize cultivation. Additionally, the systematic increase in the use of synthetic pesticides raises the resistance of harmful organisms and negatively affects the state of the natural environment.

Van der Werf H. M. G. et al. [23] indicate that intensive crop growing systems to ensure food security, which use large amounts of synthetic chemicals, cause public concern about pesticide residues that contaminate soils and water bodies with toxic substances. Marchenko T. Yu. et al. [11] have shown that the excessive reliance on chemical plant protection methods results in alarming phenomena in biocenoses and agrocenoses, primarily due to contamination of plants, soils, water, and food products with chemical pesticide residues, reduced pest resistance to protection methods, and disruption of ecosystem stability due to the loss of part of the biota caused by chemical preparations. This negatively affects human health and the state of the natural environment.

As Capanoglu E. et al. [2] assert, there is a growing interest in biological functional preparations, stimulating the development of biopreparation technologies consisting of proteins, oligosaccharides, and bioactive compounds. The value of organic biomass fractions as sources of biologically active substances has recently attracted stakeholders from the academic and industrial spheres to search for and develop new biostimulants and biopesticides [1, 28]. Driven by high economic returns and the need to improve biosafety, scientists strive to develop new biopreparations [19, 28]. Successes in discovering new compounds with biostimulant and biopesticide properties are partly driven by the rapidly

growing biopreparations market, which is projected to reach a total value of $19.5 billion by 2030 (38% biostimulants and 62% biopesticides) with an average annual growth rate of over 10% [4]. These aforementioned factors align with the new trend of "bioeconomy" and "zero waste" [17] and support the goal of sustainable agriculture to reduce fertilizer use by 20% and chemical pesticide use by 50% by 2030 [5, 6].

The purpose of the study was to determine the technical and economic efficiency of using innovative biological products in protecting corn hybrids of different FAO groups from harmful organisms in the Steppe of Ukraine.

MATERIALS AND METHODS

Research was conducted during 2021-2023 under the research program No. 10 of the National Academy of Agrarian Sciences of Ukraine "Biotechnics," under the task 10.00.04.09.P (state registration number 0119U000021) "To determine the impact of biopreparations on the productivity of innovative maize hybrids." The research was carried out in the Yelanets district of the Mykolaiv region, located in the climatic zone of the Northern Steppe [15].

The study used innovative hybrids of Ukrainian selection FAO 190 – 420. The original breeder was the Institute of Climate-Smart Agriculture of NAAS [18].

Economic efficiency calculations for growing maize hybrids were conducted using prices averaged over the years 2021–2023. The purchase prices for grain in Ukraine averaged 5,500 UAH/t during 2021–2023 (based on stock exchange data).

The technical efficiency of disease protection measures was calculated using the formula: B = (Rk – Ro) * 100 / Rk, where B is the technical efficiency, %, Rk is the disease development indicator in the control, and Ro is the disease development indicator in the experimental plot. The technical efficiency of the measures indicates the result of applying the preparation against a harmful organism under specific conditions, measured by the suppression of disease development and plant damage in treated plots compared to untreated ones (control) [20].

Additional yield (increment) was determined using the generally accepted method. The results of field research were processed using statistical methods [21, 22].

The research used microbiological preparations produced in Ukraine [https://biotekhnika.od.ua/uk, https://centrbio.com.ua], namely:

Biplan: A liquid culture form containing two strains of bacteria *Pseudomonas fluorescens* and *Pseudomonas aureofaciens*, along with biologically active substances that destroy phytopathogens through direct suppression, competition for nutrition, and exhibit insecticidal activity against early-stage codling moth larvae.

Biospectr BT: A microbiological insecticidal-fungicidal preparation produced by the Engineering-Technological Institute "Biotechnics" NAAS (Ukraine). It contains rhizosphere bacteria of the genus *Pseudomonas* with a titer of no less than 5.0·10^9 CFU/cm^3 and biologically active substances (BAS) such as phenazine-carboxylic acids and a complex of active pigments that act as active factors in the preparation.

Innovative biological drugs were used according to the recommendations of the Institute of Engineering and Technology Institute "Biotechnics" NAAS (Odesa).

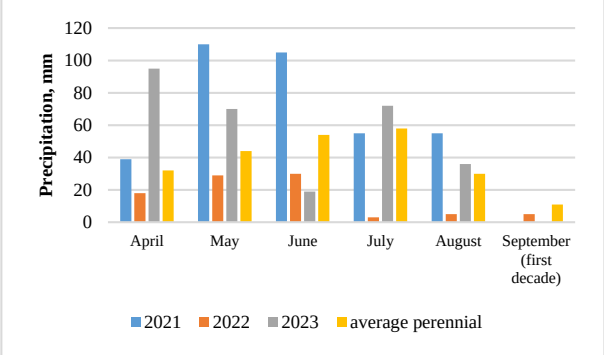


Fig. 1. Precipitation during the maize growing season, mm

Source: calculated by the authors.

The weather conditions during the research period were typical for this agro-ecological zone. Meteorological conditions of the

research years are presented in Figure 1.
Air temperatures during the research years were 1.5…2.2 °C higher than the long-term average from May to August, confirming widely recognized trends in global climate change towards warming (Fig. 2).

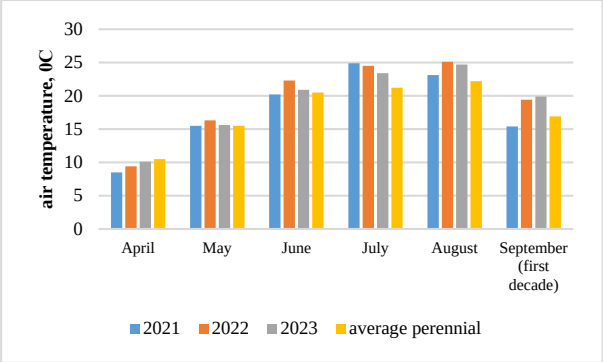


Fig. 2. Air temperature during the maize growing season, °C
Source: calculated by the authors.

Meteorological observations were carried out using the autonomous professional weather station DLS-009 (AW009) [29].
Experimental research on plants, including the collection of plant material, complied with institutional, national, or international guidelines.
The authors adhered to the standards of the Convention on Biological Diversity (1992) [30] and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979) [31].

RESULTS AND DISCUSSIONS

The biopreparations showed high technical effectiveness against maize fungal diseases. The technical effectiveness of the biopreparation Biospectr BT for fusarium ear rot (*Fusarium moniliforme* Scheld.) ranged from 25.6% to 37.9%, while for Biplan M, it ranged from 27.4% to 41.6% (Table 1).

Table 1. Technical effectiveness of the studied biopreparations on maize hybrids, % (average for 2021–2023)

Hybrid (Factor A)	Biological Preparation (Factor B)	Technical Efficiency, %		
		Stalk Borer (*Ostrinia nubilalis* Scheld.)	Ear Fusarium (*Fusarium moniliforme* Scheld.)	Common Smut (*Ustilago zeae* Beckm.)
Stepovyi (FAO 190)	Control (water treatment)	-	-	-
	Biplan M	32.6	34.9	48.7
	Biospectr BT	25.2	30.7	36.8
Oleshkivs`kyi (FAO 280)	Control (water treatment)	-	-	-
	Biplan M	21.8	41.6	42.4
	Biospectr BT	19.6	37.9	36.3
Tronka (FAO 380)	Control (water treatment)	-	-	-
	Biplan M	22.9	37.5	34.3
	Biospectr BT	19.5	25.6	27.3
Hileia (FAO 420)	Control (water treatment)	-	-	-
	Biplan M	23.8	27.4	34.3
	Biospectr BT	19.6	25.8	30.5

Source: calculated by the authors.

The technical effectiveness of the biopreparation Biplan M in controlling maize stem borer (*Ostrinia nubilalis* Scheld.) damage ranged from 21.8% to 32.6%, depending on the FAO hybrid group. The biopreparation Biospectr BT showed technical effectiveness ranging from 18.5% to 25.2%.
Biplan M demonstrated technical effectiveness against maize common smut (*Ustilago zeae* Beckm.) ranging from 34.3% to 48.7%, while Biospectr BT ranged from 27.3% to 37.8%.
Yield measurements indicated that the grain yield of the studied maize hybrids varied from 6.15 to 8.51 t/ha over the research years (Table

2). The yield increase due to biopreparation application ranged from 0.47 to 0.79 t/ha. The highest yield increase was recorded with the application of Biplan M, ranging from 0.61 to 0.79 t/ha. The highest grain productivity was observed in the hybrid Oleshkivs`kyi (FAO 280) with Biplan M application, yielding 8.51 t/ha. Increasing the FAO group of hybrids negatively affected grain yield.

Improving the efficiency of crop production involves increasing production volumes with minimal costs per unit. Thus, it is necessary to increase crop yields and reduce production costs.

Table 2 presents the results of the economic efficiency analysis of maize hybrid cultivation using biological plant protection methods.

Table 2. Economic Efficiency of Maize Hybrid Cultivation with Biopreparation Treatments (average for 2021–2023)

Hybrid (Factor A)	Biological Preparation (Factor B)	Yield, t/ha	Expenses, thousand UAH/ha	Gross Product Value, thousand UAH/ha	Production Cost, thousand UAH/t	Conditional Net Profit, thousand UAH/ha	Profitability, %
Stepovyi (FAO 190)	Control (water treatment)	6.98	18.50	38.39	2.65	19.89	108
	Biplan M	7.67	18.95	42.19	2.47	23.24	123
	Biospectr BT	7.45	18.85	40.98	2.53	22.13	117
Oleshkivs`kyi (FAO 280)	Control (water treatment)	7.72	18.50	42.46	2,40	23.96	130
	Biplan M	8.51	18.95	46.81	2.23	27.86	147
	Biospectr BT	8.42	18.85	46.31	2.24	27.46	146
Tronka (FAO 380)	Control (water treatment)	7.15	19.40	39.33	2.71	19.93	103
	Biplan M	7.87	19.85	43.29	2.52	23.44	118
	Biospectr BT	7.76	19.75	42.68	2.55	22.93	116
Hileia (FAO 420)	Control (water treatment)	6.15	20.45	33.83	3.33	13.38	65
	Biplan M	6.81	20.90	37.46	3.07	16.56	79
	Biospectr BT	6.67	20.80	36.69	3.12	15.89	76

Source: calculated by the authors.

The cost per ton of yield clearly illustrates the difference between the selling price and production costs. Depending on the yield level and associated production costs, the hybrids ranked in ascending order of cost as follows: Oleshkivs`kyi (FAO 280) – 2.23–2.40 thousand UAH/t; Stepovyi (FAO 190) – 2.47–2.65 thousand UAH/t; Tronka (FAO 380) – 2.55–2.71 thousand UAH/t; Hileia (FAO 420) – 3.07–3.33 thousand UAH/t. The cost difference between the extreme hybrids was 37.6%.

Overall, most hybrids showed a tendency for increased yield cost in variants without biopreparation application and when using the FAO 420 hybrid (Hileia). The critical cost increase (+0.93 thousand UAH/t and higher) for the Hileia hybrid is associated with its low adaptability to the arid conditions of the steppe zone.

The lowest production cost of the harvested crop, specifically 2.23–2.24 thousand UAH/t, was observed in variants with the Oleshkivs`kyi hybrid (FAO 280) when treated with Biplan M and Biospectr BT. As expected, the primary impact on the indicators of

production cost, profit, and profitability was determined by the dynamics of yield and expenses.

The profit per unit area indicator characterizes the main result of the economic efficiency of maize cultivation. Cultivation of all FAO maize hybrid groups was characterized by an increase in net profit when using the biopreparations Biospectr BT and Biplan M. Treatment with Biospectr BT increased net profit by 0.67–3.50 thousand UAH/ha compared to the no-treatment option. The use of Biplan M was more effective and stable for hybrids of all FAO groups, the additional net profit was 3.18–3.51 thousand UAH/ha. Overall, in order of increasing average profit per unit area, the hybrids formed the following ranking: Hileia (FAO 420) – 13.38–16.56 thousand UAH/ha; Stepovyi (FAO 190) – 19.89–23.24 thousand UAH/ha; Tronka (FAO 380) – 19.93–23.44 thousand UAH/ha; Oleshkivs`kyi (FAO 280) – 23.96–27.86 thousand UAH/ha.

A universal indicator of the economic efficiency of cultivating specific crops is profitability. Table 2 presents the dynamics of maize hybrid cultivation profitability depending on the FAO group and biopreparation treatments. Among the factor A hybrids, the highest profitability (>100%) was ensured by Stepovyi – 108–123%; Oleshkivs`kyi – 130–147%, and Tronka – 103–118%. Low profitability indicators (<80%) for the study conditions were noted in the Hileia hybrid – 65–79%.

Analysis of the indicator dynamics indicates a clear trend towards decreasing profitability levels in variants with increasing FAO hybrid groups. Within the factor B, the minimum profitability values (65–130%) were observed in the control variants (water treatment). In the biopreparation treatment variants, the maximum profitability was demonstrated by hybrids treated with Biplan M – 79–147%.

Among the factor A variants, the highest profitability level – 147% was observed in the Oleshkivs`kyi hybrid plots treated with Biplan M. The lowest profitability (65%) was found in the Hileia hybrid control variant.

Overall, considering the economic efficiency indicators, the optimal technology variant is the Oleshkivs`kyi hybrid (FAO 280) treated with Biospectr BT and Biplan M. These variants provided the maximum profit indicator of 27.46–27.86 thousand UAH/ha, the lowest production cost per unit yield – 2.23–2.24 thousand UAH/t, and the highest profitability in the study – 146–147%.

CONCLUSIONS

The impact of biological preparations on the grain yield of maize hybrids in FAO groups 190–420 and the economic efficiency of their application has been established. The economic indicators of growing corn hybrids FAO 190 - 420 were characterized by an increase in conditional net profit with the use of biological products Biospectr BT and Biplan M. Treatment with the biological product Biplan M was more economically feasible - the additional conditional net profit was 3.18–3.51 thousand UAH/ha. Overall, in ascending order of average profit per unit area across the experimental variants, the hybrids ranked as follows: Hileia (FAO 420) – 13.38–16.56 thousand UAH/ha; Stepovyi (FAO 190) – 19.89–23.24 thousand UAH/ha; Tronka (FAO 380) – 19.93–23.44 thousand UAH/ha; Oleshkivs`kyi (FAO 280) – 23.96–27.86 thousand UAH/ha. The studies showed that the technical efficiency of the Biplan M biological preparation in controlling damage to maize plants by the European corn borer (*Ostrinia nubilalis* Scheld.) ranged from 21.8 to 32.6%, depending on the FAO hybrid group. The Biospectr BT preparation demonstrated technical efficiency ranging from 18.5 to 25.2%. For controlling common smut (*Ustilago zeae* Beckm.), the Biplan M preparation showed technical efficiency ranging from 34.3 to 48.7%, while Biospectr BT ranged from 27.3% to 37.8%. The yield increase from the application of biological preparations ranged from 0.47 to 0.79 t/ha. The highest yield increase was recorded from the application of Biplan M (0.61–0.79 t/ha). The highest grain productivity was observed in the Oleshkivs`kyi hybrid (FAO 280) when treated with Biplan M, reaching 8.51 t/ha. An increase

in the FAO group of hybrids negatively affected grain yield.

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DETERMINANTS OF PROFITABILITY MANAGEMENT IN AGRICULTURAL ENTERPRISES: A CASE STUDY OF UKRAINE

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Abstract

The purpose of the article is to identify the key determinants of profitability management in Ukrainian agricultural enterprises under the conditions of structural economic transformation. The article investigates the determinants of profitability management in Ukrainian agricultural enterprises under conditions of economic instability and structural market transformations. It is determined that the efficiency of profit formation in the agricultural sector depends not only on financial indicators but also on the complex interaction of production, investment, and labor factors. The study analyzes the impact of asset volume, production costs, capital investments, labor productivity, and inflationary processes on the performance of agricultural enterprises. The study is based on quantitative tools of economic analysis, among which the key place was occupied by the construction of correlation-regression relationships in order to determine the nature and strength of the influence of such factors as the size of assets, the level of production costs, the volume of capital investments, the dynamics of the consumer price index and labor productivity indicators on the financial results of agricultural business entities of Ukraine. The study was based on statistical materials of the State Statistics Service of Ukraine, covering the time interval 2011–2023. The findings reveal that the growth of labor productivity plays a decisive role in ensuring financial stability, while high cost levels and price fluctuations limit the potential for profitability. It is established that balancing the cost structure through more efficient asset utilization and focusing investments on technological modernization form the foundation for sustainable financial development of the agricultural sector. It is substantiated that the use of such an approach creates the prerequisites for a long-term increase in the financial performance of agricultural sector entities and contributes to strengthening their market advantages in a competitive environment.

Key words**:** *profitability, agricultural enterprises, profitability management, investments, labor productivity, digitalization, production costs*

INTRODUCTION

The problem of profitability management in Ukraine's agricultural sector enterprises has a complex and multifactor nature, which under conditions of an unstable macroeconomic environment acquires a systemic character. In particular, prolonged war-related risks, logistical constraints, and limited access to financial resources significantly affect the

ability of agricultural enterprises to maintain stable profits. At the same time, profitability management principles based solely on assessing costs and revenues no longer ensure an adequate level of efficiency in a high-risk environment. External shocks have revealed an objective need for new methodological foundations in financial decision-making that would integrate such elements as operational efficiency and cost optimization. It is also essential to recognize that although profit formation management traditionally depends on financial performance indicators, in practice it is strongly influenced by both internal production factors and external determinants linked to financial market dynamics.

Thus, market uncertainty and restricted capital access create a need to identify profitability determinants–factors that have a stable yet statistically significant impact on the financial outcomes of agricultural enterprises. Such determinants traditionally include the level of technological modernization, capital structure, resource use efficiency, and investment volume in production, among others.

The current lack of comprehensive scientific research assessing the interrelations between these determinants and the profitability of agricultural enterprises complicates the development of effective management strategies. In this context, the development of analytical tools capable of identifying the key determinants of profitability and revealing the nature of their relationships is of particular importance in order to strengthen the financial stability of the agricultural sector as a whole and increase the market capacity of individual business entities.

At the same time, scientific discourse demonstrates increased research interest in issues of regulating the performance of agricultural enterprises, which is due to the functioning of the industry in an environment of economic turbulence. However, while most scholarly works examine the factors determining agribusiness financial performance, there is no consensus regarding their hierarchy and interconnections. Practical approaches generally emphasize the interplay between financial, production, and managerial factors, yet the comprehensive identification of profitability determinants remains a matter of debate. In this context, notable contributions have been made by scholars such as N. Antoniuk [1], I. Arakelova [2], M. Dziamulych [3-10], N. Khomiuk [11], V. Kostiuk [12], I. Mazniev [13], A. Popescu [14-23], M. Rudenko [24], V. Sarioglo [25], T. Shmatkovska [26-32], R. Sodoma [33-34], A. Verzun [36], and others. At the same time, there remains an urgent need for a more thorough study of the factors that determine the level of profitability of agricultural business entities, as well as the mechanisms for its regulation.

MATERIALS AND METHODS

The empirical basis of the work is the official statistical materials of the State Statistics Service of Ukraine, covering the time interval 2011–2023. According to the above indicators, at the end of 2023, the number of agricultural business entities was 62,960 units, which is equal to 3.3% of the total number of operating economic agents in the state [35].

The methodological framework of this study combines quantitative and qualitative approaches to the analysis of determinants influencing profitability management in agricultural enterprises. To systematize scientific approaches, concepts, and theoretical foundations, the content analysis method was applied, allowing for the generalization of findings from prior research in financial management and agricultural economics.

The use of analysis and synthesis methods made it possible to identify relationships among key economic indicators and to establish a logical sequence describing how financial, production, and investment factors affect enterprise profitability. To define the structure of interdependencies between the studied variables, the method of logical generalization was employed, enabling the development of a comprehensive system of factors that reflect the influence of various determinants on the profitability of agricultural enterprises.

To establish the intensity and direction of statistical relationships between the dependent characteristic (enterprise profits) and a set of explanatory indicators, correlation analysis tools were used. The pairwise correlation coefficient was calculated using the classical formula:

$$r_{xy} = \frac{\sum(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum(x_i - \overline{x})^2 \sum(y_i - \overline{y})^2}}$$

where: r_{xy} – is the correlation coefficient between variables x and y;
x_i, y_i – are the corresponding observations;
x, y – the mean values of the respective variables.
To test the statistical significance of the correlation coefficient, the Student t-test was used, which allows us to assess whether the obtained value of the correlation coefficient differs from zero at a given level of significance. The t-statistic was calculated using the formula

$$t = \frac{r \times \sqrt{(n-2)}}{\sqrt{(1-r^2)}},$$

where: r – the pairwise correlation coefficient;
n – the sample size.
To verify the reliability of the results and to assess the degree of influence of each factor on enterprise profitability, multiple regression analysis was applied. This method allowed for a quantitative estimation of the impact of variables with different economic meanings. All calculations were carried out using the Microsoft Excel software package, specifically the CORREL and LINEST functions and the Data Analysis – Regression tool, which provided estimates of coefficients, standard errors, t-statistics, and the coefficient of determination (R^2). Based on these results, an equation was constructed describing the dependence of agricultural enterprises' profit on the analyzed factors, followed by the development of a forecast of its future dynamics.

RESULTS AND DISCUSSIONS

In today's conditions of market instability, accounting for the factors influencing the profitability of agricultural enterprises provides a realistic foundation for making effective managerial decisions. Profitability is not a random outcome of economic activity but a reflection of the balance between resources, risks, and managerial actions. In agriculture, this balance is particularly fragile, as production seasonality, price fluctuations, and changes in state support directly affect the financial outcomes of producers. Therefore, proper consideration of profitability determinants allows management to identify the key sources of profit generation and anticipate potential challenges, responding promptly to changes in market conditions. Consequently, a deep understanding of these factors facilitates efficient capital allocation and enhances the overall competitiveness of the agricultural sector in the long term.
In practice, the profitability of an agricultural enterprise is shaped not only by financial parameters but also by a broad range of multidirectional factors that determine the efficiency of resource utilization. Financial indicators reflect only the final result of profit formation but do not explain the internal logic of its achievement. Meanwhile, managerial, technological, organizational, natural-resource, and social aspects directly influence production costs, operational efficiency, and income stability. Ignoring these components leads to erroneous conclusions and short-term decisions that fail to ensure sustainable development. As practice shows, only a combination of financial analysis with assessments of management efficiency, investment potential, and workforce quality allows for the identification of the real determinants of profitability.
From a comprehensive perspective, the factors influencing enterprise profitability can be grouped into the following categories:
- financial;
- production and operational;
- innovation and investment;
- labor-related;
- macroeconomic variables.

It should be emphasized that if profitability is evaluated beyond traditional financial analysis, it is necessary to identify an integrated set of factors linked to the enterprise's overall economic activity. Moreover, the assessment implies certain interrelations among these factors, with the only difference lying in the strength of each one's influence on the final outcome – profit formation.

Among macroeconomic factors, the rate of inflation exerts the most significant impact on agricultural profitability, as it directly determines the real value of costs and revenues. Rising input prices immediately increase production costs, while the ability to raise selling prices is often constrained by consumer purchasing power and contractual obligations. High inflation also erodes the value of money, weakens investment activity, and undermines confidence in financial forecasts. Under such conditions, even efficiently managed enterprises face the risk of declining real profits. In practice, inflationary instability forces agricultural producers to seek compensatory mechanisms, making inflation a key macroeconomic indicator that defines an enterprise's ability to maintain financial balance. Accordingly, we will consider the dynamics of inflation and changes in profit volumes and cost of production in the agricultural sector of Ukraine (Figure 1).

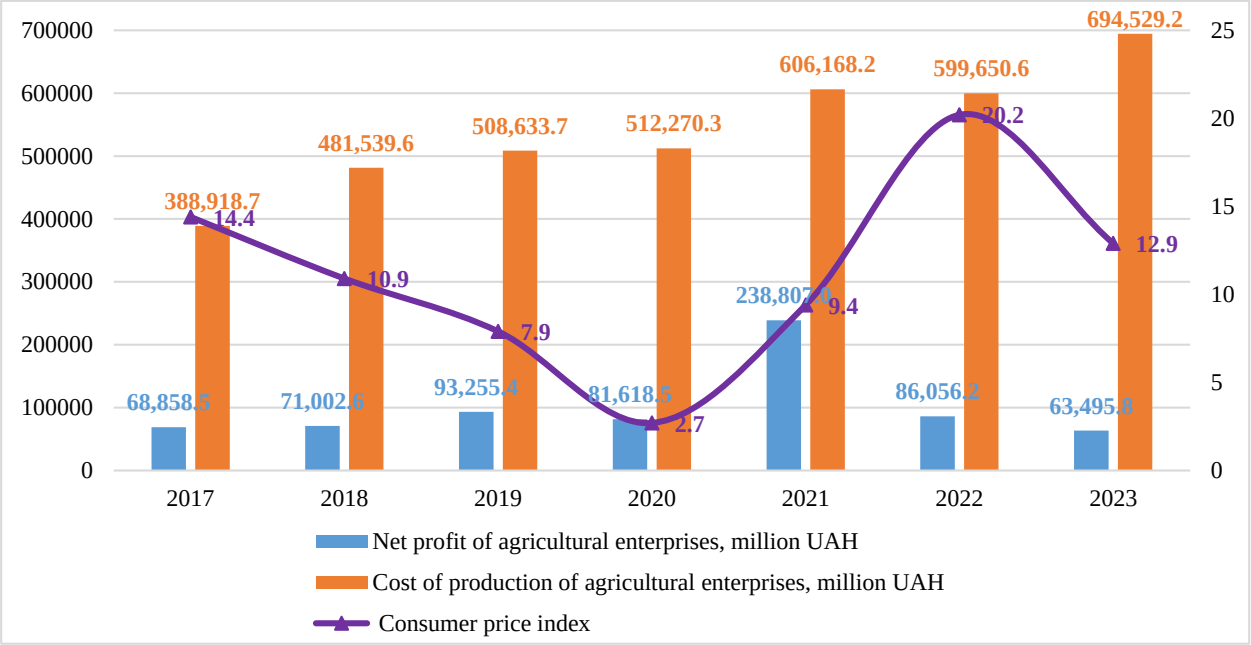


Fig. 1. Change in profitability, cost of production in the agricultural sector and inflation rate in Ukraine for 2017-2023.

Source: calculated by the author based on [35].

The diagram illustrates that the dynamics of profitability in Ukraine's agricultural enterprises during 2017–2023 reflect a complex process of adaptation to constant changes in the macroeconomic environment. In particular, the overall movement of the indicators demonstrates persistent tension between internal production costs and external inflationary pressures. At certain time intervals, a disproportion was recorded in the agricultural sector between the dynamics of the increase in production costs (over UAH 600 billion) and the increase in net financial result (up to UAH 86 billion). Such a discrepancy indicates a weakening of the effectiveness of resource use and a reduction in the level of profitability of operating activities. At the same time, during the inflationary surge of 2022, when the Consumer Price Index reached 20.2%, the balance shifted in favor of rising costs, leading to the erosion of profits among agricultural producers even despite nominal increases in production volumes.

Thus, the process of profit formation in the agricultural sector represents not a linear reaction to inflationary fluctuations, but rather

a complex system of interdependent factors in which production costs respond more rapidly than revenues. This imbalance, in our view, results in a contraction of financial reserves and increases enterprises dependence on credit resources. Overall, the graph clearly demonstrates that the stabilization of profitability is possible only through effective alignment of production strategies with the prevailing macroeconomic realities.

Moreover, the fundamental basis of an agricultural enterprise's profitability lies in its asset volume, as it determines the scale of production and the potential for generating income. A high asset value allows for more efficient utilization of machinery, technologies, and infrastructure, contributing to economies of scale and higher labor productivity. However, excessive accumulation of assets without adequate capital returns reduces profitability and creates a risk of tying up funds in low-yield resources. Therefore, the key factor is not merely the size of assets but their quality and dynamics. The optimal ratio between assets and financial results forms the foundation for long-term profitability and financial stability of agricultural enterprises. Accordingly, let us assess the trends in the volume of assets of agricultural producers in Ukraine in recent years (Figure 2).

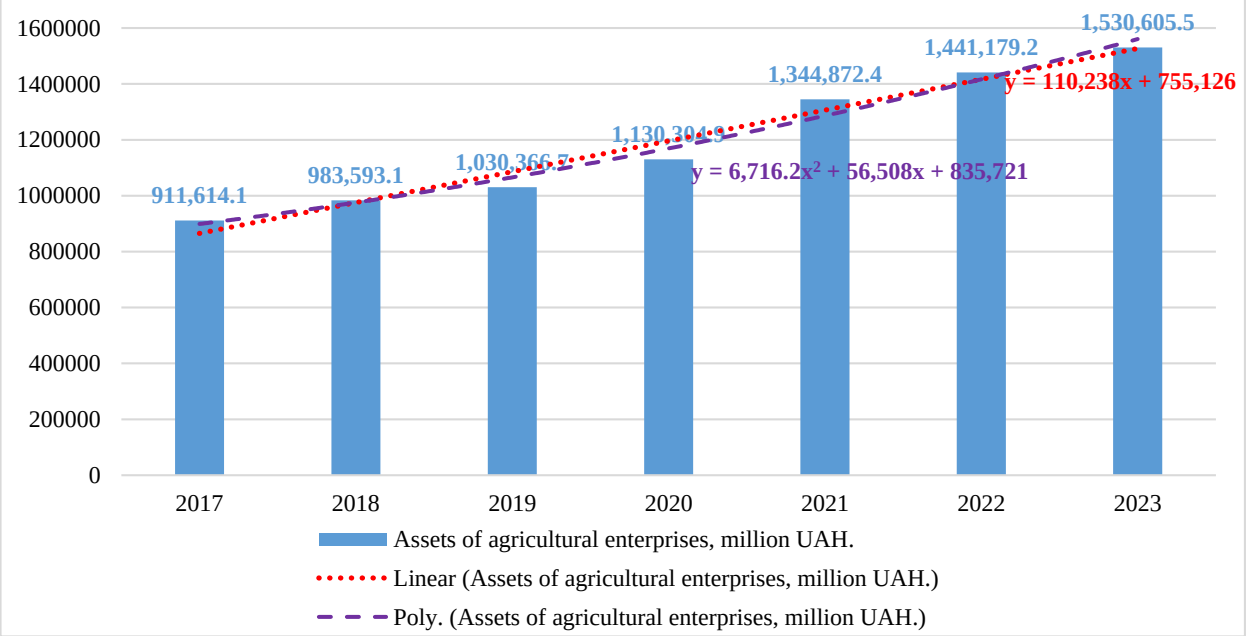


Fig. 2. Change in the size of assets of agricultural enterprises in Ukraine in 2017-2023.
Source: calculated by the author based on [35].

The analysis of the graph indicates that the process of asset formation in agricultural enterprises during 2017–2023 was characterized by an expansion of the capital base and a strengthening of investment activity. The linear trend equation demonstrates a consistent annual increase in assets of approximately 110 billion UAH, reflecting the accumulation of both production and financial resources. At the same time, the approximation by a polynomial function shows that the dynamics of assets is characterized by accelerated expansion and has a clearly nonlinear nature. Such a change reflects the process of accumulation of financial potential with the subsequent direction of resources to the modernization of the production base. As a result, the growth of asset volumes signals the formation of an investment-oriented model of development of the agricultural sector, which can be considered as a manifestation of the increase in the financial maturity of business entities. In general, such a trend creates the prerequisites for improving profitability indicators due to the increase in the cost of the material and technical basis of activity, while at the same time strengthening the adaptability of enterprises to market changes.

To determine the influence of individual factors on the process of profit formation in Ukraine's agricultural enterprises, a correlation analysis was conducted to identify the relevant interdependencies. The analysis used as variables the factors discussed above, as well as indicators of labor productivity and investment activity in the agricultural sector, which correlate with financial and production indicators and also affect profitability (Table 1).

Table 1. Dynamics of the studied indicators for 2011-2023 for the construction of the correlation-regression model

Year	Net profit of agricultural enterprises, UAH million	Volume of assets of agricultural enterprises, UAH million	Cost of production of agricultural enterprises, UAH million	Capital investments in the agricultural sector, UAH million	Consumer price index	Labor productivity at agricultural enterprises, UAH thousand per employee
2011.	25,341.3	226,031.7	127,731.1	17,039	6.9	46.7
2012	26,787.2	274,914.6	134,317.9	19,411	0.6	51.4
2013	14,984.4	313,096.8	157,670.9	19,059	-0.3	54.9
2014	21,481.4	390,607.0	189,915.7	18,796	12.1	92.8
2015	102,849.1	685,844.9	274,981.6	30,155	48.7	145.1
2016	90,613.2	1,537,319.1	326,544.7	50,484	13.9	165.7
2017	68,858.5	911,614.1	388,918.7	64,243	14.4	183.2
2018	71,002.6	983,593.6	481,539.6	66,104	10.9	209.7
2019	93,255.4	1,030,366.7	508,633.7	59,130	7.9	211.5
2020	81,618.5	1,130,304.9	512,270.3	50,680	2.7	249.6
2021	238,807.0	1,344,872.4	606,168.2	69,950	9.4	382.6
2022	86,056.2	1,441,179.2	599,650.6	51,439	20.2	279.3
2023	63,495.8	1,530,605.5	694,529.2	65,432	12.9	308.0

Source: [35].

Table 2. Parameters of the correlation-regression model for determining the influence of variable factors on the profit of agricultural enterprises in Ukraine (y)

Indicator	Coefficient (B)	Standard error	t-statistic	p-value
Year Net profit (y)	12,475.371	16,771.082	0.74	0.4812
Volume of assets (x1)	-0.009	0.029	-0.30	0.7716
Cost of production (x2)	-0.554	0.125	-4.42	0.0031
Capital investments (x3)	0.926	0.716	1.29	0.2367
Consumer price index (x4)	496.003	535.935	0.93	0.3855
Labor productivity (x5)	1,294.119	214.625	6.03	0.0005

Source: own research.

Let us consider the determined parameters of the regression model (Table 2).

For further interpretation of the interrelationships among the analyzed variables, a correlation-regression equation was constructed. It reflects the quantitative dependence of the profit of agricultural enterprises on a set of internal and external factors that shape their financial performance. The obtained equation makes it possible to assess the strength and direction of each factor's influence on the final profitability indicator.

$$y = 12{,}475.371 - 0.008813x_1 - 0.455110x_2 + 0.926160x_3 + 496.003x_4 + 1{,}294.119x_5$$

The final indicators of the correlation-regression model are presented in Table 3. Table 4 presents a matrix of paired correlation coefficients.

Table 3. Characteristics of the constructed correlation-regression relationship

Indicator	Value
R^2	0.9143
Adjusted R^2	0.8530
Fisher's F-test	14.93
p-value (F)	0.00129

Source: own research.

Table 4. Matrix of mutual correlation between the factor and the dependent variables

Indicators	Net profit (y)	Volume of assets (x1)	Cost of production (x2)	Capital investment (x3)	Consumer price index (x4)	Labor productivity (x5)
Net profit (y)	1	0.607	0.607	0.646	0.244	0.791
Volume of assets (x1)		1	0.876	0.843	0.167	0.864
Cost of production (x2)			1	0.891	0.084	0.957
Capital investment (x3)				1	0.044	0.871
Consumer price index (x4)					1	0.125
Labor productivity (x5)						1

Source: own research.

The obtained correlation-regression model indicates that profit in Ukraine's agricultural

sector results from a balance between scale and productivity on the one hand, and cost pressure on the other. The model, with $R^2 = 0.914$, shows that the most statistically significant effect originates from labor productivity ($t = 6.03$), while production costs consistently erode margins ($t = -4.42$). In other words, the market rewards efficiency but immediately penalizes uncontrolled spending. Capital «works» through productivity and modernization; however, in the short term, its coefficient is insignificant, which reflects an investment lag and competition in explanatory power with other large-scale variables.

High correlations between production costs, assets, and labor productivity (0.876–0.957) generate multicollinearity, which reduces the stability of estimates for assets and investments, as much of their influence is already embedded in labor productivity. The results obtained give reason to argue that the focus on improving profitability should not be reduced to a mechanical increase in the volume of assets or investment costs, but should involve increasing the efficiency of their use, which is manifested in an increase in labor productivity per employee. Cost control thus protects enterprise margins, while investments represent future growth that materializes once they translate into greater productivity.

Therefore, the developed model captures the economic logic of Ukraine's agricultural business: in the short term, profitability is grounded in cost discipline, whereas in the medium and long term, it depends on the institutionalization of productivity through technology, labor organization, and staff training. Consequently, the sequence «investment – productivity – profit», maintained under consistent cost control, enables agricultural enterprises to stay on a growth trajectory amid market instability.

To visualize the calculations, a forecast of changes in enterprise profit volume was constructed using the developed model (Figure 3).

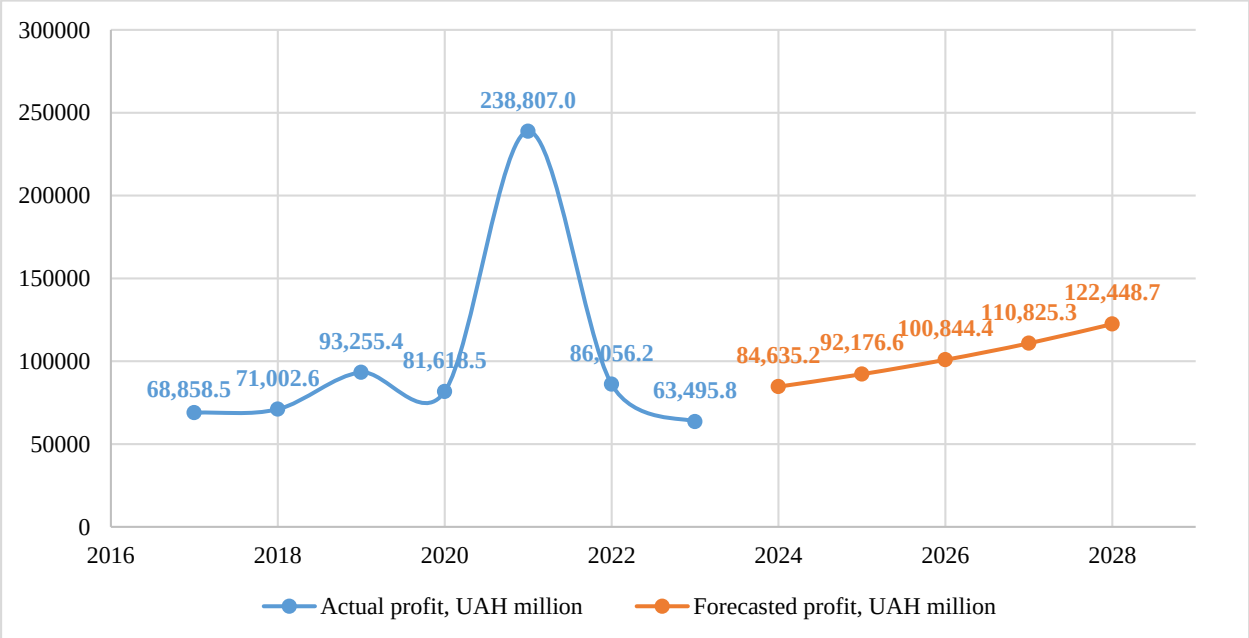


Fig. 3. Forecasted dynamics of profit for agricultural enterprises in Ukraine based on the developed correlation-regression model.
Source: own research.

The constructed graph illustrates the forecasted trajectory of profit for Ukrainian agricultural enterprises up to 2028, showing a gradual transition from the sharp fluctuations of previous years toward a more stable dynamic. The forecasting model indicates that after a period of significant losses and volatility in 2022–2023, a growth trend is expected to emerge, driven by increased investment activity and higher labor productivity. The forecast curve converges with actual values in the medium term, confirming the model's

adequacy and its ability to reflect real economic processes. The projected increase in profitability, reaching over UAH 120 billion by the end of the forecast period, demonstrates the sector's potential for restoring financial stability.

CONCLUSIONS

Thus, it can be concluded that under current conditions, the profitability of Ukraine's agricultural enterprises is shaped at the intersection of managerial decisions and structural flexibility. The balanced use of material, labor, and financial resources is a key condition for ensuring their effective development in the long term. As practice shows, successful enterprises demonstrate the ability to transform investments into higher production efficiency, which in turn reduces their sensitivity to inflationary risks and market instability. In this context, increasing production volumes, improving cost management, and developing human capital are decisive factors that determine the competitiveness of agribusiness in the medium and long term.

The developed correlation-regression model of profitability formation in agricultural enterprises reveals patterns that combine the financial, production, and macroeconomic logic of Ukraine's agricultural sector development. The results confirm that profit is not merely a consequence of external market factors but rather a reflection of the internal efficiency of asset, labor, and capital utilization. Labor productivity has proven to be the decisive factor, directly reflecting the technological and organizational maturity of enterprises. In contrast, production cost remains a constraining factor that reduces profitability even under conditions of active investment growth. The model's high accuracy, with a determination coefficient exceeding 0.9, confirms its reliability and suitability for forecasting. Therefore, it can be argued that the main strategic vector for the development of agricultural enterprises should focus on cost reduction, improved asset efficiency, and higher labor productivity, as these elements form the foundation for the financial stability of the agricultural sector.

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MODELING THE PRODUCTIVITY MANAGEMENT PROCESS IN AGRICULTURE: A CASE STUDY OF UKRAINE

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Abstract

The purpose of the study is to form an economic and statistical toolkit for quantitative analysis of the impact of determining factors on the level of labor productivity in the agricultural sector of Ukraine. as well as to substantiate directions for improving the effectiveness of managerial decision-making based on correlation and regression analysis. The study examines factors of labour productivity management in the agrarian sector of Ukraine using a correlation–regression approach and forecasting modelling. It is substantiated that the dynamics of output per employee are shaped by the combined influence of interrelated financial, economic, and production factors, among which the availability of fixed assets, financial performance, and parameters of labour resource utilisation play a decisive role. The empirical basis of the research comprises official statistical data for the period 2010–2024. The study applies methods of correlation and multivariate regression analysis to quantitatively assess the impact of fixed assets, capital investment, net profit, and average monthly wages on the level of labour productivity. It is established that the most significant positive effect on output is exerted by the volume of fixed assets and net profit, which confirms their determining role in enhancing the efficiency of labour utilisation in the agricultural sector. Based on the estimated model, a forecast of labour productivity up to 2030 is developed, indicating the preservation of an upward growth trajectory of output under an inertial development scenario.

Key words**:** *labour productivity in agriculture, productivity management, correlation and regression modelling, effectiveness of managerial decisions*

INTRODUCTION

Under conditions of significant market instability, the issue of labour productivity management in Ukraine's agricultural sector becomes particularly relevant, which is further intensified by ongoing transformations of the agrarian economy and increased requirements for the efficient utilization of labour resources. It should be noted that the instability of the performance results of agricultural enterprises is largely caused by the absence of a comprehensive approach to assessing the impact of factors that shape labour productivity, as well as by the insufficient use of quantitative methods for substantiating managerial decisions in this area. As practical experience shows, management is currently predominantly oriented toward intuitive or normative regulation of labour processes. This, in turn, does not allow for adequate consideration of the functional interrelationships between technical and economic, organisational, and financial factors that directly affect personnel labour productivity.

At the same time, the problem becomes particularly acute in the agricultural sector, where labour productivity significantly depends on such factors as the cost structure, the level of provision with fixed assets, the intensity of capital utilisation, and specific features of labour organisation. In the absence of formalised management models, these factors are considered separately in labour productivity management, which makes it

impossible to assess their combined impact and reduces the effectiveness of managerial decisions. As a result, business entities find themselves in a situation of a gap between the rate of cost growth and changes in efficiency indicators, which reduces the level of their market positions and weakens the development potential of the agricultural sector as a whole.

In scientific discourse, the issue of labor productivity growth in agriculture is traditionally covered comprehensively and covers a wide range of approaches and analytical interpretations.

In particular, applied tools for its management at the micro- and meso-levels are discussed in the works of such scholars and practitioners as N. Antoniuk [1], I. Arakelova [2], N. Khomiuk [3], V. Kostiuk [4], I. Mazniev [5], L. Mialkovska [6], M. Pavliuk [7], A. Popescu [8-19], M. Rudenko [20], V. Sarioglo [21], T. Shmatkovska [22-28], R. Sodoma [29-30], N. Vavdiiuk [32-33] and A. Verzun [34]. At the same time, there remains a need to develop economic and statistical models capable of quantitatively reflecting the impact of key management factors on labour productivity in order to enhance the efficiency of agricultural enterprises in Ukraine.

In this context, the purpose of this study is to set up an economic and statistical model for quantifying the impact of key factors on labour productivity in Ukraine's agricultural sector and to emphasize the directions to improve the effectiveness of managerial decision-making based on correlation and regression analysis.

MATERIALS AND METHODS

The information base of the study was official statistical materials for 2010–2024, which reflect trends in labor productivity and key financial and economic characteristics of the functioning of agricultural enterprises in Ukraine. The dependent variable was the output per employee as an integral characteristic of labor resource efficiency.

The system of explanatory factors includes:

- valuation of fixed assets of agricultural business entities;
- volumes of capital investments in agricultural production;
- value of net financial result;
- average level of monthly wages in the industry.

The methodological tools of the study are based on the application of a correlation-regression approach, which provided the possibility of quantitative measurement of the intensity and direction of the influence of selected determinants on the dynamics of labor productivity. At the first stage, Pearson pairwise correlation coefficients were calculated to identify the closeness of relationships between variables and to perform a preliminary diagnosis of multicollinearity. At the second stage, a multivariate linear regression model of the following form was constructed:

$$y = \beta_0 + \beta_2 x_1 + \beta_2 x_2 + \beta_2 x_3 + \beta_2 x_4 + \varepsilon \ldots. \quad (1)$$

where:

y – denotes labour productivity;

x_1–x_4 – the explanatory variables;

β_i – the model parameters;

ε – the random error term.

Parameter estimation was carried out using the ordinary least squares method, which minimises the sum of squared residuals:

$$\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \rightarrow min \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The reliability and quality of the model were tested using the coefficient of determination R^2, the adjusted coefficient R^2, the Fisher F-test, and the Student t-test for individual parameters. To enhance the interpretability of the results, elasticity coefficients were additionally calculated according to the formula:

$$E_i = \beta_i \times \frac{x_i}{y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This made it possible to determine the elasticity of labor productivity, that is, to establish the extent to which it changes in relative terms with an increase in the corresponding factor by one percent.

In general, the set of analytical tools used provided the appropriate level of scientific verification of the conclusions obtained, confirmed their statistical reliability and practical relevance for conducting industry economic research.

RESULTS AND DISCUSSIONS

The assessment of labour productivity in the agricultural sector requires a relevant consideration of the key factors that influence this indicator. The importance of their analytical evaluation is determined by the functional need to enhance the soundness of managerial decision-making. Since the agricultural sector is characterized by high resource intensity of production, it is particularly sensitive to internal organizational and economic changes. Under such conditions, labour productivity acts as an integral indicator of the efficiency of labour resource utilization and, at the same time, reflects the effectiveness of combining financial and technical–organizational aspects of agricultural production. Therefore, without an in-depth analytical examination of factor influences, its dynamics remain merely a formal indicator that is not suitable for practical use in enterprise management.

From a practical perspective, the analytical assessment of labour productivity makes it possible to identify its key determinants as well as to reveal latent interrelationships between the dependent and explanatory variables. This creates a basis for the transition to effective managerial actions aimed at optimizing the cost structure and rationalizing labour processes in the sector. It should be noted that for agricultural enterprises in Ukraine such an assessment is of particular importance, as it enables the adaptation of management approaches to sector-specific characteristics and the formation of a comprehensive view of labour productivity growth reserves.

An important determinant of the level of labor productivity in agricultural enterprises is the volume of fixed assets, because it is the material and technical base that determines the production potential and determines the effectiveness of the use of labor resources. Expanding the value of the active part of the funds and increasing the intensity of their renewal, provided they are effectively operated, ensures a decrease in labor costs per unit of output and an increase in the output per employee. In this regard, it is advisable to analyze the trends in the change of this factor in the agricultural sector of Ukraine during the recent period. (Fig. 1).

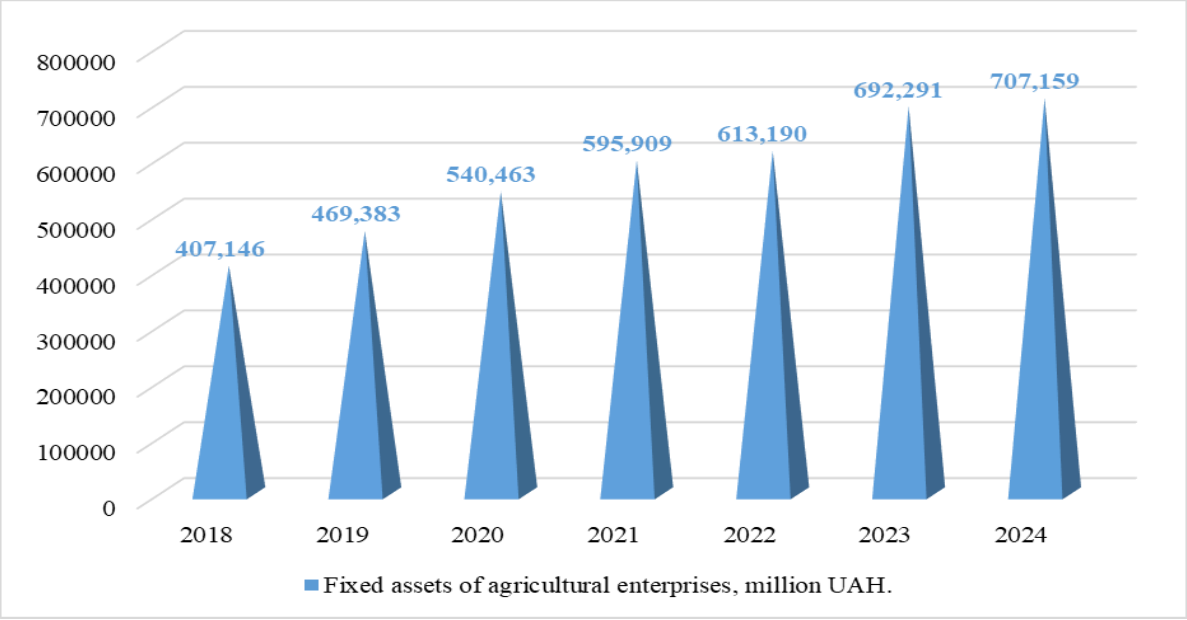


Fig. 1. Change in the cost of fixed assets and production costs in the agricultural sector of Ukraine in 2018–2024..
Source: compiled by the authors based on [31].

The analysis shows that during the studied period, a general increase in the value of fixed assets was recorded in the agricultural sector of Ukraine. At the same time, the intensity of growth and the trajectory of changes were not stable, which indicates the undulation and

heterogeneity of the dynamics of this indicator. In particular, the value of fixed assets of agricultural enterprises demonstrated a persistent upward trend, increasing from UAH 407.1 billion in 2018 to UAH 707.2 billion in 2024, which indicates a gradual expansion of the capital base and an increase in capital–labour intensity. Such dynamics reflect the intention of enterprises to preserve their production potential and to ensure technological support of labour processes even under conditions of growing cost pressure and market instability. However, as experts note, the growth of fixed assets was not accompanied by a proportional containment of production costs, which indicates a limited transformation of investment into improvements in operational efficiency [21]. Therefore, it can be concluded that the expansion of the material and technical base of agricultural enterprises in Ukraine occurred in parallel with an intensification of production cost pressure. Such dynamics create the risk of a declining return on invested resources and require more coordinated management of the interrelationship between capital investment, production costs, and the efficiency of labour utilization. Accordingly, the changes in investment volumes and financial results of agricultural enterprises over the same period are assessed below (Fig. 2).

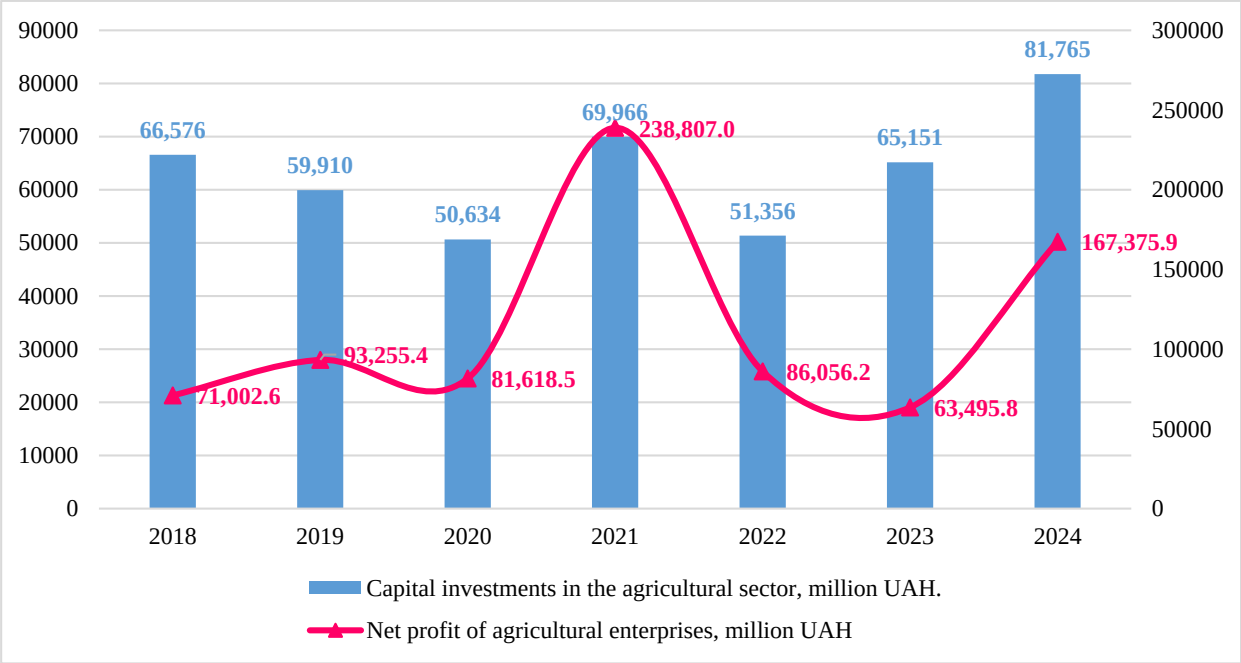


fig. 2. trends in the volume of capital investments and net financial results of agricultural enterprises in ukraine in 2018–2024.
Source: compiled by the authors based on [31].

The study shows that during the specified period the trajectory of changes in the relevant indicators was unstable and had pronounced fluctuations. at the same time, there is no clear linear or directly proportional relationship between the volume of investment and the amount of net profit, which indicates the indirect and more complex nature of their relationship. capital investment in the agricultural sector during the analysed period fluctuated within the range of uah 50–70 billion, with a peak in 2021, followed by a decline and subsequent recovery to UAH 81.7 billion in 2024. Such dynamics indicate the instability of investment activity and its sensitivity to changes in general economic conditions. At the same time, the indicator of the net financial result of agricultural enterprises was marked by significantly greater volatility. After a phase of unstable fluctuations, in 2021 a rapid increase in profitability was recorded to UAH 238.8 billion, which significantly exceeded the level of previous and subsequent periods and formed

a peak value for the studied interval. However, over the following two years net profit declined substantially, falling to levels comparable to pre-crisis values, and only in 2024 did its growth resume, reaching UAH 167.4 billion. This suggests that exceptionally high financial results were short-term in nature and were not supported by stable investment dynamics.

Overall, the presence of a structural gap between investment inputs and the financial results of agricultural enterprises can be asserted. In this context, investments are not transformed into sustained profitability growth, while financial results largely depend on external conditions and the internal efficiency of resource management.

At the same time, the long-term production performance of the agricultural sector, which is based on labour productivity growth, is directly related to personnel remuneration expenditures. These expenditures act as a key factor influencing labour performance indicators of agricultural enterprises. Therefore, changes in wage levels and trends in their dynamics in Ukraine's agricultural sector are assessed below (Fig. 3).

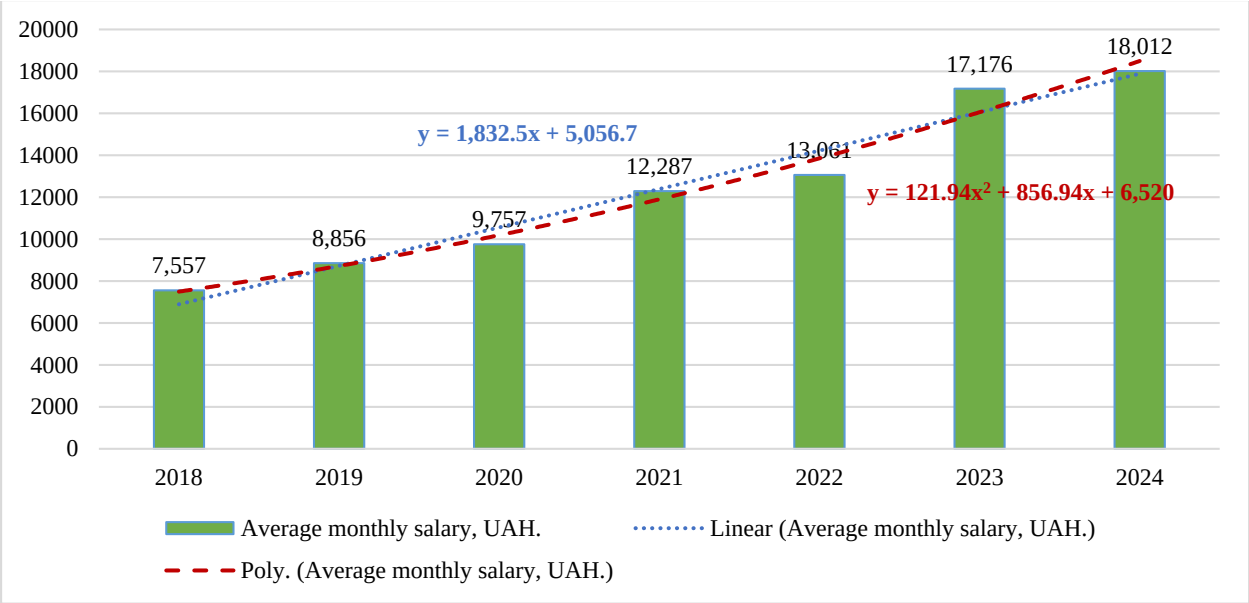


Fig. 3. Trend assessment of changes in wage levels at agricultural enterprises in Ukraine in 2018–2024.
Source: compiled by the author based on [31].

As shown in Fig. 3, the dynamics of wages at agricultural enterprises in Ukraine during the analyzed period demonstrate a stable upward trend with a gradual acceleration of growth rates. In particular, the linear trend defined by the equation y = 1,832.5x + 5,056.7 indicates an average annual increase in the average monthly wage of almost UAH 1.8 thousand, reflecting the long-term and systemic nature of rising labour remuneration costs in the agriculture. Overall, during the studied interval, the nominal average monthly wage in the agricultural sector increased from UAH 7,557 in 2018 to UAH 18,012 in 2024, which means an increase of more than 2.3 times and indicates a significant increase in the valuation of labor resources in the industry.. At the same time, the second-order polynomial trend reveals the unevenness of this dynamic and the presence of accelerated growth in the final years of the period. The shape of the curve indicates that the initial pace of wage growth was moderate; however, after 2020 a significant strengthening of the upward trend occurred. This implies that actual annual wage increases exceeded the average values determined by the linear model, particularly in 2023–2024, when growth became most intensive.

Thus, it can be concluded that there has been a structural increase in the cost of labour resources in the agricultural sector. In the absence of proportional growth in labour productivity, such a trend may transform into additional pressure on production costs, which necessitates the alignment of wage policy with

the efficiency of labour resource utilisation and the overall effectiveness of production and managerial decisions.

To obtain a generalised assessment of the impact of individual factors on labour productivity in Ukraine's agricultural sector, a correlation and regression analysis was conducted using the MS Excel analysis package to identify the relevant relationships. The variables used in the analysis correspond to the previously discussed determinants of labour productivity (Table 1).

Table 1. A set of calculated and statistical indicators for 2010–2024, formed for constructing a correlation-regression model.

Year	Labour productivity, thousand UAH (y)	Fixed assets, million UAH (x1)	Capital investment in agriculture, million UAH (x2)	Net profit of agricultural enterprises, million UAH (x3)	Average monthly wage in the agricultural sector, thousand UAH (x4)
2010	61.2	113,388	11,568.4	17,170.6	1.47
2011	74.7	118,018	17,039.5	25,341.3	1.85
2012	78.1	137,639	19,205.8	26,787.2	2.09
2013	57.9	156,013	18,919.1	14,984.4	2.34
2014	92.8	171,392	18,582.4	21,481.4	2.56
2015	145.1	210,169	29,798.5	102,849.1	3.31
2016	165.7	270,467	50,319.6	90,613.2	4.20
2017	183.2	341,622	64,084.1	68,858.5	6.06
2018	209.7	407,146	66,576.3	71,002.6	7.56
2019	211.5	469,383	59,910.1	93,255.4	8.86
2020	249.6	540,463	50,634.3	81,618.5	9.76
2021	382.6	595,909	69,966.3	238,801.0	12.29
2022	279.3	613,190	51,355.7	86,056.2	13.06
2023	308.0	692,291	65,150.6	63,495.8	14.63
2024	327.3	707,159	81,764.6	167,375.9	18.01

Source: [31].

Table 2 presents the main quantitative characteristics of the developed econometric model, which reflects the dependence of the level of labor productivity in the agricultural sector on the selected factor variables.

Table 2. Key parameters of the correlation-regression model of the influence of determinants on the labor productivity indicator in the agricultural sector of Ukraine

Indicator	Coefficient (B)	Standard error	Student's t-statistic	statistical significance level (p-value)
Constant (y)	0.498	10.362	0.05	0.963
Fixed assets (x1)	0.000535	0.000107	5.01	0.00053
Production cost of agricultural enterprises (x2)	−0.000018	0.000368	−0.05	0.963
Capital investment in agriculture (x3)	0.000630	0.000093	6.75	0.00005
Net profit of agricultural enterprises (x4)	−8.063	4.096	−1.97	0.077

Source: own research.

The correlation and regression model obtained as a result of the analysis reflects the dependence of labour productivity of agricultural enterprises in Ukraine on a set of managerial and economic factors and has the following form:

$$y = 0.498 + 0.000535x_1 - 0.000018x_2 + 0.00063x_3 - 8.063x_4$$

From the obtained equation of the econometric model, it follows that the parameter for the factor "fixed assets" (0.000535) is interpreted as the marginal effect of this factor: an increase in their value by 1 million UAH causes, under other constant conditions, an average increase in labor productivity by approximately 0.535 thousand UAH. This confirms the positive effect of capital intensity of production on the efficiency of labour utilisation and reflects the role of the material and technical base in shaping output per employee. In contrast, the coefficient for capital investment has a negative but statistically insignificant value (−0.000018), which indicates the absence of a direct short-term impact of investment activity on labour productivity. This situation may be explained by the delayed effect of investments, when their outcomes do not materialise immediately but emerge in subsequent periods after the completion of the investment cycle and the full commissioning of assets.

It should be noted that the most significant positive impact among the analyzed factors is demonstrated by the net profit of agricultural enterprises, with a coefficient value of 0.000630. This means that an increase in net profit by UAH 1 million is accompanied by an average increase in labour productivity of

UAH 0.63 thousand, which confirms the close relationship between the financial performance of enterprises and the efficiency of labour resource utilization.

At the same time, the coefficient for the wage indicator has a negative value (−8.063), which indicates the dominance of the cost effect of wage growth over its stimulating function under conditions where wage increases are not accompanied by proportional growth in output. However, it should be emphasized that this result is driven by the high correlation of this indicator with other explanatory variables and reflects the structural features of labour productivity formation in the agricultural sector. Given the relatively low values of some coefficients in the developed model, which are caused by different numerical scales of the analysed factors, an elasticity table is constructed to provide a more robust interpretation of the obtained results (Table 3).

Table 3. Elasticity of labour productivity based on the developed correlation and regression model

Factor	Elasticity coefficient
Fixed assets (x1)	1.05
Capital investment (x2)	−0.004
Net profit (x3)	0.26
Average monthly wage (x4)	−0.31

Source: own research.

The obtained elasticity coefficients indicate that the most sensitive factor influencing labour productivity is the volume of fixed assets: an increase in the cost of capital resources by 1% is accompanied by an average increase in labor productivity of approximately 1.05%, which indicates the decisive importance of providing enterprises with basic means for forming the level of production. At the same time, the net profit indicator demonstrates a positive, but less intense, effect on labor productivity: its increase by 1% results in an increase in labor productivity by 0.26% rise in labour productivity, reflecting the link between financial performance and the efficiency of labour utilization. In contrast, capital investment is characterized by an almost zero elasticity, which indicates the delayed nature of its impact. The negative value of the elasticity coefficient for the average monthly wage (–0.31) means that the increase in wages in the analyzed period was accompanied by the dominance of the cost effect without a corresponding increase in performance indicators.

Thus, it can be stated that the constructed model demonstrates the multifactorial nature of the formation of labor productivity and confirms the decisive importance of financial results and the level of capital provision in its dynamics. At the same time, the management of investment processes and labor remuneration policy requires greater internal consistency in the decision-making system of agricultural enterprises.

The assessment of model parameters provides grounds for the following generalizations:

– the coefficient of determination $R^2 = 0.987$ indicates an extremely high explanatory power of the equation, since about 98.7% of the variation in labor productivity is explained by the cumulative influence of the included management factors, which confirms the representativeness of the formed system of variables for analyzing the efficiency of using labor potential in the agricultural sector.

The adjusted coefficient of determination $R^2 = 0.982$ differs only marginally from R^2, indicating the absence of redundant factors in the model and a high accuracy of estimation, taking into account the number of explanatory variables and the sample size.

The value of the Fisher F-test equals 190.48 with a significance level of $p = 2.17 \cdot 10^{-9}$, which confirms the overall statistical significance of the model and allows rejection of the null hypothesis of no relationship between the dependent and explanatory variables. Therefore, the constructed model is econometrically reliable and suitable for analytical inference.

An analysis of the Student t-tests shows that the statistically significant factors are the volume of fixed assets and the net profit of agricultural enterprises, for which the p-values are below 0.05. At the same time, capital investment and the average monthly wage do not demonstrate independent statistical significance within the given specification, which is explained by the presence of high mutual correlation between certain explanatory variables and the delayed nature of their impact.

Overall, the obtained values of the main statistical coefficients confirm the high quality

of the model and the feasibility of its use in studying the management factors of labour productivity in Ukraine's agricultural sector.

In addition, an assessment of the correlation matrix is performed (Table 4).

Table 4. Matrix of pairwise correlations between the explanatory variables and the dependent variable

Indicators	Labour productivity (y)	Fixed assets (x1)	Capital investment (x2)	Net profit (x3)	Average monthly wage (x4)
Labour productivity (y)	1	0.607	0.607	0.646	0.244
Fixed assets (x1)		1	0.876	0.843	0.167
Production cost (x2)			1	0.891	0.084
Capital investment (x3)				1	0.044
Net profit (x4)					1

Source: own research.

The analysis of the correlation matrix indicates the presence of strong positive relationships between labour productivity and most of the explanatory variables. The maximum value of the correlation coefficient was found between the labor productivity indicator and the cost of fixed assets (r = 0.956), which indicates the key importance of the level of capitalization in the formation of output. A high degree of closeness of the connection is also observed between labor productivity and average monthly wages (r = 0.934), as well as the volume of capital investments (r = 0.892), which reflects the synchronization of changes in these indicators in the studied period. At the same time, strong interrelationships are identified among the explanatory variables themselves, in particular between fixed assets and wages (r = 0.984), which points to the presence of multicollinearity. Such a correlation structure explains the reduction in the statistical significance of certain coefficients in the regression model and requires a cautious interpretation of the partial effects of these factors.

Based on the formed correlation-regression model, we will build a forecast of changes in labor productivity in Ukrainian agriculture until 2030. (Fig. 4).

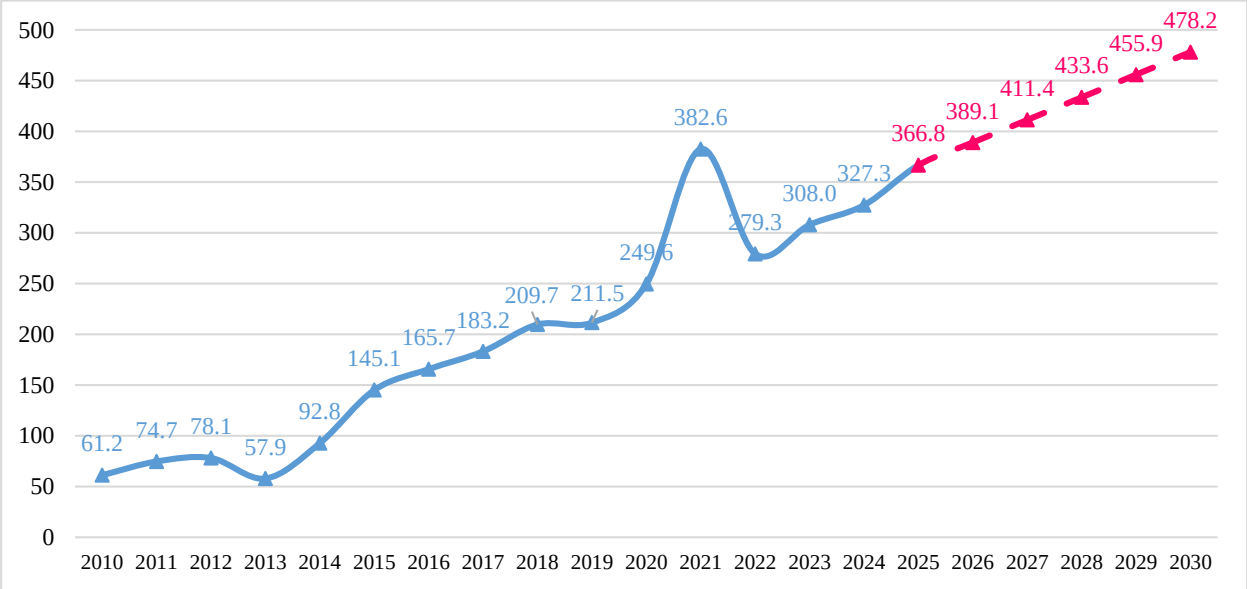


Fig. 4. Forecast of changes in labor productivity in the agricultural sector of Ukraine until 2030, thousand UAH.
Source: own research.

The forecasting results give reason to expect continued stable positive dynamics of labor productivity in the agricultural sector of Ukraine in the following time intervals. The model-based forecast, constructed using the correlation and regression relationship, demonstrates a gradual increase in labour productivity without sharp fluctuations, indicating an inertial pattern of sectoral development under the assumption that the current parameters of the factor environment remain unchanged. It is expected that the main contribution to the projected growth will be ensured by the expansion of fixed assets and the increase in net profit of agricultural enterprises. This confirms the decisive role of these factors in shaping output. At the same time, the impact of wage growth in the model

has a restraining character, which is reflected in moderate rates of projected growth. Overall, the graph illustrates that by 2030 labour productivity growth will occur in an evolutionary manner, while achieving higher growth rates will require structural changes in resource utilization and improvements in the efficiency of their management.

CONCLUSIONS

The conducted study made it possible to develop a comprehensive analytical view of the process of labour productivity management in Ukraine's agricultural sector based on a quantitative integration of financial, economic, and production parameters. The obtained results confirm that the dynamics of output per employee are shaped not by isolated and unrelated factors, but by their interaction within a unified system of managerial decision-making. The most significant role in labour productivity growth is played by the level of provision of agricultural enterprises with fixed assets and the financial performance of their operations, which reflects the leading importance of the material and technical base and the ability of enterprises to generate profit in enhancing the efficiency of labour resource utilisation. The modelling results indicate a limited short-term impact of investment activity and an ambiguous role of increasing wage expenditures, pointing to the need for a more coordinated combination of investment, financial, and human resource policies at agricultural enterprises.

The constructed correlation and regression model is characterized by high explanatory power and statistical reliability, which allows it to be used as an analytical tool for substantiating managerial decisions at the sectoral level. Ultimately, it is demonstrated that increasing labour productivity in the agricultural sector requires a systemic approach to resource management, focused not only on expanding expenditures, but primarily on improving the efficiency of their transformation into final performance outcomes.

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EUROPEAN UNION AND ROMANIAN AGRI-FOOD TRADE WITH MERCOSUR: AN ANALYSIS

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Abstract

The recently signed EU-Mercosur agreement has generated much debate as of late, as well as EU farmers' opposition. The present paper investigates the magnitude and composition of trade between the Mercosur and EU, respectively Romania, for the last five years, in order to identify potential effects of the agreement upon sensitive agri-food products. Several key economic indicators were taken into consideration for the purpose of this study, with focus on two such sensitive products - poultry meat and beef: production, consumption, self-sufficiency rates, trade – exports, imports, balance in value and quantity terms, concentration ratios and geographical orientation of the trade flows. The results show that the values and volumes of agri-food trade with Mercosur were rather low, due mostly to important tariffs and other trade barriers. The perspective of implementation of the new Tariff Rate Quotas (TRQs) for the two analyzed products show that most likely no major disruptions on those markets should be expected. Nevertheless, the EU-Mercosur Agreement provides important advantages for trade, but also appropriate protection for the EU agri-food sector and safety provisions for consumers.

Key words**:** *agri-food trade, Mercosur, EU, Romania, poultry meat, beef*

INTRODUCTION

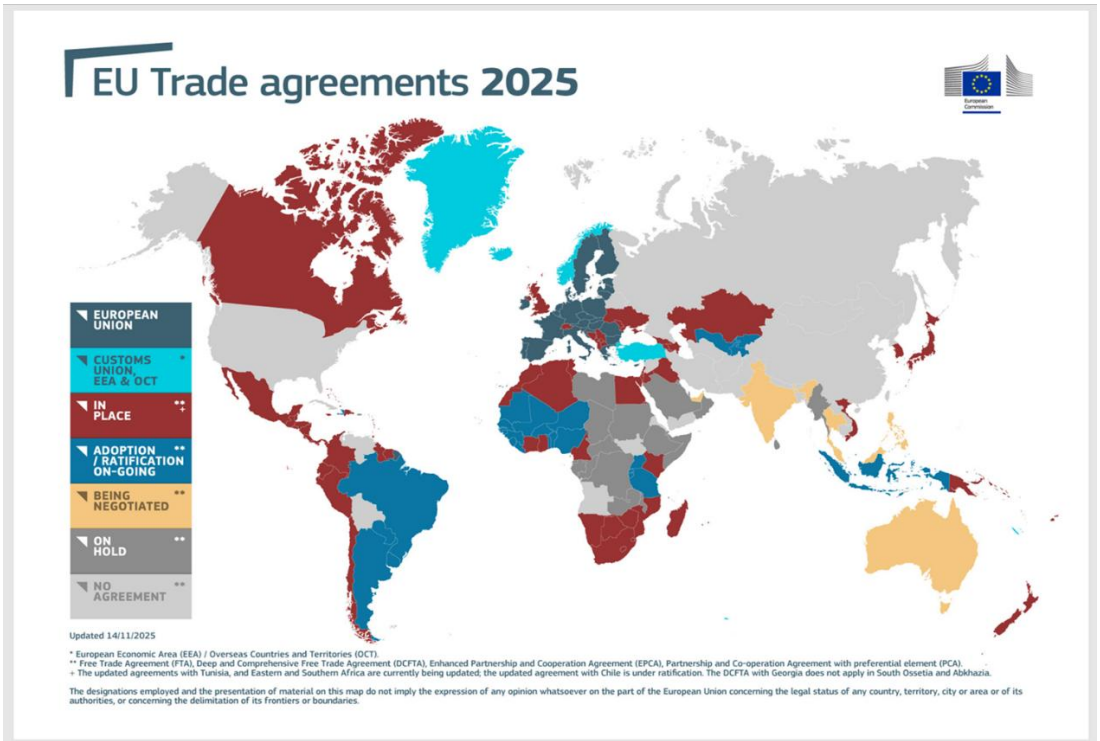
MERCOSUR (the Southern Common Market) is a South-American economic organization, established in 1991 by the Treaty of Asunción in 1991, and completed in 1994 by The Ouro Preto Protocol which formalized it as a legal personality under international law. It currently has five full members - Argentina, Brazil, Paraguay, Uruguay and Bolivia; the latter is still in the process of ratification process and incorporation of the acquis (therefore was not included in the negotiations for the agreement with the EU). It has also a suspended member (Venezuela), seven associated states (Chile, Colombia, Ecuador, Guyana, Panama, Peru and Suriname), and two observer states: Mexico and New Zealand.

Argentina, Brazil, Paraguay, Uruguay (denominated also as Mercosur 4) form a customs union and a free trade zone since 1995, and only these four countries are currently part in the recently concluded agreements with the EU.

The recently signed EU-Mercosur Trade Agreement (in December 2025) has generated much debate among policy makers and farmers in many EU countries.

The EU-Mercosur agreement has been finalized after about two and a half decades of negotiations. It is just one – albeit an important one - of many trade agreements already in place or still in various stages of negotiations or adoption between the EU and many countries or groups of countries (over 40 agreements with over 80 countries) (Map 1).

Currently, the EU has in place various forms of trade agreements, such as: Agreement on the European Economic Area; EU-UK Trade and Cooperation Agreement; Free Trade Agreements (e.g. with Andean Community, Mexico, New Zealand, Singapore, South Korea, Vietnam – to name just a few); Deep and Comprehensive Free Trade Area (with Republic of Moldova, Ukraine and Georgia); Stabilization and Association Agreements with candidate countries from the Western Balkans area; customs union (e.g. with Turkey); Euro-Mediterranean Association Agreement; Economic Partnership Agreement (with Japan); Comprehensive Economic and Trade Agreement (with Canada) etc.



Map.1. EU trade agreements map (2025)
Source: [6]

The primary aims of such agreements are facilitating trade, diminishing tariffs and gradually lowering (and eventually removing) trade barriers, in accordance with the basic objectives of the World Trade Organization. The EU preferential agreements offer to partners tariff reductions (partial or total, for unlimited volumes of products or only for quotas of goods), as well as better access to the Single Market. Non-preferential agreements are part of various types of partnership and cooperation agreements, which include commercial, political, environmental, legislative and other provisions. All these agreements aim to expand the EU's cooperation areas, in certain cases precede EU enlargements and at the same time provide support to less developed countries by facilitating trade with them.

Currently, the USA is the largest EU export destination and the second largest source of imports; but in the context of the increased volatility in trade relations between the two parties since 2025, those large shares became a vulnerability for the EU. Consequently, in order to reduce the mentioned volatility, the EU needs to diversify its export destinations. It also needs to enlarge the import source areas to face the growing insecure reliance on the few import origins for important rare minerals (such as China). In this increasingly complicated international context, the agreement with Mercosur 4, as well as the recently concluded negotiations on a free trade agreement with India seem to be part of a solution: EU-Mercosur would mean an integrated market ranging about 700 million consumers, and about 20% of the world GDP; while the agreement with India would open a huge market of 1.45 billion consumers, a country with a growing economy, which already reached the fifth largest GDP in the world in 2025 [18].

In this context, this research aimed to quantify the magnitude and trade volume and structure between Mercosur and EU, respectively Romania, during the last five years, in order to emphasize the potential effects of the agreement upon sensitive agri-food products.

MATERIALS AND METHODS

For the present study, the empirical data were collected from national (Tempo-online) and international databases (Eurostat, Faostat, Trade Map). Data for trade are of chapters 1-

24 in the Combined Nomenclature which include values for agri-food products. Various academic publications, articles, studies, analyses were consulted, together with official documents and reports from the EU Commission, the Romanian Ministry of Agriculture and Rural Development and Ministry of Economy, Digitalization, Entrepreneurship and Tourism.

Several key economic indicators were taken into consideration for the purpose of this study: production and consumption of several sensitive agri-food products, trade – exports, imports, balance in value and quantity terms, and geographical orientation of the trade flows for the last five years. The concentration ratio was calculated for exports and imports, using the formulae:

$$CRExp_n = \frac{\sum_1^n Exp}{\sum_1^{24} Exp} * 100 \quad \text{.....(1)}$$

$$CRImp_n = \frac{\sum_1^n Imp}{\sum_1^{24} Imp} * 100 \quad \text{.....(2)}$$

where:

$CRExp_n$ = concentration ratio of top n exported product groups,

$CRImp_n$= concentration ratio of top n imported product groups; n=5 or n=10.

RESULTS AND DISCUSSIONS

The EU-Mercosur trade agreement: next steps.

The negotiated agreement includes two parts: the Interim Trade Agreement (ITA) and the Partnership Agreement (EMPA).

They were both signed in January 2026, but their application will be sequential: first, the ITA (which concerns the commercial aspects) will be applied after the signing by the EU Council and the EU Parliament favorable vote.

The EU Parliament sent the legal texts to the EU Court of Justice for a supplementary check-up, which might postpone the implementation of the agreement by 18-24 months.

Yet, the EU Commission may decide its provisional application since March 2026.

The Partnership Agreement (EMPA) is far more encompassing than the ITA: besides the commercial aspects, there are many political and cooperation aspects. In order to fully enter into force, it needs to be ratified by all Member States, when it will replace ITA. After the first three years, then every other five years, the commercial part will be re-analyzed.

EU trade with Mercosur

The value of EU total trade with Mercosur countries had an overall upward trend over the last decade, despite a fall in 2020 – the pandemic year. Exports varied between 35.7 and 56.1 billion EUR in 2016-2024, while imports varied between 33.4 and 63 billion EUR (Fig. 1). The trade balance turned positive since 2012, with just two exceptions: 2022 (-7.4 billion EUR) and 2024 (-0.8 billion EUR).

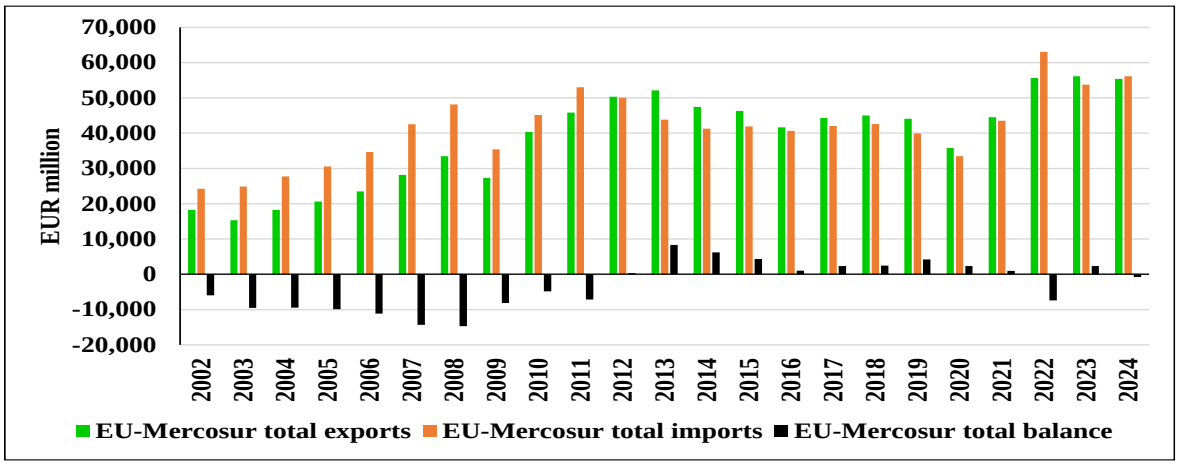


Fig. 1. Total trade between EU and Mercosur.
Source: author's calculations using Eurostat data [7].

Nevertheless, the share of Mercosur has been rather low in the total EU trade, 2.08% in exports and 2.1% in imports (averages 2020-2024) (Table 1). On the other hand, EU has a strong position in the Mercosur trade: it ranks second among the partners in goods trade, after China and ahead of the USA. In 2024, the EU exports to Mercosur consisted mostly of machinery and appliances (28.1% of total exports), chemicals and pharmaceutical products (25%), and transport equipment (12.1%).

Table 1. Share of Mercosur 4 in EU trade

Item	2020	2021	2022	2023	2024	Average 2020-2024
% in total EU exports	1.86	2.04	2.16	2.19	2.13	2.08
% in total EU imports	1.94	2.05	2.10	2.13	2.29	2.10
% in agri-food EU exports	1.20	1.16	1.26	1.40	1.39	1.28
% in agri-food EU imports	11.91	13.28	14.43	12.64	12.34	12.92

Source: author's calculations using Eurostat data [7].

Agri-food products had a rather low share in exports (1.4%) to Mercosur, but accounted for 12.3% in EU total imports. The composition of Mercosur's total exports to the EU in 2024 was reversed: agri-food products took the largest part (42.7%), while non-agricultural goods had lower shares: 30.5% mineral products, and 6.8% pulp and paper [7].

EU is a major player on the international agri-food markets, and its trade destinations and origins are diversified. Mercosur protected its agri-food markets with rather high tariffs (up to 35% on several products, e.g. wines), therefore the values of EU agri-food exports to Mercosur were not very high in 2020-2024 (2.8 billion EUR in average) (Fig. 1).

Since the agri-food products were the main goods imported by EU from Mercosur, their value was significantly higher (multiplied by a factor of 10). The result was a high deficit of the agri-food trade balance, which reached the maximum in 2022 (-25.4 billion EUR).

There are important differences between the dynamics of EU exports and imports (Fig. 2). The upward agri-food export trend was quite smooth, with an R^2 value of 0.95; on the contrary, the variability in imports was much higher (R^2 =0.54), indicating inconstancy on those markets.

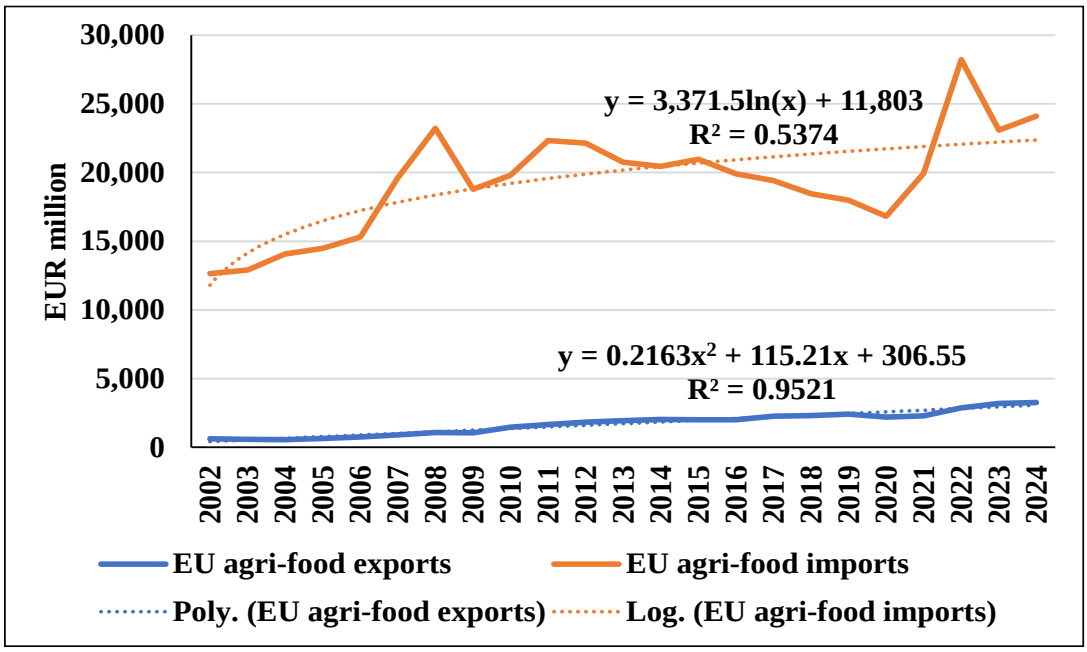


Fig. 2. Dynamics of EU-Mercosur agri-food trade
Source: author's calculations using Eurostat data [7].

The analysis of the EU-Mercosur agri-food trade by country shows that the bulk of EU exports goes to Brazil (81%, average 2020-2024), a mere 9% goes to Argentina, the remaining 10% being divided between Paraguay and Uruguay. In the case of EU agri-foods imports from Mercosur, the concentration is clear as well: 70% comes from Brazil, 26% form Argentina, while the other two countries account together only 4%.

Table 2. Top ten agri-food product groups traded by EU with Mercosur (averages 2020-2024)

Quantity (tonnes)	**HS Code – product group**	**Value (million EUR)**	***Value (% in total)***
1,416.57	**EXPORTS - TOTAL 01-24**	**2,756.29**	***100.0***
283.38	22-Beverages	513.19	*18.6*
102.69	15-Fats and oils	484.82	*17.6*
236.33	20-Processed vegetables and fruit products	233.63	*8.5*
316.14	11-Cereal flours, malt, starch	186.16	*6.8*
32.23	21-Miscellaneous processed food products (soups, sauces, ice cream etc.)	176.63	*6.4*
134.66	08-Fruit and nuts	167.21	*6.1*
64.46	23-Animal feed and fodder	137.60	*5.0*
51.93	19-Bakery and pastry products	137.44	*5.0*
25.86	12-Oilseeds	122.08	*4.4*
24.91	18-Cocoa and cocoa products	108.86	*3.9*
33,931.73	**Imports - TOTAL 01-24**	**22,438.85**	***100.0***
16,120.60	23-Animal feed and fodder	6,652.26	*29.6*
7,895.06	12-Oilseeds	4,120.29	*18.4*
1,078.19	09-Coffee, tea, spices	3,474.06	*15.5*
328.10	02-Meat	1,646.34	*7.3*
4,489.47	10-Cereals	1,188.81	*5.3*
1,224.46	20-Processed vegetables and fruit products	1,171.50	*5.2*
808.88	08-Fruit and nuts	970.17	*4.3*
128.28	03-Fish	674.76	*3.0*
154.83	24-Tobacco and tobacco products	640.91	*2.9*
297.20	15-Fats and oils	382.20	*1.7*

Source: author's calculations using Eurostat data [7].

In terms of structure of the EU agri-food trade with Mercosur, by groups of products, one can see that the range of exports is rather diversified, indicated by the concentration ratios (CR_5=57.8; CR_{10}=82.3), meaning that the top 5 product groups account for 58% of the total exports value, while the top 10 product groups (out of 24 total agri-food product groups) account for 82% of the exports value (Table 2). In 2020-2024, the main exports of EU to Mercosur were beverages (mostly wines), edible oils and various processed products (fruits, vegetables, miscellaneous preparations), but due to rather high tariff rates, no product group exceeded 520 million EUR in value. On the contrary, EU imports from Mercosur had much higher values: 6.6 billion EUR for feed and fodder (mainly oilseed cakes), 4.1 billion EUR for oilseeds (mostly soybeans), 3.5 billion EUR for coffee.

Romanian trade with Mercosur

The value of Romanian total trade with Mercosur countries varied largely (Fig. 3), but despite some peaks in 2013-2014 for exports and 2011 and 2022 for imports, it remained very small: exports never exceeded 310 million EUR, while maximum imports value reached 480 million EUR. During the last five years, total exports varied between 152 and 251 million EUR, with an annual average of 206 million EUR (2020-2024). At the same time, the imports values were double, varying between 332 and 525 million EUR, with an annual average of 426 million EUR; the resulting balance has been permanently negative; it varied between -163 and -295 million EUR, with a -220 million EUR average in 2020-2024.

Table 3. Share of Mercosur in Romanian trade

Item	**2020**	**2021**	**2022**	**2023**	**2024**	**Average 2020-2024**
% in overall Romanian exports	0.25	0.24	0.25	0.24	0.27	0.25
% in overall Romanian imports	0.41	0.46	0.42	0.33	0.33	0.39
% in agri-food Romanian exports	0.01	0.00	0.01	0.01	0.01	0.01
% in agri-food Romanian imports	3.00	3.35	3.11	2.33	1.96	2.69

Source: author's calculations using Eurostat data [7].

Such values show the extremely low share of trade with Mercosur countries in the overall Romanian trade: 0.25% for exports and 0.39% for imports respectively (Table 3).

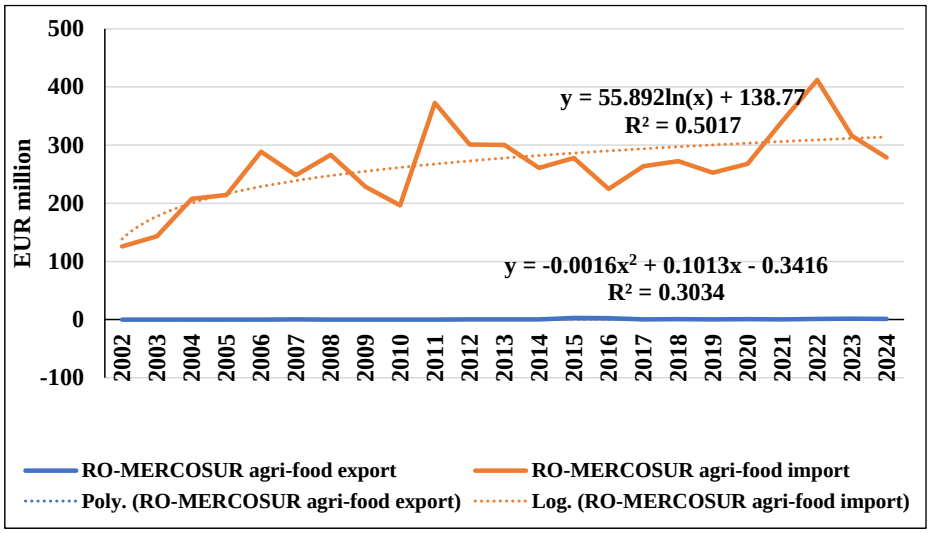


Fig. 5. Dynamics of EU-Mercosur agri-food trade
Source: author's calculations using Eurostat data [7].



Fig. 6. Distribution of the Romanian agri-food trade among the four component Mercosur countries (averages 2020-2024)
Source: author's calculations using Eurostat data [7].

A detailed look at the Romanian agri-food trade with Mercosur by each of the four component countries (Fig. 6) reveals that the bulk of exports go to Brazil, followed by Argentina and Uruguay. Brazil and Argentina are the main origins for agri-food imports. With such a discrepancy between exports and imports, the resulting balance has been permanently negative, and the Romanian agri-food trade with each of the four countries, no matter how small or large, yielded a negative balance.

The analysis of the structure of the Romanian agri-food trade with Mercosur shows that exports included chocolate, wines, tobacco products, miscellaneous edible preparations, but all values were less than 0.5 million EUR (Table 4).

Imports, albeit with much higher values, belong to a narrow range of products: top five product groups account for 97% (CR_5) of the total agri-food import values, while top 10 products (CR_{10}) account for 99.3%. More than half of the Romanian imports were soybean meals (424,000 tonnes), followed by oilseeds (mainly soybeans, 91,000 tonnes), raw sugar (74,000 tonnes), raw tobacco (7,500 tonnes) and coffee (4,200 tonnes).

Table 4. Top ten agri-food product groups traded by Romania with Mercosur (averages 2020-2024)

Quantity (tonnes)	HS Code – product group	Value (million EUR)	*Value (% in total)*
314.9	**EXPORTS - TOTAL 01-24**	**0.97**	***100.0***
58.6	18-Cocoa and cocoa products	0.41	*42.6*
61.3	22-Beverages	0.17	*17.1*
6.1	24-Tobacco and tobacco products	0.07	*7.7*
46.4	21-Miscellaneous processed food products (soups, sauces, ice cream etc.)	0.07	*7.3*
16.6	12-Oilseeds	0.07	*7.2*
49.3	08-Fruit and nuts	0.06	*6.7*
45.2	19-Bakery and pastry products	0.06	*6.6*
29.8	15-Fats and oils	0.03	*3.5*
0.3	05-Other animal origin products	0.01	*0.5*
1.2	20-Processed vegetables and fruit products	0.00	*0.5*
606.69	**Imports - TOTAL 01-24**	**323.12**	***100.0***
423.63	23-Animal feed and fodder	179.84	*55.7*
90.92	12-Oilseeds	44.61	*13.8*
7.53	24-Tobacco and tobacco products	39.06	*12.1*
74.40	17-Sugars and sugar products	35.18	*10.9*
4.24	09-Coffee, tea, spices	13.62	*4.2*
0.83	16-Processed products of meat or fish	2.53	*0.8*
0.44	21-Miscellaneous processed food products (soups, sauces, ice cream etc.)	2.51	*0.8*
1.90	08-Fruit and nuts	1.79	*0.6*
0.79	02-Meat	1.08	*0.3*
0.22	03-Fish	0.73	*0.2*

Source: author's calculations using Eurostat data [7].

Sensitive agri-food products with Tariff Quota Rates (TRQ) in the EU-Mercosur Interim Trade Agreement

Historically, the agri-food products have always been a sensitive subject, therefore, in all its trade agreements, the EU negotiated special provisions for this category of goods. The Single Market is rather well protected against cheaper imports from extra-EU countries. The Common Agricultural policy has put in place many regulations that increase production costs for farmers and food processing industry (good agricultural practices, environmental regulations aiming at lowering chemical inputs and carbon footprint, animal welfare rules, strict sanitary rules, etc.), but despite being in apparent conflict with the need for increasing economic efficiency along the agri-food value chains, their aim is ultimately to improve quality and food safety for consumers [2, 3].

The EU-Mercosur agreement has as main objective facilitating trade, by lowering tariffs and gradual diminishment of trade barriers. Yet, the Single Market should be protected from inflows of cheaper and lower quality agri-food products. Therefore, the agreement contains a list of 23 product groups considered as sensitive, that will benefit from reduction of the formerly tariffs, but within specific quotas. The main ones are beef, pigmeat, poultry meat, eggs, dairy cheese, powdered milk, sugar, honey, rice, garlic, ethanol, biodiesel [5].

EU farmers, Romanian ones included, expressed their concerns that imports from Mercosur of poultry meat and beef might disrupt the domestic market and exports.

Poultry meat: EU, Romania and the new tariff rate quota in the ITA with Mercosur.

According to DG-AGRI [10], despite the losses caused by the Avian influenza since 2015, poultry meat production increased to 14 billion tonnes in 2024. Consumption increased slightly, but continuously, from 10.22 million tonnes in 2012 up to 12.4 million tonnes in 2024, with a self-sufficiency rate varying between 109-114%. Unlike beef and pork, poultry meat is be the only meat type expected to increase production in the EU, since it is seen as a better alternative, due to its special characteristics: high protein content, lean meat, lower price than for beef and pork [15, 23]. Projections show that poultry meat consumption in EU is expected to grow every year by a similar amount as the new duty-free preferential quota (which will increase in equal increments of 30,000 tonnes per year, to a

maximum quota of 180,000 tonnes reached in the fifth year of the agreement implementation). Nevertheless, the maximum duty-free quota represents only 61% of the quantity imported from Mercosur in 2024. Therefore, no disruptions are expected on the EU poultry market caused by future imports from Mercosur. In Romania, poultry meat production increased constantly in Romania in the last decade [4]. Despite the increase in consumption (from 17.5 to 29.0 kg/capita/year between 2013 and 2024, which is higher than the average EU consumption (25 kg/year/capita), the self-sufficiency rate increased as well, to reach 99.3% in 2024 [20]. Important domestic and foreign capital investments were made in industrial-type farms, and currently, 63% of the poultry for meat inventories are in farms with more than 50,000 heads, allowing for efficient production and inclusion in regional and national value chains [16]. Thus, the poultry industry was able to regain the domestic market, and also to double its exports over the last decade [22]. In the analyzed period (2020-2024), two thirds of the exports were directed to EU countries (France, Hungary, Bulgaria, Netherlands) and one third to non-EU countries (UK, Republic of Moldova) (Table 5). Imports are slightly higher than exports, so there is a yearly commercial deficit of 35,100 tonnes (average 2020-2024) on the domestic market.

Table 5. Romanian trade with poultry meat (averages 2020-2024)

Export			Import		
Desti-nation	**Quantity (tonnes)**	**%**	**Origin**	**Quantity (tonnes)**	**%**
EU (FR, HU, BG, NL)	64,000	74%	EU (PL, HU, NL, GER)	116,000	95%
Non-EU (UK, Rep. Moldova)	23,000	26%	Non-EU (UK, Ukraine)	6,100	5%
Mercosur	0	0%	Mercosur (BR)	950 (chicken liver only)	0,8%
Total	87,000	100%	Total	122,100	100%

Source: author's calculations using Eurostat data [7].

Given that the duty-free TRQ for poultry meat is maximum 180,000 tonnes for all 27 Member States, and taking into account the upward consumption trend, it seems quite improbable to cause major disruptions on the Romanian market. Yet, it is possible that some additional imports would appear on the Romanian market directly from Mercosur or through re-exports at lower prices from other EU countries. Also, and some exports to EU countries might be partially replaced by some duty-free imports directly from Mercosur, but in low quantities.

Beef: EU, Romania and the new tariff rate quota in the ITA with Mercosur.

The EU is largely self-sufficient in beef; its production is about 6.6 million tonnes (2024) [14], mostly consumed domestically. EU is a net exporter of beef, with export worth 4.9 billion EUR (2024), almost double of the imports value; exports amount for only 8-10% of the production.

Generally, a decline of the EU red meat production is expected in the next decade: for beef, due to environmental concerns, high production costs and low productivity, and for pork due to problems linked to the African Swine Fever outbreaks, major environmental problems and health concerns [23].

The agreement does not allow duty-free access to Mercosur beef; only a maximum of 99,000 tonnes of will be allowed to enter the EU at a 7.5% duty.

Those imports will come in equal increments of 9,075 tonnes per year, to a maximum quota of 99,000 tonnes reached in the fifth year of the agreement implementation; 55% of the quota will consist of fresh or chilled meat and 45% of lower-value frozen meat [5].

The overall future maximum volume represents only 1.5% of total European beef production and is less than half of the current quantities imported from Mercosur, which were at 206,000 tonnes in 2024.

Several authors [17, 19] argue that the new open preferential TRQ for Mercosur beef imports might result in a reduction of EU producer prices by about 2% at most, which does not appear to be a major threat despite the beef prices volatility.

In the Romanian consumption model, pork ranks first (729,000 tonnes in 2024), followed by poultry meat (580,000 tonnes), beef (94,000

tonnes) and sheep and goat meat (53,000 tonnes) [20].
Investments (through the second pillar of CAP) in the bovine sector went mostly to dairy farms, but there is a slight increasing trend in beef farms, export-oriented.
Beef production in Romania is on a downward trend since 2016, down to 166,000 tonnes in 2024 [21]. Consumption decreased as well, from 6.3 to 5.1 kg/capita/year between 2015 and 2024. The self-sufficiency rate was 85.1% in 2024 [20].
Exports increased in the last five years, as have the imports (Table 6).

Table 6. Romanian trade with beef (averages 2020-2024)

Export			Import		
Destination	**Quantity (tonnes)**	**%**	**Origin**	**Quantity (tonnes)**	**%**
EU (NL, BG, CZ, GER)	6,700	94%	EU (IT, NL, PL, HU)	18,600	99.6%
Non-EU (TR, UK, MD)	440	6%	Non-EU (UK, BR)	75	0.4%
Mercosur	0	0%	Mercosur (BR)	24 (included in Non-EU)	0,13%
Total	7,140	100%	Total	18,675	100%

Source: author's calculations using Eurostat data [7].

Romania is a net beef importer, with a commercial deficit of 11,500 tonnes. Imports from Mercosur represented a mere 0.13% of the beef imports.
Given that the TRQ at (7.5% tariff) for beef is maximum 99,000 tonnes for all 27 Member States, and taking into account the downward consumption trend, it seems quite improbable to cause major disruptions on the Romanian market.
Yet, it is possible that some additional imports would appear on the Romanian market through re-exports from other EU countries at lower prices.

Advantages and protection of the EU agri-food sector.

Potential effects of trade generated by the EU-Mercosur Partnership Agreement (in economic, sustainability and regulatory terms) were assessed in a report for the EU Parliament [13], its conclusions show that the expected overall macroeconomic effects are positive, with most of the gains concentrated in the EU industry.
EU (and Romania as well) had a continuous agri-food trade deficit in relation with Mercosur.
The Agreement aims to create the conditions for a more balanced and fair trade between the two blocks, while providing protection for sensitive EU agri-food products against unfair competition.
The reduction of the currently high tariffs on EU agri-food products such as olive oil, chocolate, wine and spirits (now ranging between 10 and 35%) will provide important benefits by allowing increased opportunities for exports. As such, EU agricultural products will become more competitive on the Mercosur market, and the values of exports are expected to be by almost 50% higher in the next two decades [9].
Another advantage is the protection of special EU food and drink products against imitations by securing branding and market exclusivity. That will allow a better penetration of EU high quality agri-food products on the Mercosur market for 344 PGIs-geographical indications; out of them, 15 Romanian PGI-s will be also protected: 3 PGIs for food products (Magiun de prune Topoloveni, Salam de Sibiu and Telemea de Ibănești); 8 PGIs for wines (Cotești, Cotnari, Dealu Mare, Murfatlar, Odobești, Panciu, Recaș, Târnave); and 4 PGIs for spirits (Pălincă, Țuică Zetea de Mediești Aurit, Vinars Târnave, Vinars Vrancea) [8].
Fresh fruits such as avocados, lemons, limes, melons, watermelons, table grapes, and apples will not be subject to quotas in the EU anymore and imports will be duty-free. Coffee will also benefit from quota removal [1].
All products, and especially sensitive products on the Single Market will be protected through TRQ-s (tariff quota rates). The quotas with reduced (for beef) or zero tariffs (e.g. for poultry meat) are low: they do not exceed 1.5% of the EU production for the respective products. Quotas are rather low even for products for which EU is not self-sufficient (such as honey or rice).

A very special supplementary safeguard clause, never seen before in typical trade agreements, was included in the Mercosur agreement if increased imports only threaten to (and not even yet effectively) cause negative effects to relevant EU sectors. This particular clause extends over the imports under tariff rate quotas as well [12]. For that, EU will create a special fund (6.3 billion EUR) to combat the unlikely event of harmful impacts on EU farmers and agricultural markets.

Another important aspect is the application of fewer restrictions due to animal health issues through the "regionalization" principle: previously, all EU exports could be banned in case of disease outbreaks in certain regions; now, under the Agreement, exports from unaffected EU areas will be allowed for export despite the presence of a disease in other areas of the EU.

An extremely important aspect is maintaining strict EU rules on human, animal, plant health and food safety without exceptions, for all imports from Mercosur. All products sold on the Single market must meet all the regulations concerning the use of hormones and chemicals in agri-food production, as well as the consumer protection standards. This particular aspect is strongly debated by EU farmers and decision makers, who expressed their doubts regarding the inability of every importing Member State to perform the necessary analyses due to insufficient authorized testing laboratories.

CONCLUSIONS

Currently, the USA is the first EU export destination and the second largest source of imports; but in the context of the increased volatility in trade relations between the two parties since 2025, those large shares became a vulnerability for the EU; consequently, the EU needs to diversify its export destinations as well as to enlarge the import source areas.

The ITA agreement recently signed with Mercosur 4 (that will be followed by a more comprehensive EMPA agreement, pending ratification from all EU Member States) is a significant economic deal, concluded after two and half decades of negotiations. It is expected to reverse the deterioration of EU market shares in Mercosur imports: in 2000, the EU accounted for almost 30% of Mercosur imports, while China for less than 5%; the situation reversed since 2017, and currently China's share increased to 27%, while EU's share fell to 19% [11].

The EU-Mercosur Agreement has many objectives. It lowers or eliminates tariffs on 91% of Mercosur imports from the EU, opens previously protected sectors and markets, and enables significant economic gains for both sides, all along with important commitments regarding environmental protection, climate change and sustainable development [13].

In the last decade, the EU – Mercosur agri-food trade has been largely in favor of Mercosur. The ITA is expected to reverse this deteriorating trend. The high tariff rates on agri-food products (up to 55%) and other trade barriers (such as sanitary-veterinary rules) prevented the expansion of trade.

Agri-food products had a rather low share (1.4%) in EU exports to Mercosur in the analyzed period, but accounted for 12.3% in EU total imports. In a similar vein, Romanian agri-food products had a tiny share (0.5%) in the country's general exports to Mercosur, but took a large share (75%) of the general imports. Nevertheless, imports from Mercosur represent a small fraction of the total Romanian agri-food imports (2.69%).

In general, trade of both EU and Romania with Mercosur showed low values, except for the very necessary imports of animal feed (oilseed cakes) and soybeans, for which both EU and Romania (along with other EU Member States) are far from self-sufficiency. Imports from Mercosur recorded large variations in terms of value and quantities, proving lack of stability of trade flows on those markets.

Projections show that poultry meat consumption in EU is expected to grow every year by a similar amount as the new duty-free preferential quota (which will increase gradually over the first five years of the agreement implementation). Therefore, no disruptions are expected on the EU poultry

market caused by extra duty-free imports from Mercosur.

In Romania, poultry meat production, exports and consumption increased constantly in the last decade, and self-sufficiency reached 99.3% in 2024. Taking into account that the duty-free TRQ for poultry meat is for all 27 Member States, and given the projected upward consumption trend, it seems quite improbable to cause major disruptions on the Romanian market. Yet, it is possible that some additional imports would appear on the Romanian market directly from Mercosur or through re-exports at lower prices from other EU countries, and some exports to EU countries might be partially replaced by some duty-free imports directly from Mercosur, but in low quantities.

The analysis of the beef trade with Mercosur showed that the TRQ-s at low tariff account for a very small share of the EU production: the overall future maximum quota volume represents 1.5% of total European beef production and is less than half of the current quantities imported from Mercosur in 2024; so, the impact of those imports is expected to be insignificant.

For Romania, a similar outcome is expected, only with the mention that it is possible that some additional imports would appear on the Romanian market through re-exports at lower prices from other EU countries.

On the other hand, the Agreement enables access of Romanian high quality agri-food products (15 PGIs), while it seems to be of no real impact on imports.

Reports from the EU Commission and growing scientific literature on the subject show that the EU-Mercosur ITA is expected to yield positive macroeconomic effects, mostly concentrated in the EU industry. Historically, due to its social and economic sensitivity, the agri-food sector has always been much more difficult to negotiate and liberalize in terms of trade. Despite all the protections put in place, the new provisions in the EU-Mercosur agreement on the agri-food sector are expected to enable important commercial developments between the two economic blocks.

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MECHANISATION AND EMPLOYMENT IN AGRICULTURE: AN ASSESSMENT OF THE IMPACT OF NEW TECHNOLOGIES ON LABOUR

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Abstract

The present study assesses the impact of mechanisation on labour employment in Bulgarian agriculture during 2016–2023, at national and regional (NUTS3) levels. Mechanisation is measured through the number of newly registered machines (total and by type: tractors, combine harvesters, loaders). Official annual data are used from National Statistical Institute and Ministry of Agriculture and Food (NSI, MAF). The methodological framework includes analysis of trends and structure, correlation analysis for the entire period and the sub-periods 2016–2019 and 2020–2023, as well as regression estimates with focus on economic interpretation and regional heterogeneity. The results show sustained growth in mechanisation alongside a parallel decline in employment. At national level, a moderate but statistically insignificant negative relationship is established between overall mechanisation and employment. After 2020, however, the relationship intensifies sharply to a very strong negative correlation, corresponding to accelerated technological adaptation under conditions of labour shortage and rising labour costs. By type of machinery, the effects are differentiated: loaders have the strongest and statistically significant substitution effect; combine harvesters – moderate negative; tractors - practically zero. Regional profiles of mechanisation and employment differ substantially, but the limited length and aggregation of the series prevent a full-scale panel test. The conclusions emphasise that mechanisation is not the sole determinant of employment, but its influence is contextual and increases after 2020. Policies should combine support for modernisation with investments in human capital (training/retraining), regional targeting and measures to mitigate social effects in rural areas.

Key words**:** *mechanization, agricultural machinery, employment in agriculture, regional disparities, Bulgaria*

INTRODUCTION

As part of the primary sector in the country's economy, agriculture occupies a strategic place in regional development and the provision of food security. Bulgaria is a country with agricultural traditions, and with over 30% arable land of the total area, it stands out with potential for sustainable growth. In recent years, policies in the sector are increasingly directed towards intensification of production through investments in equipment, innovations and mechanisation [7, 20, 23].

Achieving high productivity in the agricultural sector is directly linked to technology renewal, implementation of automated systems and use of innovations that allow cost optimisation and efficiency improvement [22, 18]. The use of precision technologies supports sustainable resource management - such as water, fertilisers and fuels - whilst simultaneously minimising the environmental footprint [8]. Such technologies are already being applied in a number of European countries and demonstrate significant contribution to sustainable agriculture, but also raise questions regarding their impact on labour employment [2, 16].

On the one hand, the implementation of modern technologies in agriculture creates new opportunities for added value, loss reduction and enhancement of the competitiveness of Bulgarian farms [9, 10, 13, 24]. On the other hand, increased mechanisation may lead to a decrease in labour demand, particularly among low-skilled workers and seasonal employees. This gives rise to social and economic risks related to demographic decline, rural depopulation and the exacerbation of regional inequalities [4, 15, 17].

Scientific literature emphasises that the impact of mechanisation on employment is not

unequivocal – in some cases it may eliminate jobs, but in others it transforms the nature of work, requiring new skills, digital competence and technical training [6, 12]. Other studies even indicate that with proper support and policies, new technologies can stimulate employment in peripheral sectors – such as equipment maintenance, agricultural engineering and agronomic consultancy [21].

Numerous authors also emphasise the need for precise targeting of financial incentives, so that they not only encourage mechanisation but also support training, requalification and social adaptation of the employed [7, 13, 16]. Food security, efficient water use, organic farming and environmental practices are also areas in which strong links are observed between technological development and the need for a new type of workforce [3, 8, 11, 19, 22].

Monitoring macroeconomic indicators and the effects of new technologies on employment in the agricultural sector is particularly important in the context of the European Green Deal, which requires accelerated digitalisation and sustainable resource use, without allowing social marginalisation of the economically active population.

Therefore, the empirical focus of the present study arises precisely from this tension between modernisation and employment: whilst increasing mechanisation is key to higher productivity and sustainability, it simultaneously changes the structure, volume and nature of work. What are the specific manifestations of this relationship in the Bulgarian context in recent years?

The aim of the study is to assess the impact of mechanisation – measured through the number of newly registered agricultural machinery (total and by type) – on labour employment in Bulgarian agriculture during the period 2016-2023, both at national and regional (district) level. Special attention is paid to the temporal dynamics of the effect (before and after 2020) and to regional differences in mechanisation and employment.

In this regard, three main hypotheses are formulated:

H1 (national effect): higher mechanisation is associated with a statistically significant reduction in employment at country level;

H2 (temporal dynamics): the negative relationship intensifies during 2020-2023 compared to 2016-2019, in the context of accelerated digitalisation;

H3 (regional heterogeneity): the strength and direction of the effect vary significantly across districts.

MATERIALS AND METHODS

For the purposes of the analysis, official annual data for the period 2016-2023 from the NSI [5] regarding employment in the "Agriculture, forestry and fishing" sector are used, along with data from the public registers of the Ministry of Agriculture and Food concerning newly registered agricultural machinery following the introduction of its mandatory registration [14]. The data are presented at both national and regional levels.

First, an analysis of trends and structure is conducted. The annual dynamics of mechanisation and employment at national and regional levels are tracked, and the profiles before and after 2020 are compared. The structure of the machinery fleet is described through the contribution of the main types of equipment (tractors, combine harvesters, loaders) to overall mechanisation, whilst the structure of employment is described through distribution by region and relative shares.

Subsequently, the correlation relationship between mechanisation and employment is assessed. Standard linear correlations are used on aggregated annual values for the country and by region, both for the entire period and for the two sub-periods 2016-2019 and 2020-2023, in order to highlight the direction and relative strength of the relationship without claiming causality.

Finally, linear regressions are applied for quantitative measurement of the effect: at national level, employment is modelled as a function of the total number of newly registered machines and by type (tractors, combine harvesters, loaders). At regional level, similar simple linear relationships are assessed in order to capture territorial heterogeneity. The presentation of results is focused on economic interpretation and comparability

between periods and regions, without unnecessary technical details.

RESULTS AND DISCUSSIONS

Dynamics and Structure of Mechanisation

The mechanisation of the agricultural sector in Bulgaria during the observed time interval 2016-2023 is represented through the number of newly registered agricultural machinery (Fig. 1).

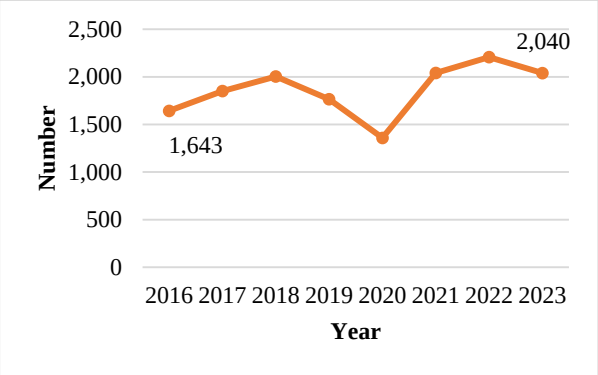


Fig. 1. Registered new agricultural machinery at the national level in the period 2016 – 2023
Source: MAF data [14].

During the period, there is increased mechanisation of production in the sector, with the exception of 2020, when a low growth in newly registered machinery is observed.

This can be linked on the one hand to the pandemic situation on a global scale and the reduced possibility for international trade relations, and on the other hand to the commencement of military actions between countries in comparative territorial proximity. In the following years, there is again an increase in agricultural machinery used in the country.

The presented data include the main types of machinery necessary for land cultivation: tractors, combine harvesters and loaders. Figure 2 presents the contribution of each type to the overall mechanisation of the sector.

Tractors have the highest significance among the presented agricultural machinery, with a number more than twice as high compared to loaders and on average ten times higher compared to combine harvesters.

It is precisely this type of machinery that stands out with the highest variation during the period and can be the subject of additional subsequent analysis.

The following Figure 3 presents a comparison of the shares of each district in the country regarding mechanisation of agriculture during the examined interval.

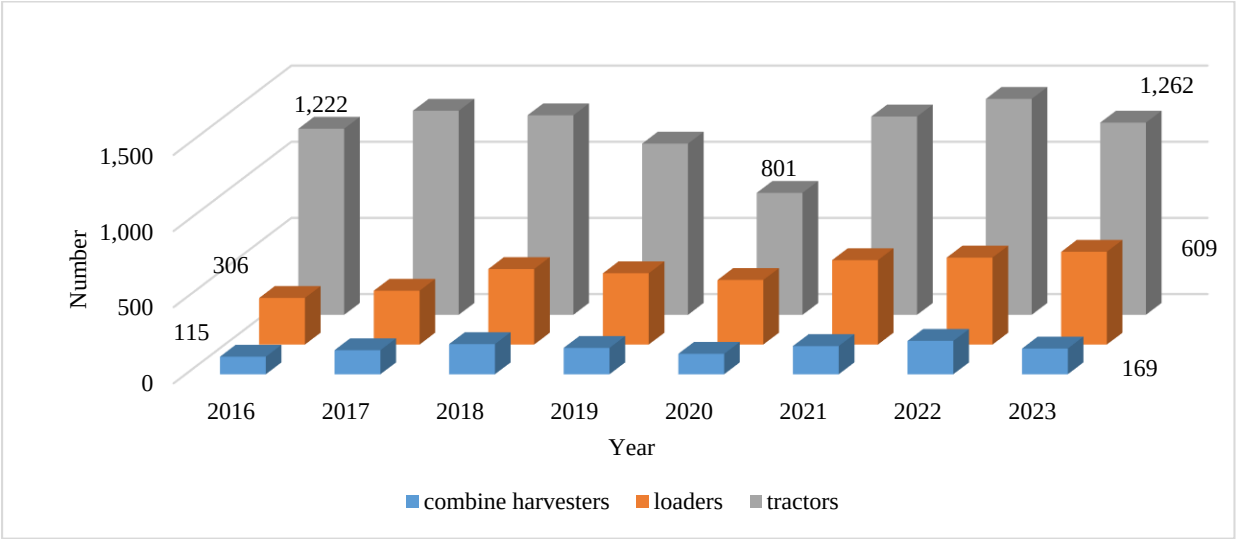


Fig. 2. Registered new agricultural machinery at the national level in the period 2016 – 2023
Source: MAF data [14].

Six districts stand out in a leading position (over 6% share of total newly registered machinery): Pleven, Varna, Burgas, Stara Zagora, Sofia-city and Plovdiv. These are large administrative centres with high population concentration and justifiably with the highest

contribution to gross domestic product at national level. Previous studies devoted to regional differences in contemporary economies establish a stable tendency towards an increase in the aggregate share of gross domestic product of the six leading districts in Bulgaria, which reaches 69.41% in 2019 [1].

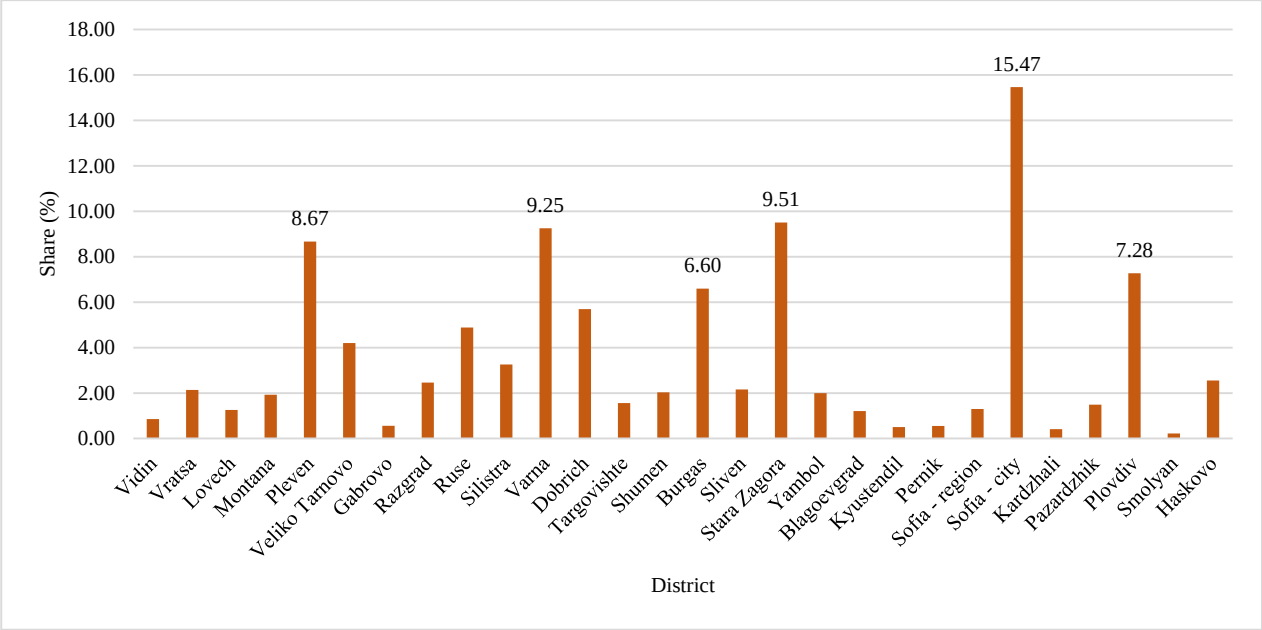


Fig. 3. Share of new registered equipment at regional level in the period 2016 – 2023
Source: Own calculations based on data from the MAF [14].

Dynamics of Employment and Territorial Profiles in Agriculture

Whilst the mechanisation of the agricultural sector on a national scale demonstrates comparative stability according to available data and conducted analyses, the data representing labour employment in the sector reveal a different tendency (Fig. 4).

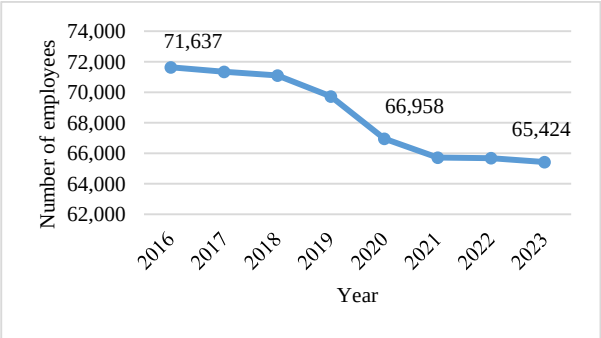


Fig. 4. Absolute employment in the "Agriculture, forestry and fishing" sector
Source: NSI data [5].

There is a significant decrease in the number of employees in the "Agriculture, forestry and fishing" sector.

The absolute size of the reduction for the study period is 6,213 persons, or 8.67 percentage points lower employment at the end of the period.

Regarding the second hypothesis H2, during the period 2016-2019, the reduction of employed personnel in the sector considerably exceeds the rate of decrease in the second time period.

After 2020, an insignificant change in engaged personnel is observed.

Table 1 presents calculated data concerning labour employment at regional level (NUTS3), in order to highlight the districts in the country with priority in the agricultural sector and to trace an existing tendency.

Plovdiv district presents itself with the most prominent highest share in labour employment in the sector. The increased contribution for the period of 0.58 percentage points should also be noted.

The fact that Sofia-city district stands out with the highest number of newly registered machinery is striking, which does not correspond with a high number of employees in the observed sector.

Table 1. Share of districts in employment in the "Agriculture, Forestry and Fisheries" sector in the national economy (%)

District	Year							
	2016	2017	2018	2019	2020	2021	2022	2023
Vidin	1.35	1.39	1.43	1.35	1.47	1.50	1.53	1.51
Vratsa	2.82	2.95	2.91	2.87	2.98	3.03	3.00	2.84
Lovech	2.10	2.15	2.17	2.13	2.11	2.17	2.20	2.20
Montana	2.34	2.36	2.33	2.35	2.42	2.46	2.37	2.45
Pleven	5.67	5.41	5.31	5.29	5.24	5.03	5.23	5.24
Veliko Tarnovo	5.72	5.63	5.51	5.40	5.41	5.45	5.47	5.39
Gabrovo	0.92	0.87	0.87	0.93	0.94	0.89	0.88	1.00
Razgrad	3.78	3.83	3.80	3.70	3.77	3.80	3.64	3.82
Ruse	4.85	4.80	4.89	4.67	4.54	4.52	4.79	4.66
Silistra	3.60	3.54	3.48	3.69	3.56	3.68	3.96	3.67
Varna	5.28	5.39	5.25	5.17	5.03	5.13	5.08	5.04
Dobrich	6.79	6.76	6.94	6.90	6.99	7.07	7.16	7.21
Targovishte	3.42	3.15	3.06	3.07	3.03	2.90	2.98	2.97
Shumen	4.06	4.10	4.08	4.01	3.78	3.72	3.66	3.86
Burgas	5.82	6.05	6.03	5.90	5.70	6.08	5.72	5.66
Sliven	3.05	3.08	3.07	3.10	3.04	3.11	3.12	3.19
Stara Zagora	5.63	5.38	5.59	5.63	5.72	5.54	5.68	5.64
Yambol	3.53	3.63	3.62	3.52	3.50	3.54	3.45	3.45
Blagoevgrad	2.54	2.70	2.81	2.91	2.88	2.79	2.88	2.84
Kyustendil	1.03	1.07	1.05	1.07	1.02	0.99	1.04	1.07
Pernik	0.87	0.93	0.89	0.95	0.95	0.92	0.92	1.00
Sofia - region	3.36	3.25	3.54	3.49	3.50	3.41	3.39	3.45
Sofia - capital	2.64	2.57	2.63	2.70	2.85	3.15	2.96	2.94
Kardzhali	1.27	1.22	1.22	1.22	1.19	1.22	1.23	1.11
Pazardzhik	4.58	4.65	4.59	4.82	5.01	4.58	4.50	4.64
Plovdiv	7.54	7.62	7.67	7.75	8.18	8.12	7.94	8.12
Smolyan	1.51	1.49	1.38	1.29	1.34	1.32	1.34	1.35
Haskovo	3.95	4.01	3.86	4.15	3.84	3.89	3.88	3.69

Source: Own calculations based on data from the NSI [5].

After Plovdiv district, Dobrich district distinguishes itself with the highest share, again with increased concentration of labour employment for the period 2016-2023, with 0.42 percentage points.

Pleven, Veliko Tarnovo, Varna, Burgas and Stara Zagora districts follow in the ranking with shares between 5.03% and 6.08% in total employment in the agricultural sector.

Analysis of the data by years in the study interval does not reveal serious changes in labour employment by districts (differences in shares are below 1%). These relatively constant levels point towards the conclusion that the reduction in overall employment in the sector is distributed proportionally at district level.

Correlation Analysis: Mechanisation and Employment in Agriculture

The correlation analysis of national data for the period 2016-2023 reveals a moderate negative relationship between mechanisation and labour employment in Bulgarian agriculture. The calculated Pearson coefficient between the total number of newly registered machines and the number of employed persons in the sector is r = -0.326, which represents a moderate negative correlation (Table 2). With a sample of eight annual observations, this correlation does not reach statistical significance at the conventional level $\alpha = 0.05$, which means that we cannot confidently assert that the observed relationship is not due to chance. Nevertheless, the negative sign of the correlation corresponds to the theoretically expected substitution effect, whereby an increase in machinery capital leads to a reduction in demand for labour.

The data demonstrate clear divergent trends during the studied period. Employment in agriculture decreases from 71,637 persons in 2016 to 65,424 persons in 2023, representing a decline of 8.7%. Simultaneously, registration of new agricultural machinery increases from 1,643 machines in 2016 to 2,040 machines in 2023, recording an increase of 24.2%. These opposite movements confirm the ongoing structural transformation of Bulgarian

agriculture towards more capital-intensive production models.

Table 2. Correlation coefficients between employment and mechanisation (Pearson)

Variables	Correlation coefficient (r)	Strength of relationship	Direction
Employment ↔ Total machinery	-0.326	Moderate	Negative
Employment ↔ Tractors	0.053	Very weak	Positive
Employment ↔ Combine harvesters	-0.387	Moderate	Negative
Employment ↔ Loaders	-0.799	Strong	Negative

Source: Own calculations

The analysis by type of machinery reveals significant variations in correlation patterns. Tractors show practically zero correlation with employment (r = 0.053), which suggests that tractor acquisition does not follow a clear pattern with respect to changes in the workforce. This can be explained by the fact that tractors are universal machines, necessary for a wide range of operations regardless of farm scale and its labour intensity. The number of newly registered tractors shows minimal growth of 3.3% over the entire period, which suggests that this segment of the machinery fleet is relatively stabilised.

Combine harvesters demonstrate a moderate negative correlation (r = -0.387) with employment, whilst their number increases dramatically by 47% over the period. This result is intuitively explicable, as combine harvesters directly substitute manual labour in harvesting operations, which traditionally require significant seasonal workforce capacity. Mechanisation of harvesting represents one of the most obvious examples of technological displacement of labour in agriculture.

The strongest negative correlation is observed with loaders (r = -0.799), accompanied by an almost twofold increase in their number during the period (growth of 99%). This strong relationship suggests that loaders are being deployed precisely in the context of a declining workforce, substituting manual operations in the handling of materials, feed and produce. The high correlation may also reflect the fact that loaders are often acquired by larger and more modernised farms, which have already transitioned to a capital-intensive model with lower labour engagement.

The temporal perspective adds an important dimension to the interpretation (Table 3). When the data are divided into two periods, a striking change in the correlation pattern emerges. During the period 2016–2019, the correlation between overall mechanisation and employment is close to zero (r = -0.037), showing practical independence between the two variables. In contrast, the period 2020-2023 demonstrates a very strong negative correlation (r = -0.944), which is an almost perfect inverse relationship.

Table 3. Correlation analysis by period

Period	Number of observations	Correlation coefficient (r)	Interpretation
2016-2019	4	-0.037	Absence of relationship
2020-2023	4	-0.944	Very strong negative relationship
Total 2016-2023	8	-0.326	Moderate negative relationship

Source: Own calculations.

This sharp change coincides with the period of the COVID-19 pandemic and may reflect several interrelated processes: accelerated deployment of machinery under conditions of labour restrictions and health risks, rising labour costs and workforce shortages, use of crisis subsidies and modernisation programmes, as well as structural adaptations of farms to the new economic realities.

From a methodological point of view, the moderate correlation at national level underscores the limitations of correlation analysis in capturing causal mechanisms. Employment in agriculture is influenced by multiple factors beyond mechanisation: demographic processes including ageing and migration, changes in land use structure and crop profile, consolidation of agricultural land and farm enlargement, fluctuations in market prices and profitability, access to financing and subsidies, as well as macroeconomic

conditions. The correlation approach does not allow the effect of mechanisation to be isolated from these accompanying factors and does not account for possible time lags between investments in machinery and subsequent changes in labour demand.

It is also important to note the limitation associated with using data on the flow of new registrations rather than the total available machinery fleet. Farms with already substantial machinery capital may register fewer new machines annually when replacing existing equipment, which does not reflect their true degree of mechanisation. Furthermore, the data do not capture qualitative changes in technologies - for example, the replacement of old tractors with more powerful and multifunctional models may not be reflected in the number of registrations, but may have a significant impact on productivity and labour demand.

The results have important implications for sector policies. The observed relationship between mechanisation and employment, particularly after 2020, shows that subsidies and programmes for agricultural modernisation, whilst successful from a technological standpoint, may have unforeseen social consequences in rural areas. The continuing decrease in employment in the sector by approximately 800-1000 persons annually represents a challenge for rural communities, especially in regions where agriculture is the main source of livelihood. Policies should take this dynamic into account and accompany it with measures for workforce retraining, development of alternative employment opportunities in rural areas, as well as support for workers' adaptation to new technological requirements in the sector.

The qualitative dimension of changes in employment also deserves attention. Mechanisation changes not only the quantity but also the nature of labour demanded. Whilst it reduces the need for unskilled physical labour and seasonal workers, it increases demand for skilled machine operators, technicians and specialists. These compositional changes are not captured by general employment data, but are important for understanding the long-term effects of technological change on rural labour markets and the need for investments in education and vocational training.

In summary, the data for the period 2016-2023 provide moderate evidence of a negative relationship between mechanisation and employment in Bulgarian agriculture, with this relationship intensifying significantly after 2020. The different correlation patterns by type of machinery show that the effect is not uniform, with loaders demonstrating the strongest substitutive role with respect to labour.

Regression Analysis: The Impact of Mechanisation on Employment

The regression analysis provides a more in-depth perspective on the quantitative influence of mechanisation on employment in Bulgarian agriculture, going beyond simple correlation relationships. Using the ordinary least squares method, we estimate several regression models with the aim of measuring the predictive power of different types of machinery on employment levels.

The simple linear regression model, using the total number of newly registered machinery as the predictor variable, shows a negative relationship with a coefficient $\beta = -3.33$ (standard error 3.94). This means that an increase in registered machinery by 100 machines annually is associated with an average reduction in employment of approximately 333 persons, ceteris paribus. The model explains 10.6% of the variation in employment ($R^2 = 0.106$), which represents weak explanatory power and indicates that mechanisation is only one of many factors affecting labour demand in the sector. The coefficient does not reach statistical significance at conventional levels ($t = -0.844$, $p > 0.05$), which suggests uncertainty in the estimate due to the small sample size.

Disaggregating the analysis by type of machinery reveals significant heterogeneity in their individual effects on employment (Table 4). Tractors show practically zero effect with a coefficient $\beta = 0.77$ and extremely low explanatory power ($R^2 = 0.003$), which confirms the earlier observation that tractor

acquisition does not follow a clear pattern with respect to changes in the workforce. Tractors as universal machines are acquired for a wide range of agricultural activities regardless of the labour intensity of the farm. Combine harvesters demonstrate a negative effect with a coefficient β = -31.98, showing that each additionally registered machine of this type is associated with a reduction in employment of approximately 32 persons. The model explains 15% of the variation (R^2 = 0.150), which is a moderate improvement compared to total machinery, but the coefficient remains statistically insignificant (t = -1.029). The relatively stronger effect of combine harvesters is intuitively explicable, as these machines directly substitute a significant volume of manual and seasonal labour in harvesting operations. The strongest influence is observed with loaders, where the coefficient is β = -20.72 with statistical significance close to conventional levels (t = -3.259, p < 0.05 for a two-tailed test). This model explains 63.9% of the variation in employment (R^2 = 0.639), which represents a significant improvement in predictive power. The strong relationship suggests that loaders play a key role in the process of labour displacement, substituting manual operations in the handling of materials, which traditionally requires permanent workforce.

Table 4. Results from regression analysis by type of machinery

Model	Independent variable	Coefficient (β)	Standard error	t-statistic	R^2	Adjusted R^2
1	Total machinery	-3.33	3.94	-0.844	0.106	-0.043
2	Tractors	0.77	5.94	0.129	0.003	-0.163
3	Combine harvesters	-31.98	31.07	-1.029	0.150	0.008
4	Loaders	-20.72	6.36	-3.259	0.639	0.579

Source: Own calculations.

The multiple regression model, including simultaneously the three types of machinery as predictor variables, offers the most complete picture of their combined effects (Table 5). In this model, the coefficients change substantially compared to the simple regressions due to controlling for the mutual relationships between different types of machinery. Tractors show a positive coefficient β1 = 2.17, which suggests that when controlling for other types of machinery, tractor acquisition may be associated with maintaining or slightly increasing employment, possibly because tractors facilitate expansion of cultivated areas, which requires additional workforce. Surprisingly, combine harvesters in the multiple model show a positive coefficient β2 = 30.05, which contradicts expectations and the simple regression model. This paradox is most likely due to multicollinearity between different types of machinery and the small sample size, which makes the estimates unstable.

Table 5. Multiple regression model

Component	Coefficient	Interpretation
Constant (α)	74,385.83	Baseline level of employment at zero machinery
B1 (Tractors)	2.17	Effect of an additional tractor when controlling for others
B2 (Combine harvesters)	30.05	Effect of an additional combine harvester when controlling for others
B3 (Loaders)	-28.91	Effect of an additional loader when controlling for others
R^2	0.759	Percentage of explained variation
Adjusted R^2	0.578	Adjusted for number of parameters

Source: Own calculations

Loaders retain their strong negative effect with β3 = -28.91, confirming their substitutive role even when controlling for other machines. The multiple model explains 75.9% of the variation in employment (R^2 = 0.759), which is a significant improvement compared to the simple models, but the adjusted R^2 (0.578) shows that part of this improvement may be due to overparameterisation with a small number of observations.

The predictive ability of the model with total machinery was tested for different hypothetical levels of mechanisation. At a level of 1,500 newly registered machines annually, the model predicts employment of approximately 69,660 persons. An increase to 2,200 machines annually is associated with predicted employment of 67,329 persons, representing a reduction of approximately 2,300 persons or 3.3%. These projections, however, must be interpreted with great caution due to the low statistical significance of the coefficient and the limited explanatory power of the model.

From a methodological point of view, the results underscore substantial limitations of the regression approach with small samples and aggregated data. With eight annual observations, the statistical power to detect effects is limited, which is reflected in the wide standard errors and low significance of most coefficients. Multicollinearity between different types of machinery, which is expected as farms typically acquire different machines simultaneously as part of broader investment plans, makes it difficult to separate their individual effects in the multiple model.

An important limitation is that regression analysis establishes associations, but not causality. The observed negative relationship between machinery and employment may reflect a substitution effect of technologies, but may also be due to reverse causality, whereby a declining workforce stimulates investments in machinery as an adaptive response to labour shortage. Third factors such as changes in market prices, structural reforms or macroeconomic conditions may simultaneously influence both employment and mechanisation, creating a spurious causal relationship. Time lags between investments in machinery and subsequent changes in employment are not modelled due to data limitations, but may be substantial in reality.

The results have practical significance for understanding the technological transformation in Bulgarian agriculture. The fact that loaders show the strongest and statistically significant effect on employment suggests that this type of machinery plays a central role in the process of mechanisation and labour substitution. Policies supporting mechanisation should take these differentiated effects into account and balance the objectives of technological modernisation with the need to manage social consequences in rural areas. The weak explanatory power of the models also shows that mechanisation is only one of many factors determining employment, which underscores the need for a holistic approach to agricultural development policies.

In conclusion, the regression analysis confirms the negative relationship between mechanisation and employment, measuring its magnitude and revealing significant differences by type of machinery. Despite the statistical limitations due to the small sample size, the results suggest that technological investments, particularly in loaders, have a measurable effect on the structure of labour demand in the sector. Further research with longer time series, regionally disaggregated data and more complex specifications including control variables and time lags is needed to establish more precisely the causal influence of mechanisation on employment.

Testing of research hypotheses

Hypothesis 1, which asserted that higher mechanisation is associated with a statistically significant reduction in employment at national level, is not confirmed. Although the analysis shows a moderate negative relationship and a negative regression coefficient, these effects do not reach statistical significance. The limited sample size and low explanatory power of the models restrict the possibility for reliable conclusions. The direction of the relationship is in accordance with theoretical expectations for a substitution effect, but the lack of statistical certainty does not allow the null hypothesis of no relationship to be rejected.

Hypothesis 2, which assumed an intensification of the negative effect of mechanisation on employment during the period 2020-2023 compared to 2016-2019, is fully confirmed. The comparison between the two periods shows a distinct transformation: initially there is no systematic relationship, but after 2020 it intensifies dramatically and acquires an almost perfect negative character. This coincides with the COVID-19 pandemic,

when accelerated deployment of machinery is provoked by labour shortages, health risks and access to crisis support programmes. Thus it is confirmed that the effects of mechanisation are highly dependent on the temporal context.

Hypothesis 3, which examined whether the strength and direction of the effect vary by region, is partially confirmed. Disaggregation by type of machinery shows significant differences: tractors do not exhibit a substantial relationship with employment, combine harvesters are associated with a moderately negative influence, whilst loaders demonstrate a strong substitution effect. Moreover, differences in the intensity of mechanisation between regions reach almost twofold values, which reflects variations in production structure, farm size, topography and access to capital. The lack of sufficiently regionally disaggregated panel data, however, does not allow full testing of this hypothesis.

In conclusion, the results show that the effects of mechanisation on employment are not homogeneous, but vary over time, by region and by type of machinery. The absence of a statistically significant effect at national level conceals the dramatic intensification of the relationship after 2020 and the distinct regional heterogeneity. This requires policies supporting mechanisation to be based on a differentiated approach, adapted both to specific regional conditions and to dynamic changes in the economic and social environment.

CONCLUSIONS

The analysis of data for the period 2016–2023 reveals a continuing structural transformation of Bulgarian agriculture towards a more capital-intensive model. Registration of new agricultural machinery increases by 24%, with loaders demonstrating the most dynamic growth, followed by combine harvesters, whilst tractors show moderate growth. Simultaneously, employment in the sector decreases by 9%, with the decline relatively evenly distributed across regions.

The empirical relationship between mechanisation and employment is characterised by nuanced complexity. At national level, a moderate negative correlation is established, which however does not reach statistical significance due to the limited sample size and the multifactorial nature of labour demand. Mechanisation explains only a small part of the variation in employment, which underscores the influence of demographic processes, migration, market conditions and structural changes.

A key finding is the dramatic intensification of the negative relationship after 2020. During 2016–2019, the two variables show practical independence, whilst during 2020–2023 a very strong negative correlation is observed. This intensification coincides with the COVID-19 pandemic and reflects accelerated technological adaptation under conditions of labour shortage and rising labour costs, which shows that the relationship between technology and employment is not static, but transforms under the influence of changing conditions.

Significant heterogeneity is observed by type of machinery. Loaders have the strongest and statistically significant effect on employment, combine harvesters show a moderate negative effect, whilst tractors demonstrate practically zero relationship. These differences reflect the specific role of each type of machinery in the production process and the degree of direct substitution of manual labour.

The results have important policy implications. Technological modernisation should be accompanied by vocational training programmes focused on operating modern machinery and working in a digital environment. Policies supporting mechanisation should take regional differences into account and adapt measures to specific local conditions. It is necessary to improve access to service facilities and financing outside major centres, as well as to balance subsidies with regard to social consequences in rural areas where livelihood alternatives are limited.

The study has limitations. The use of aggregated national data masks regional heterogeneity, the short time series of eight years limits statistical power, measurement through newly registered machinery does not

reflect the full level of mechanisation, and correlation analysis establishes associations without causal inferences. Future research could address these limitations through disaggregated data, longer time series, lagged analysis and causal methods.

We can conclude that Bulgarian agriculture is undergoing significant technological transformation with uneven and time-varying effects on employment. Mechanisation is not the sole factor determining labour demand, but its influence intensifies after 2020 and varies by type of machinery. Managing this transformation requires a balanced policy approach that combines support for modernisation with investments in human capital, regionally differentiated measures and attention to social consequences.

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THE IMPACT OF CULINARY TREATMENTS ON THE PHYSICO-CHEMICAL PROPERTIES OF RAMSON (*Allium ursinum*) HARVESTED FROM THE VÂRCIOROG FORESTS, BIHOR COUNTY, ROMANIA

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Abstract

The growing interest in natural and functional foods has led to the valorization of wild species with high nutritional potential, such as ramson (Allium ursinum). This study aimed to evaluate the effect of culinary treatments — boiling, steaming, and sous vide cooking - on the physico-chemical properties of ramson harvested from the forests of the Vârciorog area, Bihor County, Romania. Treatments were applied at 100°C for boiling and steaming, and at 50°C and 75°C for the sous vide method. The results showed significant changes in water activity, pH, vitamin C content, phenolic compounds, and photosynthetic pigments. Boiling caused the greatest losses of bioactive compounds, whereas sous vide cooking best preserved the nutritional value and antioxidant activity. In conclusion, thermal treatments significantly influence the nutritional quality and physico-chemical properties of ramson, with the sous vide method proving to be the most effective for maintaining the plant's beneficial characteristics.

Key words**:** *ramson (Allium ursinum), culinary treatment; physico-chemical properties, bioactive compounds*

INTRODUCTION

Wild edible plants have gained increasing scientific and commercial interest in recent years, as consumers shift toward foods with natural, functional, and health-promoting properties. Among these species, *Allium ursinum* L. (ramson or wild garlic) is a spring herbaceous plant belonging to the Amaryllidaceae family, widely distributed in shaded, humid deciduous forests across Europe. Owing to its rich profile of bioactive compounds—including sulfur-containing molecules, polyphenols, carotenoids, flavonoids, vitamins, and essential minerals—ramson has been associated with antioxidant, antimicrobial, anti-inflammatory, and cardioprotective effects, which support its use as a functional food ingredient [16].

The increasing interest in natural, functional, and sustainable foods has led to intensified research on edible wild plants. Ramson (*Allium ursinum*), a perennial species from the Amaryllidaceae family, is widespread in European deciduous forests and valued for its high content of bioactive compounds such as allicin, flavonoids, polyphenols, vitamins, and essential minerals [2], [3]. Owing to these compounds, ramson exhibits antioxidant, antimicrobial, anti-inflammatory, and cardioprotective properties, being considered a plant with high functional potential [15].

Known popularly as "wild garlic," Allium ursinum is traditionally used as a spring vegetable with a distinct taste and strong aroma similar to that of cultivated garlic. Traditionally the young leaves are consumed raw in salads, sauces, and spreads, or included in various traditional dishes (juices, seasonings, fillings, soups, cheeses), or incorporated into various regional culinary preparations, ramson is valued not only for its pungent flavor reminiscent of garlic but also for its nutritional density. Its high content of bioactive compounds, vitamins, and minerals [2], fibers, phenolic compounds, and chlorophylls contributes to both its dietary relevance and technological potential,

influencing texture, color stability, and aroma in food products. Furthermore, extracts from *A. ursinum* have demonstrated antimicrobial activity in several studies, indicating possible applications in natural food preservation.

Despite its culinary popularity, scientific information regarding the impact of domestic cooking on the physicochemical and nutritional properties of ramson remains limited. Thermal treatments such as boiling, steaming, and sous vide cooking are known to alter plant tissues by affecting membrane permeability, pigment stability, enzymatic activity, and the extractability of phytochemicals. Moderate heat may enhance the release of phenolics, chlorophylls, and antioxidants, while excessive temperature or prolonged exposure can lead to degradation of thermolabile compounds, including vitamin C and carotenoids. Similar trends have been described for other leafy vegetables; however, specific data for ramson are scarce.

Beyond its nutritional value, ramson also has technological importance due to its content of fibers, polyphenols, and sulfur compounds that can influence the texture, stability, and sensory qualities of food products [11]. Moreover, ramson extracts can act as natural antimicrobial agents, extending the shelf life of foods.

Although the culinary use of ramson is well known, information regarding the effects of thermal treatments on its physico-chemical and nutritional properties is limited. Thermal treatments such as boiling, steaming, or the sous vide method can significantly modify the cellular structure of plant tissues, influencing the availability of bioactive compounds and pigment stability [4], [11]. Culinary treatments may also cause losses of thermolabile compounds (C vitamin, pigments) as well as the release of phenols and antioxidants through cell wall degradation [5], [9].

During thermal processing, the plant tissue of ramson may partially lose its cellular integrity, resulting in structural and functional changes of bioactive components. The rupture of cell walls can facilitate the release of phenolic compounds, chlorophylls, and carotenoids, temporarily increasing antioxidant capacity [11], [5]. However, high temperatures can cause thermal degradation of vitamins and photosynthetic pigments, leading to losses in nutritional quality [12],[17].

Several studies on leafy green vegetables have shown that mild thermal treatments, such as steaming or sous vide cooking, help preserve pigments and antioxidant activity, while boiling causes greater losses of soluble and thermolabile nutrients [9], [13].

In this context, the present study aims to evaluate the influence of the most common culinary methods — boiling, steaming, and sous vide — on the physical (water activity and pH) and chemical (chlorophyll, carotenoid, phenolic compound, moisture, ash, protein, fat, mineral, and vitamin C content) properties of ramson (*Allium ursinum*) harvested from the forests of the Vârciorog area, Bihor County, Romania.

MATERIALS AND METHODS

Sample Collection

Approximately 10 kg of fresh ramson (*Allium ursinum* L.) leaves were manually harvested in April from deciduous forests in the Vârciorog area, Bihor County, Romania. Harvesting was carried out in the morning hours, during the young vegetative stage of the plant, avoiding damaged or aged leaves. Samples were placed in perforated polyethylene bags and transported in refrigerated boxes (4 ± 1°C) to the analysis laboratory.

In the laboratory, the leaves were washed with distilled water to remove impurities, drained, and gently dried on absorbent paper. The samples were then divided into two groups: the first served as the control (raw ramson), while the second was subjected to various culinary treatments.

Culinary Treatments

Three commonly used culinary methods were selected: boiling, steaming, and sous vide cooking. Each treatment was applied to 500 g portions of fresh leaves.

Boiling (B): samples were immersed in boiling water (100°C) for 5 and 10 minutes.

Steaming (S): samples were cooked in steam at 100°C for 5 and 10 minutes, without direct contact with water.

Sous vide (SV): samples were vacuum-sealed and cooked in a thermostatic water bath at 50°C and 75°C for 10 and 20 minutes.

After treatment, the samples were rapidly cooled in an ice-water bath to stop the thermal process. Part of each sample was used immediately for the determination of water activity (a_t) and pH, while the rest was frozen at –80°C and subsequently lyophilized (Christ Alpha 1-2 LDplus, Germany). The lyophilized samples were finely ground using a stainless-steel grinder and stored in airtight containers at –20°C until analysis.

Physical Properties

Water activity (a_t): determined at 25°C (±0.2°C) using an AquaLab 4TE analyzer.

pH: measured directly in aqueous suspensions (1:10 w/v) with a digital pH meter calibrated with buffer solutions of pH 4 and 10.

Chemical Composition

Moisture, crude protein, ash, and lipid contents were determined according to official AOAC methods [1]:

Moisture Content: Moisture was determined gravimetrically by drying the samples at 105 °C to constant weight. Approximately 2–5 g of homogenized material were weighed in pre-dried, tared crucibles, dried in a hot-air oven, cooled in a desiccator, and reweighed. Moisture content was calculated from the loss in mass.

Crude Protein: Crude protein was quantified using the Kjeldahl procedure. Samples were digested with concentrated sulfuric acid in the presence of a catalyst, followed by alkalization with NaOH, steam distillation, and titration of the released ammonia. Total nitrogen was converted to crude protein using a factor of 6.25.

Ash Content: Ash was determined by dry ashing. Samples were carbonized and subsequently incinerated in a muffle furnace at 500–550 °C until a constant mass was achieved. The inorganic residue remaining after cooling in a desiccator was recorded as total ash content.

Lipid Content: Total lipids were measured by Soxhlet extraction. Dried samples were placed in cellulose thimbles and extracted continuously with a non-polar solvent (hexane or petroleum ether). After extraction, the solvent was evaporated, and the lipid residue was dried and weighed.

Results were expressed as percentages of dry matter (% DM).

Determination of Chlorophyll and Carotenoid Content

Pigment determination was carried out according to the non-maceration method, adapted for green plant tissue [6]. Approximately 500 mg of dried, ground sample was suspended in 2 mL dimethyl sulfoxide (DMSO) in a test tube and incubated at 60°C for 20 minutes. The supernatant was decanted, and extraction was repeated with an additional 3 mL DMSO.

The final extract volume was adjusted to 10 mL, and absorbance was measured using a UV–Vis spectrophotometer at wavelengths of 645 and 663 nm for chlorophyll and 480 nm for carotenoids, with DMSO as a blank [8].

Total chlorophyll (mg/L):

$$\text{Chlorophyll total } (\text{mg/L}) = 20.2 \times A_{645} + 8.02 \times A_{663}$$

Carotenoids:

$$\text{Carotenoids } (\text{mg/L}) = A_{480} + (0.114 \times A_{663} - 0.638 \times A_{645})$$

Results were expressed in mg/g dry sample.

Determination of Antioxidant Activity (DPPH)

The antioxidant activity of ramson extracts was determined using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging method [7]. About 0.1 mL of methanolic extract (obtained from 1 g dried sample in 10 mL of 80% methanol) was mixed with 3.9 mL of DPPH solution (0.1 mM in methanol). The mixture was incubated for 30 minutes in the dark at room temperature.

Absorbance was measured at 517 nm using a UV–Vis spectrophotometer (UV-1800, Shimadzu, Japan), with pure methanol as a blank. Antioxidant activity was calculated as the percentage of DPPH inhibition and expressed as Trolox equivalents (µmol TE/g dry sample), based on a standard calibration curve.

$$\text{Inhibition (\%)} = \frac{A_0 - A_s}{A_0} \times 100$$

where: A_0 - is the absorbance of the control (DPPH solution without sample), and A_s is the absorbance of the sample.

Determination of Total Phenolic Compounds and Vitamin C

Total Phenolic Content (TPC) was determined using the Folin–Ciocalteu method, adapted for ramson extracts [14]. About 0.2 g of lyophilized sample was extracted with 10 mL of 80% methanol (v/v) for 1 hour under constant agitation (150 rpm) at 25°C. The extract was centrifuged at 4,000 rpm for 10 minutes, and the supernatant was used for analysis.

For determination, 0.5 mL of extract was mixed with 2.5 mL of Folin–Ciocalteu reagent (diluted 1:10 with distilled water). After 5 minutes, 2 mL of 7.5% sodium carbonate solution was added. The mixture was incubated in the dark for 30 minutes at room temperature, and absorbance was measured at 765 nm (Shimadzu UV-1800).

Results were expressed as milligrams of gallic acid equivalents per gram of dry matter (mg GAE/g DM), based on a calibration curve using gallic acid standard solutions (0–200 mg/L).

Vitamin C (Ascorbic Acid) content was determined using the 2,6-dichlorophenolindophenol (DCPIP) titration method 967.21 [1]. Approximately 5 g of fresh or rehydrated sample was homogenized in 25 mL of 1% oxalic acid solution (v/v) and filtered through Whatman no. 1 paper.

A 10 mL aliquot of filtrate was titrated with standard DCPIP solution (0.01%) until a persistent pale pink color appeared for 15 seconds. The vitamin C content was calculated as:

Vit. C (mg/100g) = (V_1 x F x 100) / m,

where:

V_1 = titrant volume (mL) used for the sample,

F = calibration factor determined withstandard ascorbic acid solution,

m = mass of sample (g).

Results were expressed as mg ascorbic acid per 100 g fresh sample (mg AA/100 g).

Fatty Acid Analysis

The fatty acid profile of ramson leaves was determined from lipids extracted according to AOAC [1]. Extracted lipids were methylated to form fatty acid methyl esters (FAME) using boron trifluoride–methanol (BF_2–methanol, 14%) following AOAC 969.33 [1].

FAME analysis was performed by gas–liquid chromatography (GC) using a Perkin-Elmer AutoSystem XL (USA) equipped with a BPX70 capillary column (60 m × 0.25 mm × 0.25 µm) and a flame ionization detector (FID). The injector and detector temperatures were maintained at 250°C, and helium was used as the carrier gas (1 mL/min).

Fatty acids were identified by comparing retention times with those of FAME standards (Supelco 37 Component FAME Mix, Sigma-Aldrich). Results were expressed as mg/g lipid extract, and fatty acids were grouped as saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA), calculated as percentages of total identified fatty acids.

Nutrient Retention

Nutrient retention represents the proportion of nutrients remaining in the product after thermal treatment relative to the initial content in raw samples [10]. It was calculated for analyzed parameters (proteins, lipids, vitamin C, total phenolics, chlorophylls, carotenoids, and minerals) using the formula:

$$\text{True nutrient retention(\%)} = \\ = \frac{\text{Nutrient content per g cooked sample}}{\text{Nutrient content per g raw sample}}\ x100$$

Values were corrected for weight changes after cooking (water and mass losses). This approach allows direct comparison of the efficiency of each culinary treatment (boiling, steaming, sous vide) in preserving the bioactive compounds and nutritional value of ramson.

Statistical Analysis

All experimental determinations were performed in triplicate, and results were expressed as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was used to evaluate significant differences between samples subjected to different culinary treatments. Differences were considered significant at $p< 0.05$.

When significant differences were observed, the Tukey HSD post hoc test was applied for mean comparison

RESULTS AND DISCUSSIONS

Physico-chemical properties

The applied culinary treatments produced significant changes ($p< 0.05$) in the pH of ramson samples, especially for boiling, where an increase from 6.32 (raw sample) to 7.84 was observed after 10 minutes of treatment. The rise in pH can be attributed to the release of basic mineral compounds and the degradation of organic acids during thermal exposure, an effect also reported in other studies on leafy greens [11].

Moisture content increased slightly in boiled samples ($p< 0.05$), from 88.4% in the raw sample to 92.1% after 10 minutes of boiling, due to water absorption during processing. By contrast, sous vide samples showed minimal variation in moisture, confirming that this method reduces water loss and the evaporation of volatile compounds.

Total ash—an indicator of mineral content—varied significantly among samples ($p< 0.05$), with higher values in the sous vide treatment at 75 °C/10 min (14.2%) compared to the raw sample (12.7%), suggesting more efficient retention of mineral elements.

Crude protein content increased slightly after moderate heat treatments, especially at 75 °C/10 min sous vide (from 16.1% to 17.8% on a dry basis), a rise explainable by moisture reduction and consequent concentration of the solid fraction.

Photosynthetic pigments (chlorophylls and carotenoids)

Following culinary treatments, a significant modification ($p< 0.05$) in total chlorophyll content was observed (Fig. 1).

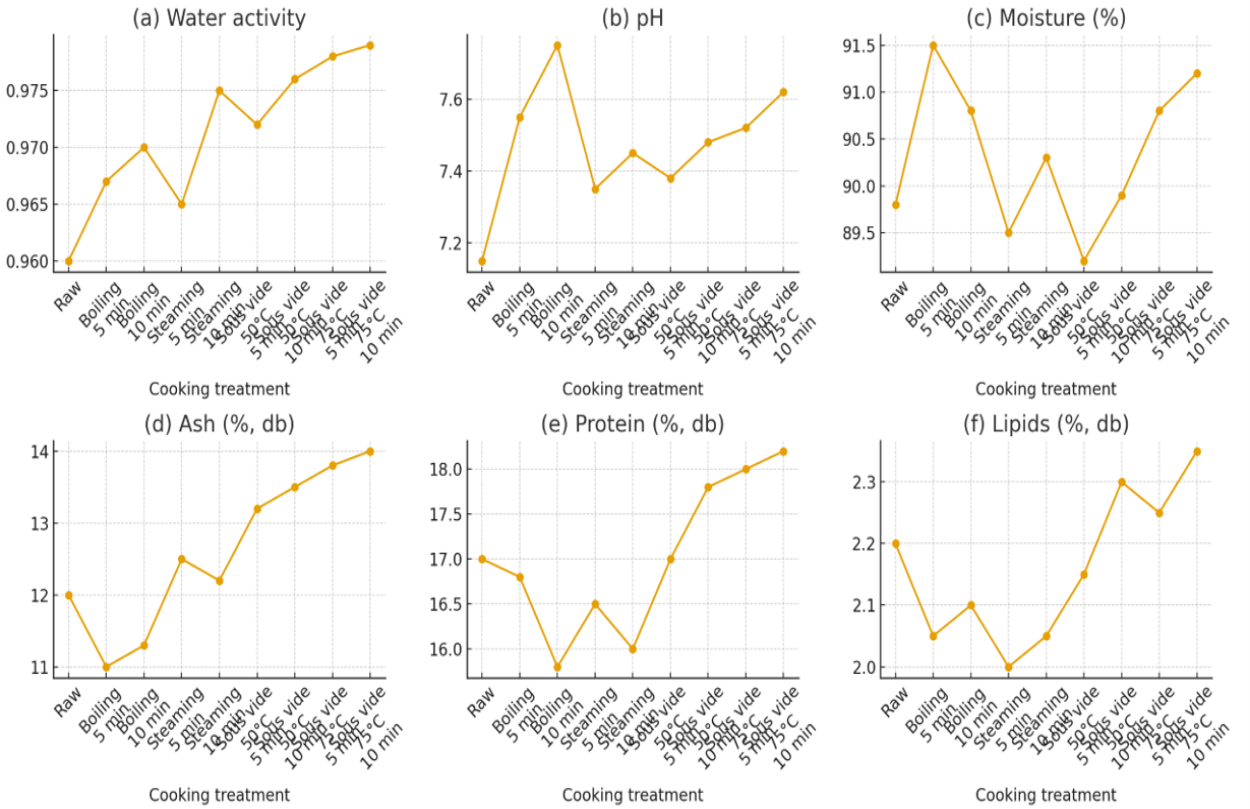


Fig. 1 The effect of culinary treatments on water activity, pH, moisture, ash, protein and lipid content of Allium ursinum (scallion)
Source: own results based on the determinations.

The raw ramson sample showed an average value of 3.84 mg/g DM, which increased to 8.92 mg/g DM after 5 minutes of boiling, followed by a slight decline at longer treatments. The initial increase is explained by the release of chlorophyll from plant cells as a

result of cell wall disorganization, whereas prolonged exposure to high temperatures leads to pigment degradation [5]. Carotenoid content increased from 0.21 mg/g DM in the raw sample to 1.83 mg/g DM in samples treated sous vide at 75 °C/10 min, remaining higher than in conventionally treated samples. This suggests that controlled cooking at moderate temperatures contributes to better preservation of liposoluble pigments.

Antioxidant activity

All thermal treatments produced a significant increase ($p< 0.05$) in antioxidant activity (Fig. 2) compared to the raw sample, except for steaming for 10 minutes, where a slight reduction was observed.

The highest antioxidant activity was recorded for samples treated sous vide at 75 °C/10 min (58.3 µmol TE/g DM), followed by samples boiled for 5 minutes (54.6 µmol TE/g DM). These results indicate that moderate thermal treatments can enhance antioxidant capacity through improved extractability of bioactive compounds from disrupted tissues.

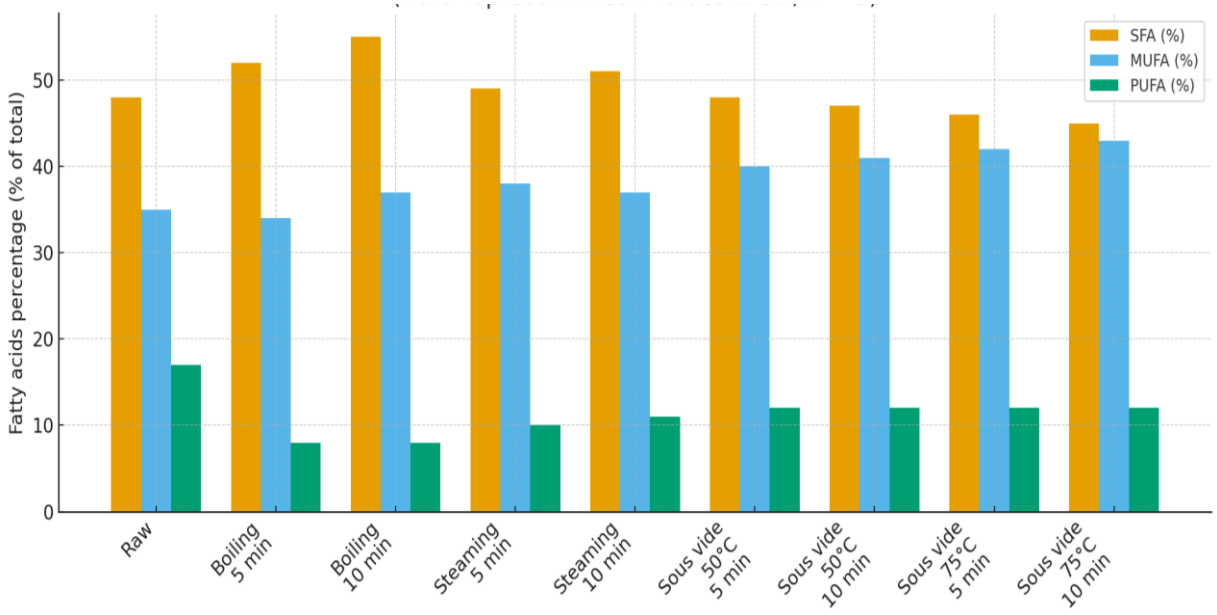


Fig. 2 Effect of cooking treatments on the content of SFA, MUFA, PUFA (Data represent mean values ± 50, n = 3)
Source: own results based on the determinations.

Values of water activity, pH, moisture, crude protein, ash, and lipid content for raw and thermally treated ramson samples are presented in Table 1.

Culinary processing caused a slight but statistically significant ($p< 0.05$) increase in water activity, with values ranging from 0.958 to 0.987 in heat-treated samples, compared with the raw sample (0.946).

Significant differences ($p< 0.05$) were noted among all treatment conditions tested, indicating that both the cooking method and exposure time influence the water balance of plant tissue. The increase in water activity after thermal treatments can be explained by structural modifications of cell walls and the release of intracellular water—a phenomenon frequently observed in leafy vegetables subjected to cooking [9], [11].

Likewise, the pH of ramson samples increased significantly ($p< 0.05$) following thermal treatments, from 6.35 in the raw sample to 7.81 after 10 minutes of boiling, as a result of the release of alkaline mineral compounds and the degradation of organic acids during cooking.

Table 1. Effect of culinary treatments on water activity, pH, moisture, ash, protein and lipid content of Allium ursinum (scallion).
(Values are expressed as mean ± standard deviation, n = 3. Different letters indicate significant differences between treatments, according to Tukey's test, $p < 0.05$.)

Culinary treatments	Time (min)	Water activity	pH	Moisture (%)	Ash (%, db)	Protein(%, db)	Lipid (%, db)
Raw ramson	–	0.946 ± 0.004^{d}	6.35 ± 0.02^{f}	88.4 ± 0.3^{c}	12.7 ± 0.3^{b}	16.2 ± 0.5^{b}	2.1 ± 0.1^{b}
Boiling	5	0.962 ± 0.005^{c}	7.32 ± 0.04^{c}	91.2 ± 0.5^{ab}	11.4 ± 0.4^{c}	15.7 ± 0.3^{bc}	2.0 ± 0.2^{b}
	10	0.972 ± 0.006^{b}	7.84 ± 0.05^{a}	92.1 ± 0.6^{a}	10.8 ± 0.2^{c}	14.9 ± 0.4^{c}	1.9 ± 0.1^{b}
Steaming	5	0.963 ± 0.004^{c}	6.91 ± 0.03^{c}	89.8 ± 0.4^{bc}	12.2 ± 0.3^{b}	15.8 ± 0.2^{bc}	2.0 ± 0.2^{b}
	10	0.971 ± 0.005^{b}	7.05 ± 0.03^{d}	90.6 ± 0.5^{b}	11.9 ± 0.2^{b}	15.3 ± 0.3^{c}	2.0 ± 0.1^{b}
Sous vide (50°C)	5	0.975 ± 0.006^{b}	6.58 ± 0.03^{c}	89.5 ± 0.4^{bc}	13.1 ± 0.3^{b}	16.8 ± 0.4^{b}	2.2 ± 0.1^{ab}
	10	0.978 ± 0.004^{ab}	6.72 ± 0.02^{d}	90.2 ± 0.3^{b}	13.6 ± 0.4^{b}	17.2 ± 0.5^{b}	2.3 ± 0.1^{ab}
Sous vide (75°C)	5	0.983 ± 0.003^{a}	7.12 ± 0.03^{d}	90.8 ± 0.3^{b}	14.0 ± 0.3^{ab}	17.5 ± 0.4^{b}	2.3 ± 0.1^{a}
	10	0.987 ± 0.004^{a}	7.28 ± 0.04^{c}	91.3 ± 0.4^{ab}	14.2 ± 0.3^{a}	17.8 ± 0.3^{a}	2.4 ± 0.1^{a}

Source: own results based on the determinations.

Mineral composition

The effect of different culinary treatments on the content of major minerals (K, Mg, Ca, Na, Fe, and Zn) in ramson samples is presented in Table 2. All thermal treatments produced significant variations ($p< 0.05$) in mineral content, depending on method and duration.

Potassium (K) in the raw sample was 612.4 mg/100 g DM, and values increased slightly to 645.2 mg/100 g DM in samples treated sous vide at 75 °C/10 min, indicating good retention of this element under controlled cooking conditions. In contrast, boiled samples showed significant decreases ($p< 0.05$), reaching 382.7 mg/100 g DM after 10 minutes, due to diffusion of potassium into the cooking water.

For magnesium (Mg), values ranged from 218.6 mg/100 g DM (raw) to 243.1 mg/100 g DM (sous vide at 75 °C/10 min), whereas boiling caused significant losses ($p < 0.05$), reducing the concentration to 145.4 mg/100 g DM. This behavior confirms the greater stability of Mg when cooking without direct contact with water [4].

Table 2. Effect of culinary treatments on mineral content (mg/100 g SU) of Allium ursinum (scallion).

Culinary treatments	Time (min)	K(mg/100g)	Mg (mg/100g)	Ca(mg/100g)	Na(mg/100g)	Fe(mg/100g)	Zn (mg/100g)
Raw ramson	–	612.4 ± 8.5^{b}	218.6 ± 5.2^{b}	2,875.6 ± 44.8^{b}	486.3 ± 12.4^{b}	18.4 ± 0.6^{c}	7.4 ± 0.2^{b}
Boiling	5	528.1 ± 10.2^{c}	186.9 ± 4.8^{c}	2,732.1 ± 56.7^{b}	705.4 ± 15.1^{a}	17.1 ± 0.5^{c}	7.7 ± 0.3^{b}
	10	382.7 ± 9.8^{d}	145.4 ± 6.3^{d}	2,614.9 ± 42.3^{c}	624.8 ± 11.8^{a}	15.1 ± 0.4^{d}	6.9 ± 0.3^{c}
Steaming	5	598.5 ± 8.9^{b}	210.7 ± 5.5^{b}	2,915.2 ± 38.4^{b}	492.6 ± 10.9^{b}	19.3 ± 0.7^{b}	7.8 ± 0.2^{b}
	10	575.2 ± 9.1^{b}	204.3 ± 4.9^{b}	2,838.4 ± 45.2^{b}	478.2 ± 9.6^{b}	18.6 ± 0.5^{b}	7.5 ± 0.3^{b}
Sous vide (50°C)	5	631.8 ± 10.5^{b}	225.6 ± 5.8^{b}	3,124.7 ± 52.9^{ab}	481.7 ± 8.7^{b}	20.9 ± 0.6^{ab}	8.1 ± 0.2^{ab}
	10	645.2 ± 11.3^{b}	236.9 ± 6.1^{b}	3,247.8 ± 48.3^{a}	486.4 ± 9.3^{b}	21.7 ± 0.7^{ab}	8.2 ± 0.2^{a}
Sous vide (75°C)	5	652.9 ± 9.6^{b}	243.1 ± 5.2^{a}	3,282.4 ± 44.1^{a}	493.2 ± 10.5^{b}	22.7 ± 0.8^{a}	8.3 ± 0.3^{a}
	10	667.3 ± 10.4^{a}	241.8 ± 6.0^{a}	3,348.2 ± 50.7^{a}	489.5 ± 9.7^{b}	22.1 ± 0.6^{a}	8.1 ± 0.2^{a}

Source: own results based on the determinations.

Calcium (Ca) content increased significantly ($p< 0.05$) in sous vide samples, reaching a maximum of 3,348.2 mg/100 g DM at 50 °C/10 min, compared to 2,875.6 mg/100 g DM in the raw sample. This apparent increase can be explained by reduced moisture and the relative concentration of solids. For sodium (Na), a transient increase was observed in samples boiled for 5 minutes (705.4 mg/100 g DM), followed by a decrease at longer treatments, suggesting a bidirectional diffusion effect between the cooking medium and plant tissue.

For iron (Fe), values ranged from 18.4 mg/100 g DM (raw) to 22.7 mg/100 g DM (sous vide

75 °C/5 min), with retention up to 123%, whereas boiling for 10 minutes caused a significant decrease to 15.1 mg/100 g DM.

Zinc (Zn) showed relatively good stability, with values between 7.4–8.1 mg/100 g DM and no significant differences among methods ($p > 0.05$). However, the best retention was observed with sous vide at 50 °C/10 min, yielding 8.3 mg/100 g DM, representing approximately 112% retention relative to the raw sample. Overall, the results show that conventional cooking methods (especially boiling) lead to significant mineral losses, whereas the sous vide technique ensures superior retention of macro- and microelements due to the absence of direct contact with water and precise temperature control. These findings are consistent with recent studies on thermally treated leafy vegetables [9], [11]. Water activity and pH increase significantly with treatment intensity, particularly during boiling. Boiling results in the greatest losses of ash and proteins due to leaching into the water. By contrast, sous vide, especially at 75 °C, ensures superior nutrient retention and better stability of physico-chemical parameters. Boiling caused the greatest mineral losses (especially K and Mg) due to diffusion into the aqueous medium. Steaming preserved a substantial fraction of minerals, but the highest retention values were achieved with sous vide at 75 °C. The sous vide method preserved 95–120% of the initial mineral content, indicating superior efficiency compared with conventional treatments. Chlorophyll and carotenoid values increased significantly ($p < 0.05$) after moderate thermal treatments (boiling 5 min and sous vide 75 °C) Table 3. Total phenolic content and antioxidant activity followed a similar trend, confirming the positive correlation between phenolics and antioxidant capacity (r = 0.91). Sous vide treatments, particularly at 75 °C, provide the best preservation and valorization of the bioactive compounds in ramson compared with prolonged boiling and steaming.

Table 3. The effect of culinary treatments on the content of chlorophyll, carotenoids, total phenolic compounds and antioxidant activity of Allium ursinum (leurda).

Culinary treatments	Time (min)	Total chlorophyll (mg/g SU)	Carotenoids (mg/g SU)	Total phenolic compounds (mg GAE/g SU)	Antioxidant activity (µmol TE/g SU)
Raw ramson	–	3.82 ± 0.14^{d}	0.23 ± 0.01^{c}	21.4 ± 0.8^{d}	43.2 ± 1.3^{c}
Boiling	5	8.75 ± 0.25^{a}	1.58 ± 0.06^{ab}	29.7 ± 1.1^{b}	55.1 ± 1.8^{ab}
	10	7.12 ± 0.18^{b}	1.32 ± 0.04^{b}	25.9 ± 1.0^{c}	49.8 ± 1.5^{b}
Steaming	5	6.85 ± 0.21^{bc}	1.41 ± 0.05^{b}	28.2 ± 0.9^{b}	52.3 ± 1.6^{b}
	10	6.21 ± 0.20^{c}	1.28 ± 0.05^{b}	26.3 ± 0.8^{c}	48.6 ± 1.4^{bc}
Sous vide (50°C)	5	7.94 ± 0.24^{b}	1.65 ± 0.06^{a}	30.8 ± 1.2^{b}	53.9 ± 1.7^{b}
	10	8.21 ± 0.23^{a}	1.72 ± 0.05^{a}	31.9 ± 1.3^{b}	56.4 ± 1.9^{a}
Sous vide (75°C)	5	8.43 ± 0.22^{a}	1.76 ± 0.04^{a}	32.1 ± 1.0^{b}	57.2 ± 1.6^{a}
	10	8.35 ± 0.25^{a}	1.83 ± 0.05^{a}	32.6 ± 1.1^{a}	57.8 ± 1.5^{a}

Source: own results based on the determinations made

Tabel 4. Effect of culinary treatments on the fatty acid profile (% of total lipid, dry matter) of Allium ursinum (scallion).

Culinary treatments	Time (min)	SFA (%)	MUFA (%)	PUFA (%)
Raw ramson	–	48.6 ± 1.2^{b}	35.2 ± 1.0^{b}	16.2 ± 0.6^{b}
Boiling	5	52.9 ± 1.4^{a}	38.7 ± 1.3^{a}	8.4 ± 0.5^{c}
	10	54.3 ± 1.6^{a}	39.1 ± 1.2^{a}	6.6 ± 0.4^{c}
Steaming	5	50.4 ± 1.3^{b}	37.8 ± 1.1^{ab}	11.8 ± 0.5^{b}
	10	51.6 ± 1.5^{ab}	36.9 ± 1.2^{b}	10.5 ± 0.5^{b}
Sous vide (50°C)	5	47.9 ± 1.1^{b}	40.8 ± 1.0^{a}	11.3 ± 0.6^{b}
	10	46.8 ± 1.2^{b}	42.2 ± 1.2^{a}	11.0 ± 0.4^{b}
Sous vide (75°C)	5	45.7 ± 1.3^{b}	43.5 ± 1.3^{a}	10.8 ± 0.5^{b}
	10	46.1 ± 1.4^{b}	44.7 ± 1.4^{a}	9.2 ± 0.6^{bc}

Source: own results based on the determinations made.

The following table 4 presents only the main groups of fatty acids (% of total lipid) and highlights the effect of culinary treatments (boiling, steaming, sous vide).

Boiling increased the proportion of SFA (saturated fatty acids), probably due to thermal degradation of unsaturated fatty acids. Sous vide treatments favoured the retention of MUFA (oleic acid) and PUFA (linoleic and linolenic acid), thus preserving a healthier lipid profile. In particular, the sous vide method at 75°C for 5–10 minutes maintained an optimal balance between SFA, MUFA and PUFA, confirming the increased stability of fatty acids under mild processing conditions.

The present study shows that the physicochemical and biochemical attributes of *Allium ursinum* are markedly influenced by the type and intensity of thermal processing. Although all culinary treatments induced detectable modifications, the magnitude of these changes varied substantially among methods, reflecting the different interactions between heat, plant microstructure, and the solubility of specific constituents.

The results obtained in this study on the effect of culinary treatments on *Allium ursinum* revealed significant ($p < 0.05$) changes in the main physicochemical and biochemical properties, depending on the processing method and duration.

The increase in water activity (aw) and pH observed in cooked samples, especially in boiled ones, can be explained by the partial degradation of cell walls and the release of free water from tissues. This phenomenon is more pronounced in long-duration thermal treatments, where the permeability of the cell membrane increases, favoring the loss of soluble compounds [12].

Ash content (a proxy for total minerals) decreases significantly during boiling, moderately during steaming, while in sous vide the losses are minimal due to the lack of contact with an aqueous medium. The same trend is observed for proteins: high losses during boiling (diffusion + denaturation), intermediate losses during steaming, and minimal losses in sous vide (50–75 °C). Lipids are the least affected in absolute terms; however, at higher temperatures and longer exposure times, losses may occur through oxidation or leaching.

For pigments, moderate treatments (boiling 5 min; sous vide 75 °C for 5–10 min) lead to increases in chlorophylls and carotenoids compared to the raw sample, due to matrix permeabilization and facilitated extraction. At longer exposures, pigments degrade (pheophytin formation, isomerization / degradation of carotenoids), and the values decrease. Total phenolic compounds exhibit a similar pattern: an increase under mild treatments (release from cell walls), followed by decreases when temperature/time increase.

Antioxidant activity (DPPH) increases overall after moderate treatments—showing a positive correlation with phenolics and pigments—but decreases under intense or prolonged processes, where thermal and oxidative degradation of sensitive compounds (e.g., vitamin C, certain flavonoids) predominates.

Regarding minerals, K and Mg show the highest losses during boiling (diffusion into the cooking water), steaming maintains levels close to the control, while sous vide ensures the best retention (often ≥95%). Na remains relatively stable among treatments; Ca is well preserved (low solubility), and Fe/Zn show better retention during steaming and sous vide compared to boiling.

The analysis of the fatty acid profile indicates differential sensitivity: SFA (C16:0, C18:0) are thermally stable; MUFA (especially C18:1) are maintained or even relatively increased under short sous vide treatments (5–10 min), suggesting superior preservation; PUFA (C18:2, C18:3) are the most vulnerable to heat/time, showing marked decreases during boiling and prolonged sous vide due to thermal oxidation. Short steaming preserves the PUFA fraction best among conventional methods.

Overall, the findings indicate that sous vide (≈75 °C, 5–10 min) provides the best compromise between culinary quality/safety and the preservation of bioactive compounds, minerals, and the lipid profile of wild garlic, whereas traditional boiling results in the greatest losses of soluble and heat-sensitive components.

Altogether, the results demonstrate that culinary processing can both enhance and diminish particular nutritional attributes of *A. ursinum*, depending on conditions. While boiling leads to the most pronounced nutrient losses, controlled methods such as steaming and especially sous vide effectively maintain the functional and nutritional value of ramson. These findings underscore the relevance of selecting appropriate preparation techniques, not only for consumer health but also for the valorization of wild edible plants as functional food resources.

CONCLUSIONS

The findings of this study demonstrate that thermal processing exerts a significant influence on the physicochemical and nutritional characteristics of *Allium ursinum*. The magnitude and direction of these changes depend strongly on both the cooking method and exposure time. Among the tested techniques, boiling consistently produced the greatest deterioration, primarily due to leaching of soluble compounds into the cooking water and degradation of heat-sensitive molecules. This led to notable reductions in minerals, vitamin C, phenolics, and polyunsaturated fatty acids.

In contrast, steaming and particularly sous vide cooking were more effective at preserving the structural integrity of plant tissues and retaining bioactive compounds. Sous vide treatments at 75 °C for 5–10 minutes ensured the highest overall retention of chlorophylls, carotenoids, phenolic compounds, and antioxidant capacity, while maintaining stable protein, lipid, and mineral profiles. These results highlight the advantages of low-temperature, controlled processing in limiting oxidative and thermal degradation.

Overall, the study indicates that sous vide represents a superior culinary method for preparing ramson, offering an optimal balance between sensory quality, nutritional preservation, and functional potential. Such insights can support the development of innovative food products based on *Allium ursinum* and contribute to the sustainable use and valorization of local wild plant resources.

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CLIMATE VOLATILITY AND THE EVOLUTION OF AGRICULTURAL RISK GOVERNANCE IN THE REPUBLIC OF MOLDOVA

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Abstract

Agriculture in the Republic of Moldova is highly exposed to climate variability due to its structural dependence on rain-fed production and the predominance of climate-sensitive crop systems. Recurrent droughts, frosts, and extreme weather events have generated significant fluctuations in Gross Agricultural Output (GAO), affecting farm incomes and increasing fiscal pressure on public budgets. This research examines how climate-induced production volatility has influenced the evolution of agricultural risk governance mechanisms in Moldova. The analysis combines quantitative assessment of output dynamics and insurance performance with qualitative evaluation of legislative and institutional reforms. Results show that agricultural output is characterized by frequentcontraction episodes associated with drought years. The subsidized agricultural insurance system has increased in financial terms, although coverage remains concentrated in a limited number of drought-prone crops and regions. Risk structure analysis indicates a growing share of drought-inclusive and multi-peril contracts, reflecting increasing recognition of systemic climate risks. At the same time, the persistence of ex post compensation measures highlights the continued fiscal exposure of the government. The findings suggest that Moldova's risk governance framework has evolved toward a layered model combining preventive insurance and reactive budgetary interventions, yet challenges remain regarding diversification, fiscal sustainability, and resilience under intensifying climate uncertainty.

Key words**:** *climate volatility, agricultural insurance, risk governance, drought, subsidized insurance*

INTRODUCTION

Agricultural activity is inherently exposed to risk and uncertainty due to its dependence on natural and climatic factors. Unlike most economic sectors, agriculture faces systemic production risks generated by drought, excessive rainfall, temperature extremes, and other weather-related shocks. Farm incomes are therefore significantly more volatile than non-agricultural incomes, making income stabilization a central objective of agricultural risk management [16, 17].

Climate change has intensified these vulnerabilities. Rising land temperatures and increasing frequency of extreme weather events contribute to production instability and yield fluctuations [1]. Empirical evidence confirms that climate variability significantly affects crop yields and agricultural productivity in Eastern European countries [14, 25]. Moreover, climate-induced instability influences agricultural trade patterns and regional resilience [12, 20]. Recent evidence shows that climate change, pandemic-related disruptions, and external market shocks significantly alter farmers' trading behavior and risk exposure, reinforcing the systemic nature of agricultural uncertainty in the region [3]. Recent research further shows that extreme weather events can weaken the resilience of agricultural economies, reinforcing the need for effective risk management mechanisms [29].

Agricultural insurance is widely recognized as a key instrument for managing production risk by stabilizing farm income and facilitating investment decisions. However, crop insurance markets are characterized by structural imperfections such as adverse selection, moral hazard, and correlated systemic risk [15, 5]. These market failures often prevent the efficient functioning of purely private insurance schemes. Consequently, government intervention through premium subsidies, regulatory frameworks, and public reinsurance has become a defining feature of agricultural insurance systems worldwide [13].

Empirical studies show that demand for crop and revenue insurance is influenced by premium levels, perceived risk, and policy design [6, 27]. Insurance programs can reduce income variability and support farm-level financial stability, yet their effectiveness depends on institutional design and public support mechanisms.Economic evaluations of agricultural insurance schemes demonstrate that efficiency outcomes vary significantly depending on subsidy structures and market design, highlighting the importance of well-measured public intervention [2].

In the Republic of Moldova, agriculture remains highly exposed to climatic risks due to its strong dependence on rainfall and limited financial capacity of producers [4]. The introduction of subsidized agricultural insurance [21] and subsequent regulatory adjustments have aimed to strengthen risk governance mechanisms. Complementary emergency compensation measures adopted through Government Decisions [8, 10, 11] further reflect the growing role of the government in managing climate-related shocks.

Despite the growing literature on climate impacts and agricultural insurance, limited research examines the interaction between climate-induced production volatility and the institutional evolution of agricultural risk governance in transition economies. Therefore, this study analyzes how climate variability has influenced the development of subsidized agricultural insurance and public compensation mechanisms in the Republic of Moldova, assessing their role in stabilizing agricultural production and farm incomes.

MATERIALS AND METHODS

This research includes quantitative analysis of agricultural production volatility and insurance market performance with qualitative institutional examination of the evolution of climate risk governance mechanisms in the Republic of Moldova during the period 2000–2024. The quantitative component focuses on measuring agricultural output dynamics, identifying climate-related contraction periods, and assessing the performance and fiscal sustainability of subsidized agricultural insurance schemes. The qualitative component examines the development of the legislative and institutional framework governing agricultural risk management, with particular emphasis on the interaction between ex ante insurance mechanisms and ex post compensation instruments. The integration of empirical volatility analysis with institutional assessment enables a comprehensive evaluation of Moldova's evolving climate risk governance framework.

The analysis uses official data on agricultural output (2000–2024), insurance performance (2022–2024), and relevant legislative acts governing agricultural risk management in Moldova. Statistical data were obtained from the National Bureau of Statistics, National Bank of Moldova and AIPA reports [18, 19, 28].

The performance of the subsidized agricultural insurance system was evaluated using key insurance indicators, including the loss ratio (indemnities to premiums), subsidy intensity (public support relative to premiums), and coverage dynamics measured through changes in contracts, insured area, and insured sums. These indicators provide insight into the actuarial balance, fiscal dependence, and risk exposure of Moldova's insurance system.

Institutional evolution was examined through qualitative analysis of legislative acts and policy reforms, classified according to their governance function as preventive (ex ante insurance), reactive (ex post compensation), or structural measures. This approach enables assessment of how Moldova's agricultural risk governance framework adapted in response to increasing climate volatility.

RESULTS AND DISCUSSIONS

Over the past two decades, Moldova's agricultural sector has combined steady expansion with recurring climate-related disruptions. Although production and trade have grown, progress has often been affected by droughts and extreme weather events. Because agriculture remains highly dependent on climate-sensitive crop production, output

fluctuates considerably from year to year. This variability has become a defining feature of the sector, directly contributing to income instability and economic vulnerability.

Plant production clearly dominates Moldova's agricultural sector, generating over 70% of total Gross Agricultural Output (GAO), while livestock accounts for roughly 30%. This structure makes the sector highly sensitive to weather conditions. Crop yields react immediately to drought, frost, or rainfall shortages, whereas livestock production tends to evolve more gradually and remains relatively stable. As a result, overall agricultural performance largely depends on developments in plant production.

The evolution of Gross Agricultural Output between 2000 and 2024 (Table 1) reflects this pattern.

Table 1. Major Climate-Induced Agricultural Contraction Years in Moldova (2000–2024)

Year	Gross Agricultural Output (mln MDL)	Annual Change (%)	Plant Production (mln MDL)	Animal Production (mln MDL)
2000	8,268	-	5,790	2,202
2001	8,646	4.6	5,727	2,655
2002	9,474	9.6	6,298	2,870
2003	10,354	9.3	7,086	2,937
2004	11,819	14.2	7,900	3,524
2005	12,688	7.4	8,449	3,851
2006	13,734	8.2	9,079	4,278
2007	**12,825**	**-6.6**	**7,941**	**4,509**
2008	**16,503**	**28.7**	**10,600**	**5,519**
2009	**13,300**	**-19.4**	**7,861**	**4,987**
2010	**19,873**	**49.4**	**13,616**	**5,786**
2011	22,619	13.8	15,751	6,347
2012	19,922	-11.9	11,968	7,529
2013	23,814	19.5	15,480	7,930
2014	27,254	14.4	17,341	9,417
2015	27,193	-0.2	18,082	8,584
2016	30,362	11.6	21,098	8,768
2017	34,142	12.4	24,435	9,191
2018	32,637	-4.4	22,883	9,190
2019	34,597	6.0	24,670	9,248
2020	**30,061**	**-13.1**	**20,389**	**9,135**
2021	**48,434**	**61.1**	**37,838**	**9,683**
2022	**40,617**	**-16.1**	**27,209**	**12,728**
2023	**41,800**	**2.9**	**28,837**	**11,850**
2024	**41,632**	**-0.4**	**28,015**	**12,144**

Source: Own calculation on the basis of data from National Bureau of Statistics [19].

Although GAO increased from 8,268 mln MDL in 2000 to 41,632 mln MDL in 2024, growth has not been linear. Significant declines occurred in 2007, 2009, 2012, 2020, and 2022—years marked by severe droughts or multiple overlapping shocks. These downturns highlight the structural vulnerability of the sector and underline the importance of strengthening agricultural risk governance mechanisms.

The first major disruption during the period under review occurred in 2007, when GAO fell by 6.6%, mainly due to a severe drought that caused cereal losses of around 63%. This year clearly demonstrated how quickly extreme weather can reverse previous gains. The pattern continued in 2009, when output declined by 19.4% under the combined pressure of unfavorable weather conditions and the spillover effects of the global financial crisis. In 2012, another drought led to a further contraction of 11.9%, once again exposing the vulnerability of crop production to rainfall shortages.

The period after 2020 reflects growing climatic instability and stronger agricultural fluctuations. In 2020, GAO decreased by 13.1%, reflecting the combined impact of severe drought and disruptions linked to the COVID-19 pandemic. Plant production, which dropped to 20,389 mln MDL, accounted for most of the decline, confirming its higher sensitivity compared to livestock. The sharp rebound in 2021 (+61.1%) shows how strongly agricultural output responds to favorable weather, but also highlights the increasing amplitude of fluctuations. The renewed contraction in 2022 (-16.1%), again associated with low precipitation, confirms the persistence of hydrometeorological risks. Although 2024 recorded only a slight decrease (-0.4%), winter frost affecting early crops shows that climate-related threats are becoming more diverse and not limited to drought alone.

Since the early 2000s, climate risk management in Moldova's agricultural sector has gradually developed into a structured legal and institutional framework that combines market-based insurance mechanisms, structural support measures, and ad hoc budgetary interventions (Table 2). In practice, this model distributes climate-related losses among farmers, private insurers, and the government, although the balance of

responsibility has shifted over time and remains imperfect.

As climate volatility intensifies, through recurrent droughts and heatwaves, irregular rainfall, late spring frosts, and localized storms, also the consistency and fiscal sustainability of this system have become increasingly important.

Its capacity to function effectively now plays a central role in maintaining sectoral stability, safeguarding farm viability, and protecting rural incomes.

Table 2. Evolution of Agricultural Climate Risk Governance Instruments in the Republic of Moldova (2004–2025)

Year	Legal Act (Republic of Moldova)	Type of instrument	Financial mechanism	Climate relevance
2004 (in force 2005)	Law No. 243/2004 on subsidized insurance of agricultural production risks *(later abrogated)*	Preventive (ex ante) – foundational law	Government co-financing of insurance premiums (commonly 50–60%, differentiated by crops; exceptional higher shares possible in specific years)	Covers systemic hazards: drought, hail, storm, low temperatures/frost, flood; pests/diseases (production risk framing)
2005	Government Regulation implementing subsidized agricultural insurance (adopted to operationalize Law 243/2004)	Operational framework	Subsidies paid via agricultural support financing mechanism (annual planning)	Makes climate-risk coverage administratively functional (not only declarative)
2012	Government Decision No. 766/2012 (drought support)	Reactive (ex post)	Direct budgetary transfers / exceptional aid rules	Shows limits of insurance penetration during systemic drought shock
2017	Government Decision No. 455/2017 (allocation of FNDAMR resources)	Financial governance instrument	Structured allocation rules for the National Fund	Integrates insurance into broader agricultural policy budgeting (risk + development)
2020 (in force 2021)	Law No. 183/2020 on subsidized insurance in agriculture	Preventive (ex ante) – second-generation framework	Premium subsidies financed from the agricultural/rural development fund; annual lists and subsidy-rate governance	Explicitly includes climate perils (excessive drought; frosts incl. late spring), strengthening climate-risk specificity
2022	Law No. 92/2022 on insurance / reinsurance activity	Market-institutional framework	Solvency, governance, supervision requirements	Indirect but enabling: supports capacity to carry correlated climate risks
2023	Law No. 71/2023 on subsidies in agriculture and rural development	Structural reform	Unified national financing framework for support measures (incl. insurance)	Links risk transfer (insurance) with adaptation investments (irrigation, modernization, resilience)
2024	Government Decision No. 644/2024 (drought & heat compensation—wheat/maize)	Reactive (ex post)	Emergency allocation with eligibility rules, ceilings, verification	Confirms recurrent drought as systemic; complements (but can also substitute) insurance
2025	Government Decision No. 594/2025 (late spring frosts + storm damage, Cahul)	Reactive (ex post)	100 million MDL allocated from Government intervention fund; administered via AIPA; detailed eligibility and per-ha payment rules	Highlights expanding hazard profile beyond drought: late frosts + severe storms; institutionalizes rapid relief protocols

Source: Elaborated by authors based on [7, 8, 9, 10, 11, 21, 22, 23, 24, 26].

The preventive component of Moldova's climate risk governance was formally established through Law No. 243/2004 on subsidized agricultural insurance [21], which entered into force in 2005 and signaled a shift from mainly ad hoc post-disaster support to a more structured system of contractual risk transfer via the insurance market. The law introduced government co-financing of insurance premiums generally covering 50–60%, with differentiated rates depending on the product group thereby reducing costs for farmers and encouraging the uptake of climate risk insurance.

Implementation began in 2005 through government regulations that clarified eligibility criteria, required documentation, and the conditional nature of support: farmers could receive premium subsidies only if they concluded compliant insurance contracts and paid their own share of the premium. Importantly, the scheme was not automatic. Each year, the list of eligible crops and insurable risks was approved in line with available public resources. From the outset, subsidized agricultural insurance in Moldova functioned as a budget-dependent policy instrument subject to administrative verification, rather than as an unconditional entitlement.

An important update in the legal framework is that Law No. 243/2004 [21] no longer serves

as the current legal basis for subsidized agricultural insurance. The mechanism was reformed and re-codified through Law No. 183/2020 [22] on subsidized insurance in agriculture, which abrogated Law No. 243/2004 [21] and entered into force on 16 January 2021. This reform did not remove the preventive instrument; instead, it modernized and strengthened its regulatory structure.

Law 183/2020 [22] organizes agricultural insurance into clearly defined product categories, particularly quantitative yield insurance, quality insurance, and insurance of multiannual plantations. It also provides a clearer specification of covered climate-related risks, including excessive drought and late spring frosts, alongside hail, floods, torrential rains, storms, and other hazards. The law further introduces more detailed procedures for damage notification, the establishment of investigation commissions, and loss assessment, thereby improving transparency and consistency in the indemnification process. By linking premium subsidization to annual governance rules and approved risk lists, the new framework reinforces the position of preventive climate risk transfer as a regulated element of agricultural policy, shaped by both actuarial considerations and the fiscal capacity of the government.

The implementation of the preventive insurance scheme, both under the earlier and the revised framework, has relied on the Agency for Intervention and Payments in Agriculture (AIPA) as the operational intermediary that translates legal norms into practical budgetary transfers and compliance controls. AIPA verifies the conformity of insurance contracts, checks eligibility conditions and supporting documentation, authorizes subsidy payments, and provides the administrative backbone through which the government's co-financing share is executed [28]. This role is not only technical, as in a system where insurance uptake remains incomplete and climate losses are increasingly systemic, implementation quality determines whether subsidized insurance functions as a genuine ex ante stabilizer or remains marginal relative to ex post compensation. The broader framework of agricultural public support was further structured through Government Decision No. 455/2017 [8], which established the methodology for allocating resources from the National Fund for the Development of Agriculture and Rural Areas (FNDAMR) across support measures, including premium subsidies. By formalizing allocation procedures and prioritization rules, this decision embedded the insurance subsidy measure into a disciplined public finance framework and strengthened policy coherence by linking risk-transfer support to the overall annual distribution logic of agricultural assistance.

A major institutional consolidation followed with Law No. 71/2023 [24] on subsidies in agriculture and rural development, which further unified the financing architecture by consolidating agricultural support measures within a coherent fund-based system. Crucially, this reform should be interpreted as an integration of an already-existing insurance subsidy mechanism, implemented since 2005 and re-regulated in 2020/2021, rather than as the creation of insurance support itself. By bringing different instruments under a unified financing logic, Law 71/2023 [24] potentially improved coordination between risk transfer and long-term resilience-building investments such as irrigation infrastructure, technological modernization, diversification, and climate-adaptive practices. At the same time, consolidation may intensify competition for scarce budgetary resources across measures, meaning that premium subsidy allocations can become vulnerable in years marked by fiscal stress or when emergency interventions absorb a large share of available public funds, an issue that directly affects the preventive capacity of the system.

Despite the existence of this preventive architecture, repeated episodes of severe climatic stress have revealed the limits of insurance penetration and the structural difficulty of insuring highly covariant risks, especially drought under conditions of climate change. Moldova's legal framework therefore contains a second pillar: reactive (ex post) public compensation mechanisms activated

when losses exceed the capacity of insurance uptake and actuarial absorption. This logic is illustrated by Government Decision No. 766/2012 [25], adopted after a major nationwide drought, and by Government Decision No. 644/2024 [10], which introduced compensation for farmers affected by drought and extreme heat in wheat and maize production. Such instruments operate as stabilization mechanisms designed to prevent cascading insolvency and broader rural economic contraction in extreme years. Their design increasingly reflects awareness of incentive problems: the practice of excluding already insured land from additional compensation is a policy attempt to preserve complementarity between ex ante insurance and ex post aid, and to reduce moral hazard and double compensation. Nevertheless, the recurrence of these interventions suggests that ex post fiscal measures are not merely exceptional but risk becoming a structurally anticipated feature of agricultural policy under intensifying climate volatility.

The most recent development further confirms this trajectory. Government Decision No. 594 [11] approved a detailed regulation for granting financial aid to farmers affected by late spring frosts in 2025 (notably sugar beet and perennial plantations) and by a severe storm event in Cahul district affecting vineyards. Unlike premium subsidies, this instrument is financed through an explicit allocation of 100 million MDL from the Government Intervention Fund, functioning as a pure ex post compensation scheme. Its differentiated design, covering full reimbursement of seed costs for re-sown sugar beet crops, fixed per-hectare payments for fully damaged perennial plantations, compensation proportional to the degree of damage, and specific support for vineyard infrastructure affected by storms, which reflects a shift toward a more precise and tailored approach to loss assessment and relief. The mechanism is no longer uniform but adapted to the specific nature and intensity of damage.

At the same time, the growing need for dedicated emergency regulations in response to climate shocks highlights the rising fiscal exposure of the government. Even when disasters are geographically limited, their impact can be severe, placing additional pressure on public resources and revealing the increasing financial implications of climate variability for agricultural policy.

To assess the practical functioning of the revised risk governance framework, it is necessary to examine the recent dynamics of the subsidized agricultural insurance system. Table 3 presents the evolution of key insurance indicators in Moldova over the period 2022-2024, including participation levels, financial volumes, subsidy allocations, claims activity, and loss ratios. These indicators provide a quantitative basis for evaluating market development and fiscal involvement during the implementation phase of the updated legislative framework.

Table 3. Evolution of Subsidized Agricultural Insurance in Moldova (2022–2024)

Indicators	2022	2023	2024	Change 2022–2024
Contracts in force	471	487	522	+10.8%
Gross written premium (MDL)	93,198,712	104,973,726	128,987,911	+38.4%
Government subsidy (MDL)	54,973,194	51,451,220	38,975,014	–29.1%
Sum insured (MDL)	974,151,826	1,226,646,752	1,394,610,411	+43.2%
Claims paid (number)	384	340	497	+29.4%
Indemnities paid (MDL)	54,357,829	44,375,745	57,029,609	+4.9%
Loss ratio (%)	58.3%	42.3%	44.2%	-

Source: based on data from National Bank of Moldova and Agency of Interventions and Payments in Agriculture [18, 19].

Although the number of contracts increased moderately by 10.8%, financial expansion was more pronounced: gross written premiums rose by 38.4%, while the total sum insured expanded by 43.2%. This suggests not only growing participation but also higher insured values per contract, reflecting either increased coverage levels, higher production values, or greater risk awareness among producers. At the same time, government subsidy allocations declined by 29.1%, indicating a relative

reduction in direct fiscal support intensity despite overall market growth. Claims dynamics confirm the climate-sensitive nature of the system. While the number of claims increased significantly in 2024, total indemnities over the three-year period rose only modestly (+4.9%), resulting in loss ratios fluctuating between 42% and 58%. These levels suggest that, despite recurrent climate shocks, the insurance portfolio remained actuarially sustainable and did not generate excessive fiscal pressure. Overall, the evidence points to a system that is expanding in scale while maintaining relative financial balance, though continued exposure to systemic climate events may challenge this equilibrium in the longer term.

To complement the aggregate insurance indicators, it is necessary to examine the internal structure of the insured portfolio, as portfolio composition directly influences climate risk exposure and actuarial performance. Changes in the distribution of insured areas across crops may alter the system's vulnerability to specific hazards, particularly drought and temperature-related shocks. Accordingly, Tables 4 and 5 analyze the structural configuration and dynamics of insured crop areas during 2020–2024.

Table 4. Share of Main Insured Crops in Total Insured Area (%), 2020–2024

Crop	2020	2021	2022	2023	2024
Sunflower	37.1	34.4	25.7	24.2	45.5
Maize	52.5	30.7	33.4	17.8	24.6
Wheat	7.6	26.9	34.7	40.6	26.4
Other crops	2.8	8.0	6.2	17.4	3.5

Source: based on data from Agency of Interventions and Payments in Agriculture [28].

The structure of insured crop areas is characterized by a high degree of concentration, with sunflower, maize, and wheat jointly accounting for more than 90% of the portfolio throughout the period (Table 4). Although maize dominated in 2020, wheat gained significant weight between 2021 and 2023 before declining again in 2024, when sunflower re-emerged as the leading insured crop. These fluctuations indicate dynamic reallocations within the portfolio, likely reflecting climate conditions, market incentives, and evolving risk perceptions among producers.

Table 5. Structural Dynamics of Insured Crop Areas (Index 2020 = 100)

Crop	2021	2022	2023	2024
Sunflower	318	240	83	339
Maize	200	220	43	129
Wheat	1,201	1,560	673	951

Source: based on data from Agency of Interventions and Payments in Agriculture [28].

Relative to the 2020 baseline, insured areas exhibit substantial volatility, particularly for wheat, which expanded sharply in 2022 before contracting in subsequent years (Table 5). Sunflower and maize also display marked oscillations, confirming that the insurance portfolio remains highly sensitive to production variability and climate exposure. Despite some adaptive adjustments, the persistent dominance of a few drought-prone crops implies limited diversification and continued vulnerability to correlated climate shocks.

Table 6. Structure of Insured Climate Risks by Category (2021–2024)

Risk Category	Insured Area (ha)				Subsidy (thous. MDL)			
	2021	2022	2023	2024	2021	2022	2023	2024
Single-peril risks	6.817	3.323	6.752	4.291	12.563	3.897	13.810	13.628
Multi-peril (without drought)	2.997	2.029	1.515	6.204	14.763	7.663	13.844	20.441
Drought-inclusive contracts	3.875	9.639	4.722	8.893	5.763	8.514	9.212	16.658

Source:based on data from Agency of Interventions and Payments in Agriculture [28].

Beyond crop composition, the structure of insured hazards provides additional insight into the climate sensitivity of the insurance portfolio. The distribution of insured risks reflects not only producers' exposure but also their perception of dominant climatic threats. The data on insured risk types during 2021–2024 reveal a strong concentration in multi-peril combinations centered around hail,

drought, and spring frost—hazards that are recurrent and increasingly systemic in Moldova's climate profile.

By examining insured areas and subsidy allocations across risk categories, it becomes possible to assess how the insurance system responds to evolving climate patterns and whether risk transfer mechanisms align with the actual structure of climatic exposure.

The structure of insured risks evolved notably during 2021–2024. In 2021, coverage was largely dominated by single-peril and frost-related multi-peril contracts, reflecting the climatic concerns of that year. From 2022 onward, drought-inclusive contracts expanded significantly, confirming excessive drought as a primary systemic risk. In both 2022 and 2024, combinations including drought account for substantial insured areas and increasing subsidy allocations. Pure single-peril contracts remain marginal, while the growing importance of multi-peril combinations involving drought and frost indicates recognition of compound climate risks. Overall, the year-to-year fluctuations in coverage reflect adaptive responses to changing climatic conditions and highlight the climate-sensitive nature of the subsidized insurance system.

Beyond crop and hazard composition, the territorial distribution of insured risks provides insight into the spatial dimension of climate exposure and fiscal support allocation. Regional disparities in insured area and premium volumes reflect differences in production structure, climate vulnerability, and insurance uptake. Table 7 presents the distribution of insured agricultural risks across Moldova's development regions during 2021–2024, including insured area and the corresponding financial contributions of farmers and the government.

The data indicate significant regional variation in both insured area and financial intensity over the period 2021–2024. While the North region initially dominated in 2021 in terms of insured area and subsidy allocation, its trajectory fluctuated in subsequent years before stabilizing at relatively high financial levels in 2024. The South region records the largest insured area in 2024, reflecting its structural exposure to drought-prone crop production and increasing risk awareness.

Table 7. Regional Distribution of Insured Agricultural Risks in Moldova (2021–2024)

Year	Region	Insured Area (ha)	Farmer Contribution (thous. MDL)	Government Subsidy (thous. MDL)
2021	North	9,629.7	9,069.4	21,024.4
	Center	4,277.9	4,223.9	9,720.5
	South	4,081.2	2,776.2	6,416.6
	UTA Gagauzia	233.9	67.9	138.6
2022	North	4,757.6	10,539.0	9,037.2
	Center	3,269.7	5,083.5	6,376.2
	South	5,757.1	5,621.1	6,037.3
	UTA Gagauzia	1,114.3	433.8	1,012.1
2023	North	8,909.6	18,033.6	28,558.6
	Center	2,237.4	12,222.5	12,318.6
	South	5,285.0	10,972.8	14,506.5
	UTA Gagauzia	2,256.0	2,260.5	2,303.0
2024	North	7,768.2	33,940.6	27,598.5
	Center	8,067.7	6,478.6	20,268.7
	South	11,851.5	11,613.6	22,436.1
	UTA Gagauzia	3,337.5	1,117.1	2,743.2

Source: based on data from Agency of Interventions and Payments in Agriculture [28].

The Center region shows pronounced volatility, with a contraction in insured area during 2022–2023 followed by a substantial expansion in 2024, indicating dynamic adjustment in insurance uptake. UTA Gagauzia maintains a comparatively smaller but steadily increasing insured area across the four-year period, suggesting gradual integration into the subsidized insurance system. Overall, the regional distribution confirms that insurance demand and fiscal support remain spatially differentiated, corresponding to heterogeneous climate risk profiles and production structures across the country.

CONCLUSIONS

The findings of this study confirm that climate variability remains a central structural constraint for agricultural development in the Republic of Moldova. Repeated drought and extreme weather episodes have generated significant production volatility, directly affecting farm incomes and increasing pressure

on public finances. Given the large share of crop production in total agricultural output, the sector remains highly vulnerable to systemic climatic shocks.

Although the subsidized agricultural insurance system has expanded in recent years, both in terms of insured sums and financial allocations, its structure remains concentrated in a limited number of crops and regions. The increasing share of drought-inclusive and multi-peril contracts reflects improved recognition of compound climate risks; however, persistent reliance on emergency compensation measures indicates that preventive mechanisms are not yet fully sufficient to absorb systemic shocks.

From a policy perspective, strengthening agricultural risk governance requires moving beyond reactive fiscal interventions toward a more resilient and financially sustainable framework. This includes enhancing insurance penetration among small and medium-sized producers, promoting greater portfolio diversification across crops and regions, and improving the actuarial design of subsidized products to better reflect differentiated climate exposure. In addition, closer integration between insurance mechanisms and broader climate adaptation policies—such as irrigation development, drought-resistant crop varieties, and risk-reducing technologies—is essential.

Ensuring long-term fiscal sustainability will require careful calibration of subsidy intensity and improved monitoring of regional risk concentration. A gradual shift toward more risk-based pricing, combined with targeted support for vulnerable producers, could strengthen market discipline while maintaining social protection objectives. Overall, Moldova's transition toward a layered risk governance model represents important progress, but continued institutional refinement and strategic policy coordination will be critical under conditions of intensifying climate uncertainty.

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VARIABILITY OF ONION SUPPLY AND PRICES IN PAKISTAN MARKET- A STUDY CASE IN CENTRAL PUNJAB DISTRICT. IMPLICATIONS FOR STAKEHOLDERS

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Abstract

This study aims to measure variability, instability, seasonal indices, price elasticity of supply and Compound Annual Growth Rate of prices and arrivals of onion in the Agriculture Produce Market of Lahore city and Gujranwala city. The monthly data of prices and arrivals collected from secondary source over the period of seven years for studying market dynamics related to Agriculture Produce Market of Lahore city and Gujranwala city. The analysis of Coefficient of Variation shows fluctuations in monthly arrivals and prices. The instability in market prices is more than arrivals. Results shows that prices tended to inflate during second half of the years. The inverse relationship between prices and arrivals is confirmed. Price elasticity of supply shows both positive and negative values depending on concern seasonal pattern of onion marketing. Policy makers should encourage local production of onion and provision of information to concern stakeholders especially farmers and consumers in order to increase their welfare.

Key words**:** *instability, market, relationship, stakeholders, variability*

INTRODUCTION

Around the world, Onion is widely consumed as a vegetable [2]. The Onion (*Allium cepa* L) is one of the important essential food crops in Pakistan. It is widely consumed by the households in the Pakistan throughout the year. It is used in sauces, soups and for preparation of seasonal vegetable foods. Onion have a key role in human nutritional health benefits, generation of farm income, alleviation of poverty and earnings of foreign currency through export.

There is 2.2 million tonnes production of onion in Pakistan for year 2023-24 which is 20.4 percent higher than last year as per [7]. Production of onion crop in Punjab during 2023-24 is 0.46 million tonns which shows 2.7 percent positive growth over the same interval of past year. There are two big Agricultural Produce Markets (APMs) in Punjab located at district Lahore and district Gujranwala which deals with trading of onion. The area and production of onion in these two districts is illustrated in Table 1.

Table 1. Area and Production of Onion

Year	Area (Ha)		Production (Tons)	
	Lahore	Gujranwala	Lahore	Gujranwala
2017-18	61	1,053	393	12,169
2018-19	49	1,080	316	12,547
2019-20	35	1,849	235	31,041
2020-21	25	1,110	179	30,286
2021-22	10	722	61	16,359
2022-23	83	1,028	582	23,904
2023-24	50	617	622	14,688

Source: Crop Reporting Service, Government of the Punjab [23].

Table 1 reflects that after 2019-20 both the area and production of onion in both the districts have shown decreasing and fluctuating trend and such trend have some relationship with market arrival of concern crop in the APM. The fluctuation in market arrivals in the agriculture produce markets are mainly linked with the variation of output of crops.

[10] observed that variation in the prices of agricultural commodities mostly occur because of their seasonal production nature and

irregular arrivals in APM. The market arrivals and concern market prices lead to major variations due to seasonality nature of production of onion crop. Furthermore, high price fluctuation may arise from year to year and within the same marketing season. In such case, it initially occurs because of production and then it causes changes in the behaviour of demand pattern [19]. Determination of prices in the agriculture sector does not have important link with demand. High fluctuation in the supply of crop have important impact on variability of prices and supply is highly inelastic for any crop [14]. Among the various categories of food, there is a highest volatility in the prices of onion [18]. It is perceived that volatility in prices is mainly occurs due to variations in the market arrivals [20]. Farmers face major challenges due to price volatility which is mainly caused by fluctuations in production and supply [22]. Although production of onion crop has increased by 2.7 percent in Punjab during Financial Year (2023-24) but as per report of Pakistan Bureau of Statistics, among fifty-one essential food items' list, the highest (140.84) percent change is observed in case of onion regarding yearly average prices in Pakistan [7]. As per findings of [10], high fluctuation in market prices of onion can impose significant problems for both farmers and consumers. It is observed that fluctuations in the prices of onion impacted the interest of both concern farmers (producers) and consumers of onion [6].

This present research study is carried out in APMs of Pakistan located in Lahore city and Gujranwala city for analyzing the monthly economic behaviour of both market arrivals and market prices. Furthermore, selection of these two APMs based on two reasons including higher market arrival of onion and because of majority of population buying onion from these APMs. Supply from these APMs also supplied to the northern districts of Punjab province where no such large APM have existed. Present study would provide valuable decision-making guidelines for all concern stakeholders especially farmers and consumers regarding trading with reference to onion. Policy makers can stabilize the market prices of onion by managing arrivals of onion in both the APMs of Pakistan. From literature, it is observed that very limited research studies have analyzed dynamics nature of market price and arrival of onion concerning with APMs of Lahore and Gujranwala cities of Pakistan. It is pertinent to mention that his present study would provide a novel policy input regarding supply chain mechanisms including production, distribution and consumption of onion in the various areas.

Moreover, the aim of present study is to estimate variability, instability and seasonal indices of market prices and arrivals. Further, Price Elasticity of Supply (PES), Compound Annual Growth Rate (CAGR) and Karl Pearson correlation coefficient would also analyze in the APM of Lahore city and Gujranwala city

MATERIALS AND METHODS

In order to measure various market dynamics of onion, the APM of Lahore city and Gujranwala City are selected. These two cities have major APM for conducting agribusiness of onion and comparatively abundant supply of onion noticed in these two markets located in Lahore and Gujranwala City as compared to other cities of Punjab province. It would assist to properly understand various economic aspects of prices and arrivals of onion.

This present study based on secondary data source. Monthly data of prices and arrivals of onion of APM of Lahore City and Gujranwala City were collected over the period of seven years (2018-2024) from Agriculture Marketing Information Service (AMIS).

The variability in market arrivals and prices of onion in the APM of Lahore City and Gujranwala City during the years 2018 to 2024 including monthly consideration was computed by using Coefficient of Variation (C.V) statistical tool.

[4] has computed the C.V by using market arrival and prices data. C.V has been used for estimating variability in market arrivals and prices of onion. Mathematically, C.V is calculated as by using below mention formula:

$$C.V = \frac{\text{Standard Deviation}}{\text{Mean}} * 100 \text{.....(1)}$$

The Cuddy-Della-Valle Index is applied in this research study for estimating instability in market prices and arrivals of onion over the period of time.

By using C-D-V Index, [4] has estimated instability in market arrivals and prices of onion. The appropriate mathematical formula for estimation of Cuddy-Della-Valle Index is defined as below.

$$C - D - V\ Index = CV * \sqrt{(1 - R^2)} \text{.....(2)}$$

In order to analyze seasonality variations in APM of Lahore and Gujranwala city, monthly data was employed related to prices and market arrivals. Moreover, seasonal indices of market arrivals and prices of onion were estimated by using the simple average approach. For calculation of seasonal arrival and price index, initially compute seven years average price/arrival of onion for each month and for whole period. Afterwards, by using seven years annual average price/arrival as a base, index is constructed by dividing each seven-year monthly price/arrival by the overall seven-year average. This tool was employed by [5] regarding to study seasonal variation of major vegetables.

The Karl Pearson correlation coefficient was employed for investigating the degree and direction of relationship between market prices and market arrivals of onion in concern market. The research study of 12] investigated the extent of relationship between market arrivals and market prices by applying Karl Pearson Correlation Coefficient. Furthermore, Karl Pearson correlation coefficient is estimated by using below mentioned statistical formula:

$$\text{Karl Pearson correlation coefficient} = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \text{.....(3)}$$

In order to measure responsiveness of quantity supplied to its price, Price Elasticity of Supply (PES) is computed. PES is important to calculate because it assists the various concerning stakeholders to understand the changes in decisions pattern of suppliers due to changes in the supply of a commodity in the market and consequently it impacts the market arrivals and prices dynamics of concern market.

[14] has estimated price elasticity of supply for vegetables by considering below mention formula:

$$PES = \frac{\%\ Change\ in\ quantity\ supplied}{\%\ Change\ in\ price} \text{.....(4)}$$

The CAGR is mainly used for the purpose to measure trends. In the present study, trends in term of growth of prices and arrivals has been computed by using CAGR.

[21] examined the trends in market arrivals and prices of vegetables in Pokhara Wholesale market of Nepal by computing CAGR analytical tool. Mathematical formula of CAGR is as follow:

$$CAGR = \left(\frac{Final\ Value(Year\ Z)}{Initial\ Value(Year\ X)}\right)^{1/N} - 1 \text{.....(5)}$$

RESULTS AND DISCUSSIONS

Analysis of variability is important for understanding mean and C.V. across the months.

Table 2 shows the monthly variability in market arrivals and prices of onion in both the markets. Highest mean arrival of onion (APM of Lahore city) is observed during the month of October (24,090.32 quintal). Moreover, highest value of C.V (26.06 %) is observed during the month of February concerning with APM of Lahore city. As far as APM of Gujranwala city is concerned, highest mean arrival (46,188.33 quintal) and highest value of C.V(33.55 %) are observed during the month of April. Moreover, with regard to C.V, it is consistent with the results of [4] and [15] regarding their research study of market arrival of onion in Ahmednagar and Bangalore markets. The highest mean market prices (Rs.52,367.74 and Rs.47,264.52) observed in the December for both APMs. Furthermore, highest C.V (30.63%) is noted in February (APM of Lahore city) and highest C.V (33.92 %) is observed during the month of August (Gujranwala city) regarding Lahore city is noted in the month of February and for Gujranwala city the highest value of C.V (33.92 %) is noted during the month of August. There is a violent increase in the prices of onion from September to December and it is aligned with the study of [16].

Table 2. Monthly Variability in Market Arrivals and Prices of Onion

Month	APM (Lahore City)				APM (Gujranwala City)			
	Supply		Prices		Supply		Prices	
	Mean	C.V %	Mean	C.V %	Mean	C.V %	Mean	C.V %
Jan	19,319.35	9.83	47,775.81	19.31	24,426.61	12.85	45,451.61	21.45
Feb	20,075.86	26.06	39,887.93	30.63	23,044.83	25.25	39,601.72	30.70
Mar	22,353.48	17.84	40,817.74	16.45	33,161.29	23.62	33,161.29	23.62
Apr	22,920	18.82	32,651.67	26.06	46,188.33	33.55	32,323.33	25.31
May	21,770.97	23.49	24,577.42	25.11	27,120.97	21.29	24,529.03	22.54
Jun	23,156.67	17.82	27,295	22.06	30,525	21.24	24,846.67	23.22
Jul	21,025.81	17.48	26,988.71	16.85	34,803.23	15.42	25,122.58	18.31
Aug	17,790.32	24.15	35,764.52	26.40	35,622.58	23.66	31,562.9	33.92
Sep	22,000	14.31	40,060	10.17	37,705	17.77	34,930	20.77
Oct	24,090.32	17.03	43,024.19	12.67	37,206.45	15.27	40,356.45	14.51
Nov	21,353.33	13.77	49,601.67	13.12	30,677.67	14.19	46,248.33	16.47
Dec	19,938.71	19.99	52,367.74	18.68	24,793.23	18.78	47,264.52	23.79

Source: Own calculation.

Figure 1 shows the U-shaped curve of prices behaviour in both the APMs while Figure 2 revealed that mean monthly arrivals in APM of Gujranwala city is higher than APM of Lahore city. Further, there are some points which justify an inverse relation between the prices and arrivals.

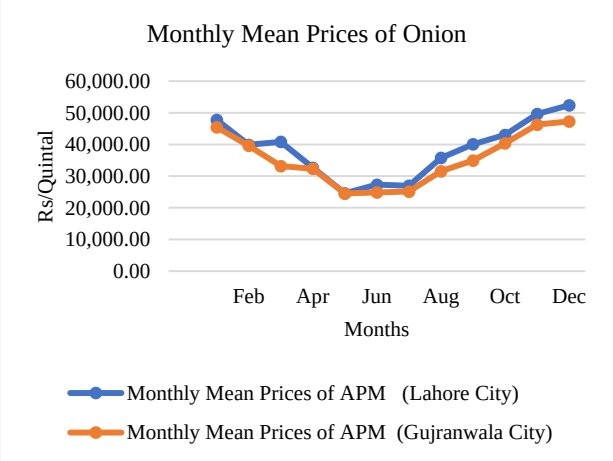


Fig. 1. Monthly Mean Prices of Onion
Source: own processing based on data

As per Table 3, there was a high C.V value (67.52 %) of prices and high instability value (32.03) of prices related to APM of Lahore City. While, there was also high C.V Value (62.06 %) of prices and medium instability of prices observed concerning with APM of Gujranwala city.
Moreover, with reference to market arrival, there was C.V value (9.38 %) and low instability (2.6) of arrivals in case of APM Of Lahore city.

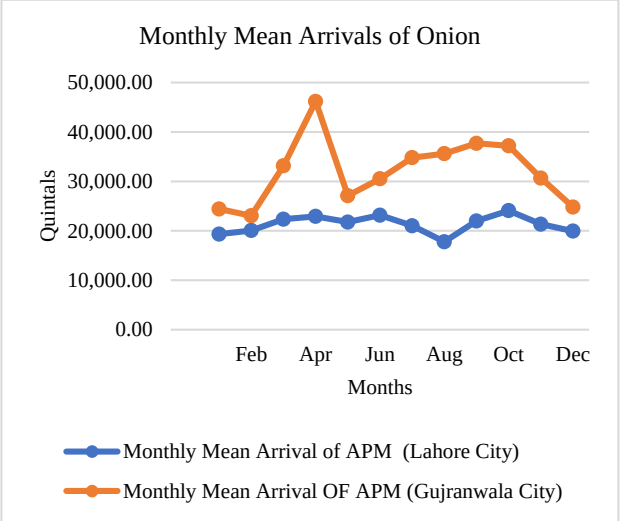


Fig. 2. Monthly Mean Arrivals of Onion
Source: own processing based on data

Table 3. Instability in Lahore City and Gujranwala City Markets

City	Variable	C.V (%)	Instability Index	Inference
Lahore City	Supply	9.38	2.6	Low Instability
	Prices	67.52	32.03	High Instability
Gujranwala City	Supply	13.66	3.79	Low Instability
	Prices	62.06	29.43	Medium Instability

Source: Own calculation.

The APM of Gujranwala City shows comparatively high value of C.V(13.66 %) with a low instability value (3.79). It is evident from the table 3 that instability in prices are higher than arrivals of onion. This is agreed with the findings of [22], [13] and [17].
The seasonal variation in prices are caused by changes in arrival as a result of seasonal

variability in production of concern crop. Table 4 shows that arrival index (114.89) is highest during the month of October in APM of Lahore city and this finding is in line with the research study of Nayak and Srivastava (2024) [13]. While in case of APM of Gujranwala city, its highest value (141.56) occur during the month of April. Furthermore, price indices for both the markets (Lahore City and Gujranwala city) shows highest values (138.60 and 133.26) during the month of December because during June to April, local supply is insufficient and supply from other provinces fulfils demand in these APMs of Punjab. Findings of this study are in consistent with the study of [9] and [11] related to seasonal indices of onion arrival in Solapur market and wholesale markets of Gujarat (Mahuva, Ahmedabad and Gondal).

Table 4. Seasonal Monthly Indices of Market Arrivals and Prices of Onion

Month	Supply Index (%)		Prices Index (%)	
	Lahore City	Gujranwala City	Lahore City	Gujranwala City
Jan	92.14	77.36	126.44	128.14
Feb	89.57	68.27	98.76	104.45
Mar	106.61	105.02	108.03	113.93
Apr	105.78	141.56	83.63	88.19
May	103.83	85.89	65.05	69.16
Jun	106.88	92.94	69.91	67.79
Jul	100.3	110.22	71.43	70.83
Aug	84.85	112.81	94.65	88.99
Sep	101.54	115.56	102.60	95.30
Oct	114.89	117.83	113.87	113.78
Nov	98.55	94.02	127.04	126.18
Dec	95.09	78.52	138.60	133.26

Source: Own calculation.

Figure 3 and Figure 4 shows the seasonal behaviour pattern of market prices and arrivals of onion in both the APMs.

The table 5 shows the monthly correlation coefficient between market arrivals and market prices of onion in both the APMs. The inter-relationship between market arrivals and prices analysed for various months over different concern years. Results from table 5 confirmed an inverse relationship between market arrivals and prices in both the APMs and it in line with the theoratical approach (negative relationship between arrivals /supply and prices) and such negative relationship is also confirmed from the research study of [1]. Moreover, findings of this research study are in agreement with the [3] and [4] regarding analysis of relationship between arrivals and market prices of onion.

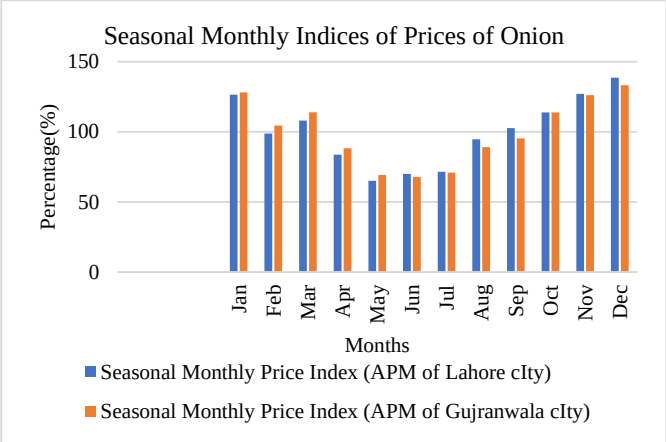


Fig. 3. Seasonal Behaviour Pattern of Monthly Indices of Market Prices of Onion
Source: Own calculation.

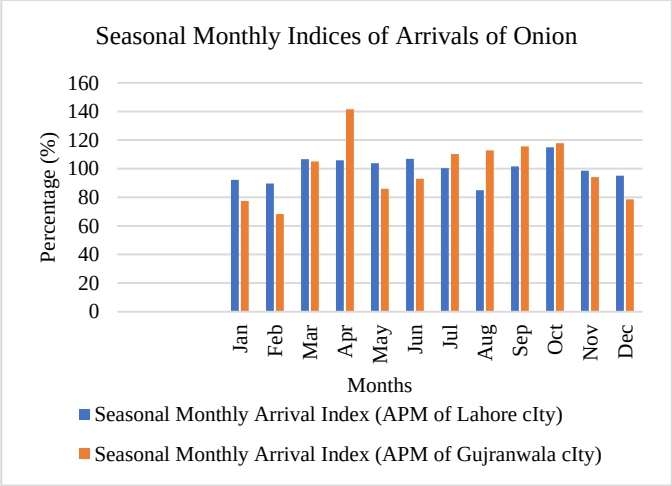


Fig. 4. Seasonal Behaviour Pattern of Monthly Indices of Market Arrivals of Onion
Source: Own calculation.

Study of such type of relationship provide valuable encouragement to the farmers regarding to adjust their decisions about cropping pattern and market supply by considering prices factor.

This finding is valuable for policy makers regarding to stabilize market prices in the market. Consequently, farmers and other stakeholders including consumers' welfare would increase.

Table 5. Monthly Correlation Coefficients of Market Arrivals and Prices of Onion

Month	APM of Lahore City	APM of Gujranwala City
Jan	-0.965	-0.955
Feb	-0.898	-0.897
Mar	-0.969	-0.955
Apr	-0.911	-0.901
May	-0.866	-0.883
Jun	-0.911	-0.884
Jul	-0.945	-0.925
Aug	-0.917	-0.85
Sep	-0.988	-0.944
Oct	-0.981	-0.975
Nov	-0.983	-0.974
Dec	-0.966	-0.944

Source: Own calculation.

Table 6. Price Elasticity of Supply of Onion in APM of Lahore City

Months	2018	2019	2020	2021	2022	2023	2024
Jan	-	-	-	-	-	-	-
Feb	-0.17	0.12	-2.96	-0.19	-0.19	-0.87	-0.59
Mar	0.04	0.45	0.54	-3.62	0.34	-0.30	0.25
Apr	0.25	0.09	-1.38	-1.87	-0.03	0.09	0.72
May	-0.02	0.82	0.31	1.35	-33.46	0.26	-0.59
June	43.05	0.44	-0.97	0.45	1.65	2.99	-0.12
Jul	-0.18	-0.37	0.95	-1.29	1.31	1.32	-6.92
Aug	5.14	-0.57	8.55	-5.67	-0.22	-0.01	-0.79
Sep	-1.46	0.74	1.00	1.06	-5.09	-0.69	4.28
Oct	-1.97	0.87	0.49	-0.19	-0.52	0.80	-4.87
Nov	1.41	-1.07	0.24	-0.10	-0.27	-0.69	31.80
Dec	1.19	0.08	0.45	1.33	-0.58	-0.01	-10.82

Source: Own calculation.

Table 6 shows price elasticity of onion in APM of Lahore city in different months over the period of seven years (2018 to 2024). Mostly price elasticity of supply ranges from 0 to 1 (relatively inelastic) and it is mainly due to its nature of production, consumption pattern and marketing dynamics and it is consistent with the study of [8] in Egypt. There are both positive and negative price elasticity of supply values indicating that when prices are higher, producers tend to supply more to the APM and reduce supply when their input cost of production rises as compared to their profit from output.

Table 7 showed various values of PES of onion concerning with APM of Gujranwala city.

Further, there are 0 to 1 range, greater than one values of price elasticity of onion, positive and negative values of PES.

The CAGR of prices and market arrivals of onion in the APM of Lahore city and Gujranwala city are estimated and shown in Table 8. There is a positive growth rates (36 % and 33 %) in the prices of onion over the period of seven years in both the APMs which is mainly due to rising population and resultantly demand have increased which pulls the prices upward.

Table 7. Price Elasticity of Supply of Onion in APM of Gujranwala City

Months	2018	2019	2020	2021	2022	2023	2024
Jan	-	-	-	-	-	-	-
Feb	0.21	-0.39	-4.65	0.11	0.58	-0.43	-1.01
Mar	-1.04	0.45	-8.59	10.88	0.43	-1.36	1.71
Apr	67.87	2.89	-3.24	-5.05	0.52	0.05	1.16
May	5.72	-2.37	1.32	1.93	2.71	2.52	0.06
June	1.55	0.21	3.15	-0.20	0.24	-3.49	1.39
Jul	0.2	0.93	2.54	-0.03	-0.40	0.68	-1.88
Aug	-6.20	0.34	7.14	5.93	-0.21	0.61	-0.18
Sep	0.64	-0.15	0.48	-0.04	-5.41	-0.38	-0.44
Oct	-5.71	0.00	-0.26	0.08	-1.06	0.64	-0.45
Nov	3.76	-1.75	-8.30	2.48	-0.81	-0.75	-0.73
Dec	7.67	1.02	0.88	0.38	0.17	-0.83	0.96

Source: Own calculation.

Moreover, there is only five percent CAGR value regarding market arrival in APM of Lahore city which is less as compared to growth in prices. However, there is a negative growth rate (-4%) in market arrivals of APM of Gujranwala city which indicates that growth of prices is on higher side but growth of supply has been decreasing and it shows that production of onion is required to be increased in Gujranwala district and in surrounding districts in order to ensure stabilization between the prices and arrivals. There is a positive relationship between growth rate of arrivals and market prices per annually concerning with APM of Lahore city and it is in line with the findings of [5].

Table 8. CAGR of Prices and Supply of Onion

Variables	CAGR (%)	
	APM (Lahore City)	APM (Gujranwala City)
Prices	36	33
Arrivals	5	-4

Source: Own calculation.

CONCLUSIONS

This present study investigates the marketing dynamics of prices and market arrivals in APM of Lahore City and Gujranwala city which are located in central Punjab of Pakistan. It is observed that large number of populations are consuming onion from these two markets and that's why comparatively abundant supply arriving in these markets. By focusing on data

(2018 -2024), this research study analyzed the various dynamics of marketing which are valuable for various stakeholders especially for farmers and consumers regarding to make decisions related to production, distribution and consumption of onion. Although very few researchers have analyzed dynamics of prices and arrival in concern APM but no one has studied the marketing dynamics of prices and arrivals by using various statistical tools (which are considered in this present study) regarding APMs of central Punjab (Pakistan). The present study is an innovative research study for understanding marketing behaviour of prices and arrivals by using various statistical and analytical tools including C.V, instability index, Seasonality, Correlation Coefficient (using Karl Pearson method), PES and CAGR. The findings indicate that highest mean arrival of onion observed during the month of October and April with highest C.V in August and April for APM of Lahore city and Gujranwala city. Moreover, both the APMs (Lahore city and Gujranwala city) have shown highest mean prices in the month of December because of occurrence of supply of onion from outside of Punjab province and highest C.V are observed during February and August. The estimation from C-D-V Index have revealed that there is high instability (APM of Lahore city) and medium instability (APM of Gujranwala city) in prices of onion and it requires attention for stabilization. Moreover, there are low instability regarding the market arrivals of onion for both the markets. It is critical to analyze the seasonal behaviour of arrivals and prices of onion because it provides the important overview to the concern stakeholders regarding making of future decisions concerning with production and marketing of onion. Highest arrival index observed during October (APM of Lahore city) and during April (APM of Gujranwala city). Furthermore, highest prices index noted for both the APMs during the December month because majority of supply is arriving in these markets from outside of Punjab province which consequently increased expenses for distributors and lead to higher prices in the market. Estimation from Karl Pearson correlation coefficient revealed key finding in this study which is an existence of negative relationship between arrivals and market prices of onion in APM of Lahore and Gujranwala city. This important finding provides useful input to the policy makers for formulation of policies regarding effective adjustment and stabilization of market prices of onion in order to increase the welfare of concern stakeholders in an efficient manner. The findings related to elasticity of supply indicates that mostly value of elasticity of supply range from 0 to 1 because of production, consumption and marketing dynamics related to onion. Moreover, there are both positive and negative values of PES depending on favorable prices and increased cost of production for the producers. In order to make decisions related to production of onion for ensuring sustainable agribusiness practices, the analysis of growth rates of prices and market arrivals plays an important role. The CAGR estimations indicates that there is positive growth in the prices of onion in both the APMs because of rising population and which resultantly increased demand for onion in the concern market. Moreover, there is a positive growth in arrivals of onion in APM of Lahore city and negative growth for APM of Gujranwala city and such negative growth needs to be address for ensuring sustainability in agribusiness sector. Our study offers useful recommendations for policy makers on how to stabilize the prices in the APM by effective consideration of supply. Policies should be formulated for increase in local production of onion and also in other districts of Punjab so that transport cost and other concerning costs would be reduced in the supply chain of onion. Agriculture sector should encourage the farmers to grow onion by linking them with stakeholders for trading in concern markets. Furthermore, it is pertinent to mention that farmers should be given proper information in order to assist them for making future decisions regarding when to grow and when to sell the crop in the market. Analysis of this study serve as novel guidelines for the concern farmers' community, other concern stakeholders and for consumers. Lastly, it is worthwhile to highlight

few limitations and potential paths for future research study. Firstly, this present study is limited to two APMs of central Punjab. Secondly, there is no proper availability of secondary data both at district level and at provincial level related to cost of production of individual farmers in the Pakistan which are growing onion crops in their field. Therefore, future research can be targeted to expand the analysis to more APMs of Pakistan. Moreover, it is also suggested that primary research requires to be conducted at district level in order to estimate cost of production of individual farmers' farm in the concern district so that more useful analytical and economical results would be obtained for provision of valuable information/guidelines to concern stakeholders in order to increase their welfare status.

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EVALUATION OF THE DECOUPLING OF ONE HEALTH PRESSURES IN CATTLE FARMING IN ROMANIA

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Abstract

A vital area of Romanian agriculture, cattle raising has a big impact on the country's economy, society, and environment. Simultaneously, this industry creates a number of interrelated stresses on ecosystem health, natural resource quality, and, indirectly, human health—aspects that are theoretically integrated within the One Health paradigm. In this regard, evaluating the sector's ability to lessen these demands without jeopardizing economic functioning becomes a significant topic of concern for agricultural policies and research. This study uses official Eurostat data to analyze the evolution of the primary indicators of environmental pressure and livestock structure in order to evaluate the decoupling of One Health pressures in the Romanian cattle breeding industry. The study's goals are to analyze cattle herd dynamics, evaluate environmental pressures using nitrogen and phosphorus balances, analyze the density of the cattle livestock industry, and combine these factors into a composite One Health pressure index that can be used as a synthetic assessment tool. A composite One Health pressure index, which combines nutrient balances, livestock density, and the percentage of organic farming, and specific indicators, such as cattle density in relation to the agricultural area used, were developed as part of the descriptive and comparative research methodology. The results highlight a gradual reduction in cattle numbers, associated with low or negative levels of nitrogen and phosphorus balances, indicating a relatively low pressure on the environment in terms of nutrient loading. In parallel, the constant increase in organic agricultural area suggests a structural transition towards practices with lower impact on ecosystems. The analysis of the pressure index shows the existence of a process of partial decoupling of One Health pressures, achieved mainly through extensification of the sector and structural changes, rather than through increases in technological efficiency. The findings highlight the fact that Romania's cattle industry is undergoing a structural change phase that may have an impact on economic performance but also helps to lessen One Health demands. The study emphasizes the necessity for integrated policies that concurrently support environmental sustainability and the livestock sector's economic viability and offers a helpful analytical tool for supporting agricultural policy decisions.

Key words: *decoupling, One Health, cattle breeding, environment, sustainable agriculture, Romania*

INTRODUCTION

One of the historic pillars of Romanian and European agriculture is cattle rearing, which is crucial to rural economies and food security [12]. In addition, the cattle industry is acknowledged as a significant contributor to environmental stress due to its extensive use of natural resources, production of excess nutrients, and involvement in the deterioration of soil and water [3, 13, 15]. In this regard, the One Health concept - which highlights the interconnectedness of animal health, environmental health, and human well-being - has grown in popularity as a paradigm for analyzing the sustainability of agri-food systems. The European Green Deal's and the "From Farm to Fork" strategy's explicit goal of separating economic performance from adverse environmental effects makes this concept even more pertinent. The relationship between livestock and environmental pressures - particularly those related to nutrient emissions, land usage, and production intensification - has been thoroughly discussed in the literature. Livestock density is a major factor in nitrogen and phosphorus surplus, which directly affects soil fertility and water quality, according to numerous studies [1, 2, 14]. Other research highlights that reducing livestock numbers or changing the structure of production does not automatically lead to a proportional reduction in pressures, if it is not accompanied by

adjustments in management and land use practices [10, 17]. Thus, the focus of recent research has shifted from the isolated analysis of environmental indicators to integrated assessments, capable of capturing simultaneously the economic, ecological and structural dimensions of the livestock sector.

In parallel, the concept of "decoupling" has gained increasing importance in studies on agricultural sustainability. Decoupling refers to the capacity of an economic sector to maintain or improve its productive and economic performance while reducing environmental pressures [8]. In the field of animal husbandry, research has shown that decoupling is possible in certain contexts, in particular by optimising animal density, improving nutrient management and expanding low-impact agricultural practices [9, 18]. However, the literature indicates significant differences between countries and regions, determined by the structure of farms, the level of intensification and the adaptive capacity of production systems. Studies applied in the European context have frequently used aggregated data to compare the performance of Member States, but fewer analyses have focused on the detailed assessment of a single country, from the perspective of a specific animal husbandry sector. In the case of Romania, existing research highlights a particular profile: relatively low stocking density compared to the European average, but high vulnerability to nutrient imbalances and structural fluctuations in the sector [12]. The literature also highlights the fact that the transition to more sustainable practices, including the expansion of organic farming, has significant potential to reduce pressures, but the concrete impact on the livestock sector remains insufficiently documented [16].

In this context, One Health approaches have been used mainly as a conceptual or normative tool, with the emphasis on the need to integrate policies and decisions at the agri-food system level [11]. Much less often, these approaches are operationalized through measurable indicators, allowing the assessment of the dynamics of pressures and the degree of decoupling over time. The lack of complex indicators, adapted to the livestock sector and applied at national level, represents a significant gap in the specialized literature, especially for agricultural economies in transition, such as Romania.

Based on these considerations, this research aims to contribute to the existing literature by assessing the decoupling of One Health pressures in the Romanian cattle sector, using official Eurostat data. The analysis is based on indicators relevant to the pressures exerted on the environment, namely the balance of nutrients (nitrogen and phosphorus), cattle density and the extension of organic agricultural areas, integrated into a coherent analytical framework. The chosen methodology enables identifying structural trends pertinent to sustainability and recording the sector's evolution over the medium term.

The main aim of the study is to assess whether the evolution of the Romanian cattle sector indicates a process of decoupling between One Health pressures and the dynamics of livestock production. In this sense, the research aims to: analyze the evolution of cattle herds and sector density, as an indicator of intensification; evaluate the dynamics of the nutrient balance, as an expression of environmental pressures; and integrate these dimensions into a composite indicator of One Health pressure, capable of reflecting the general trends of the sector. By achieving these objectives, the study provides an empirical basis for understanding the relationship between the structure of cattle livestock and the associated pressures, contributing both to the academic literature and to the substantiation of strategic decisions in the field of sustainable agriculture.

MATERIALS AND METHODS

The research methodology was based on the use of Eurostat data, aggregated at national level for Romania, in order to assess the decoupling of One Health pressures associated with the cattle sector. The analysis covered the period 2010–2024.

The livestock pressure was quantified by cattle density, calculated as the ratio between the

cattle herd expressed in livestock units - LSU and the utilized agricultural area -UAA and measured the intensity of land resource use by the cattle sector, thus:

$$D_{\text{bovine}} = \frac{\text{LSU}_{\text{bovine}}}{\text{UAA}}, \quad \text{.....(1)}$$

where:

D_{bovine} - bovine livestock density

$\text{LSU}_{\text{bovine}}$ - livestock units corresponding to bovine animals

UAA - utilised agricultural area

Environmental pressure was assessed through the gross nutrient balance, using separately the nitrogen balance and the phosphorus balance, expressed in kg/ha AUA. These indicators reflect the difference between the total inputs of nutrients into the agricultural system and the outputs through agricultural production, constituting standard proxies for the risks of soil and water pollution. Negative values indicate an extensive regime or underuse of nutrients, while positive values signal potential environmental pressures.

The transition to low-pressure agricultural practices was captured by the share of organic agricultural area in total AUA, expressed as a percentage. This indicator reflects structural changes in agricultural management and the adoption of production systems compatible with reducing cumulative pressures on the environment and public health.

Based on these variables, a composite One Health pressure index for the cattle sector was constructed, used as a synthetic tool for comparative analysis over time. The index aggregates information from cattle density, nitrogen balance, phosphorus balance and share of organic farming, being calculated as the arithmetic mean of the standardized indicators, as follows:

$$OHPI = \frac{1}{n}\sum_{i=1}^{n} I_i, \quad \text{.....(2)}$$

where:

$OHPI$r - One Health pressure index

I_i - individual pressure indicators included in the analysis.

Indicators expressing direct pressures, such as livestock density and nutrient balance, contributed positively to the calculated index, while indicators of transition to sustainable practices, such as organic farming, had a compensating role.

The use of pressure indicators computed at the agricultural level as a whole is one of the study's limitations since it makes it impossible to isolate the precise contribution of each livestock species to the nutrient balance. Apart from the cattle industry, other livestock-related industries including pig, poultry, sheep, and goat husbandry also contribute to environmental stresses, especially in large-scale farming systems. However, the method employed offers a pertinent evaluation of the systemic pressures related to agriculture and their connection to the dynamics of the cattle industry in the lack of official species-disaggregated data for nutrient balances.

RESULTS AND DISCUSSIONS

To ensure better analytical clarity and a coherent highlighting of the mechanisms of decoupling between livestock activity and One Health pressures, the results are structured in four distinct subchapters:

(i) evolution of the cattle breeding sector,

(ii) dynamics of nutrient balances,

(iii) evolution of the One Health composite pressure index and

(iv) economic implications of the decoupling process.

This structuring allows for a differentiated interpretation of the relationships between livestock intensity, agricultural resource use and pressures on ecosystems, as well as a more rigorous assessment of the sustainability of the sector in the medium and long term. The national agricultural demands, including the contribution of all livestock branches and crop production systems, are reflected in the indicators of the nitrogen and phosphorus balance as well as the percentage of organic agricultural land. Given the crucial role the cattle industry plays in the utilization of agricultural land and the structure of agro-zootechnical systems, particularly through the direct connection with permanent grasslands and fodder crops, cattle density is employed in this study as a structural indicator. Without just attributing these pressures to a specific

livestock species, this method enables the evaluation of the relationship between the evolution of the cattle industry and overall agricultural pressures.

1. Evolution of the cattle breeding sector in Romania

The cattle breeding sector in Romania has experienced, during the analyzed period, a continuous process of structural adjustment, reflected by the reduction of herds and the modification of the patterns of exploitation of agricultural land. This evolution is determined by economic, institutional and technological factors, including the restructuring of farms, market pressures, changes in agricultural policies and constraints related to the profitability of livestock activities. The dynamics of cattle herds constitute an essential indicator for understanding the relationship between livestock activity and the pressures exerted on agro-ecosystems, as the size of the herds directly influences nutrient flows, the use of forage areas and the amount of animal manure generated.

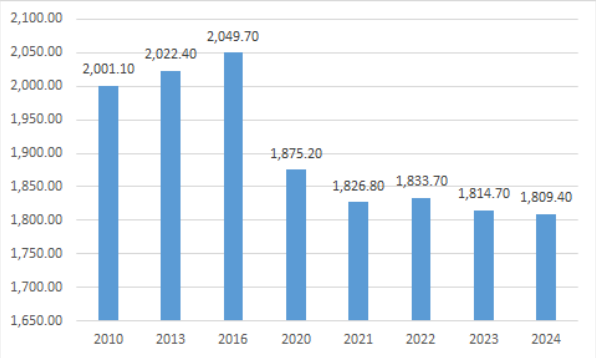


Fig. 1. Evolution of cattle herds in Romania, between 2010-2024
Source: own processing, Eurostat [5].

The cattle herd's evolution shows a structural decline trend that became more noticeable after 2016 but then stabilized. This dynamic illustrates the livestock industry's managerial adjustment process, which is influenced by shifting market and regulatory conditions, farm restructuring, and economic pressures. By lowering the nutrient load and the amount of animal waste, the herd reduction directly indicates a decrease in the cumulative pressures on soil and water, hence minimizing the dangers connected with environmental imbalances. Simultaneously, the sector's decline creates economic vulnerabilities in situations where there is no compensation through improved production efficiency, particularly in rural communities that depend on cattle raising. The stabilization of herds at a lower level is due to the transition to a less intensive livestock model, in which management decisions aim to maintain economic viability while reducing pressures on agricultural ecosystems. This evolution creates the premises for a partial decoupling between livestock activity and One Health pressures, conditional, however, on the adoption of management practices oriented towards efficiency, biosecurity and the integration of animal production with the sustainable use of agricultural land.

2. Dynamics of nitrogen and phosphorus balances in agriculture

Gross nitrogen and phosphorus balances are key indicators of the pressures exerted by agricultural systems on soil and water resources, reflecting the degree of balance between nutrient inputs and outputs at the agro-ecosystem level. In the absence of official data broken down by animal species, these balances provide a synthetic assessment of the cumulative pressures generated by the entire agricultural sector, in close relation to the dynamics of livestock farming. Analysis of the evolution of nutrient balances allows the identification of persistent structural imbalances and the highlighting of the link between the intensity of agricultural activities, the use of inputs and the sustainability of soil fertility in the long term.

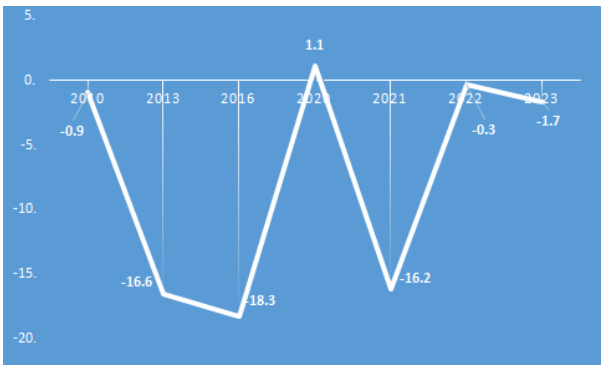


Fig. 2. Evolution of nitrogen surplus in agriculture in Romania
Source: own processing, Eurostat [4].

Figure 2 highlights a highly volatile dynamics of the gross nitrogen balance/hectare, characterized predominantly by negative values. The decreases in the indicator in the intervals before 2020 indicate a high nitrogen deficit, associated with an increased absorption of inputs, due to both the exploitation of soil reserves and the reduction of fertilizer inputs, which creates a high structural pressure on soil fertility, with a direct impact on the stability of agricultural production, in the medium term.
The evolution of the nitrogen balance indicates the inability to maintain a balanced level of nutrients, with alternations between underfeeding and temporary corrections, which amplifies the risk of soil quality degradation and loss of efficiency in the use of agricultural resources.

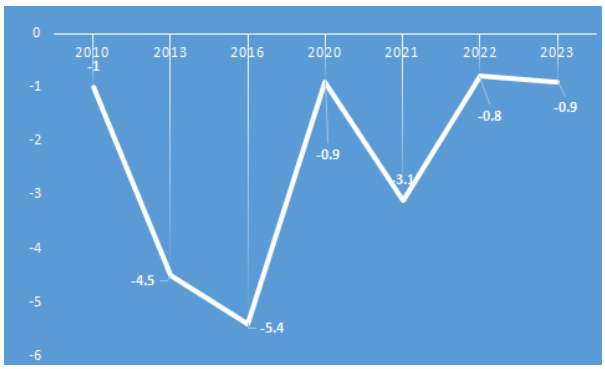


Fig. 3. Evolution of phosphorus surplus in Romanian agriculture
Source: own processing, Eurostat [4].

The data in Figure 3 indicate a persistent phosphorus deficit, which describes an agricultural system in which the export of phosphorus through plant production and/or the level of extraction from the soil exceeds the aggregate phosphorus input from mineral fertilizers and organic sources, which deepens the deficit with the direct effect of increasing pressure on long-term fertility: repeated deficit accelerates the depletion of soil phosphorus reserves, reduces nitrogen use efficiency and limits production potential, especially in rotations with consuming crops. Simultaneously, it is noted that there is little danger of phosphorus buildup and systematic losses in groundwater, with the "hot spots" being merely local.

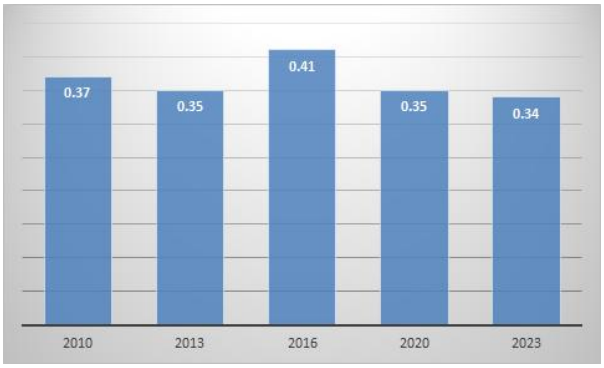


Fig. 4. Evolution of cattle density in Romania
Source: own processing, Eurostat [6].

The evolution of cattle density (Figure 4) highlights a livestock system characterized by a relatively low level of intensification, resulting from sector restructuring, farm fragmentation and the decline in livestock numbers on commercial farms. This dynamic reflects persistent difficulties in farm consolidation, limited access to capital and the slow adoption of intensive farming technologies. Maintaining a low cattle density has the effect of reducing pressure on soil and water resources by limiting the accumulation of nutrients from animal manure. At the same time, this extensive structure constrains the economic performance of the sector, reduces the efficiency of agricultural land use and limits the capacity to integrate livestock with crop production.

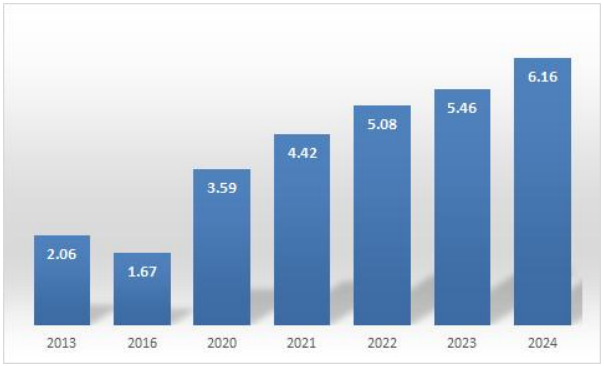


Fig. 5. Evolution of the share of organic agricultural area in Romania (% of UAA)
Source: own processing, Eurostat [7].

The solution consists in promoting a model of controlled intensification, based on the optimal sizing of livestock in relation to the agricultural area used, the integration of nutrient circuits and the increase in the managerial capacity of farms, which will allow improving

zootechnical performance without amplifying environmental pressures, favoring the long-term stability of the cattle breeding system.

Figure 5 highlights an upward trend in the organic agricultural area in Romania, as a result of structural changes in agricultural practices. The steady expansion of organic farming reflects both farmers' adaptation to new agricultural policy requirements and increasing pressures related to the use of chemical inputs and the management of environmental impacts.

From a causal perspective, this evolution is driven by the reorientation of production systems towards less intensive forms, by financial incentives specific to organic farming and by the growing demand for products obtained through sustainable methods. The transition is also accelerated by the need to reduce the risks associated with soil degradation and diffuse pollution.

The effects of this dynamic are manifested by reducing pressures on nutrient cycles, improving the functioning of agro-ecosystems and increasing the resilience of the agricultural system. At the same time, the expansion of organic agriculture contributes to reducing dependence on external inputs, with favorable implications for the long-term stability of production.

In operational terms, solutions to strengthen this trend aim at more coherent integration of livestock with organic crop production, supporting the conversion of mixed farms and optimizing value chains for organic products, so that the transition is sustainable both from a functional and economic point of view.

3. Evolution of the One Health Composite Pressure Index in the Cattle Sector

To capture in a synthetic form the relationship between livestock activity, environmental pressures and the transition to sustainable agricultural practices, a One Health Composite Pressure Index was constructed. This index integrates indicators that express direct pressures on ecosystems, such as cattle density and nutrient balances, alongside indicators that reflect the structural transition to low-impact systems, such as the share of organic farming.

Using the index allows the assessment of the relative dynamics of pressures over time and the identification of stages in which the decoupling between livestock activity and One Health requirements becomes more evident.

Table 1. Structure of the One Health pressure Index in the Romanian cattle sector

Year	Nitrogen balance	Phosphorus balance	Bovine density	Organic share	Nitrogen balance norm	Phosphorus balance norm	Bovine density norm	Organic share norm	One Health Pressure Index	OHPI raw	OHPI normalized	Δ OHPI
2013	-16.6	-4.5	0.35	2.06	0.91	0.80	0.86	0.10	0.67	-4.67	0.67	5.34
2016	-18.3	-5.4	0.41	1.67	1.00	1.00	0.00	0.00	0.50	-5.41	0.50	5.91
2020	1.1	-0.9	0.35	3.59	0.00	0.02	0.86	0.51	0.35	1.04	0.35	-0.69
2021	-16.2	-3.1	-	4.42	0.89	0.50	-	0.73	0.71	-4.96	0.71	5.67
2022	-0.3	-0.8	-	5.08	0.07	0.00	-	0.90	0.32	1.33	0.32	-1.00
2023	-1.7	-0.9	0.34	5.46	0.14	0.02	1.00	1.00	0.54	0.80	0.54	-0.26

Source: own processing, Eurostat [4, 5, 6, 7].

4. Economic implications of the decoupling process

The decoupling process identified in the Romanian cattle sector has ambivalent economic implications. On the one hand, reducing livestock numbers and maintaining a low animal density leads to a decrease in pressure on natural resources and a reduction in the risks associated with nutrient pollution. On the other hand, this evolution limits the sector's capacity to generate added value and support farmers' incomes, especially in rural areas dependent on livestock activities.

The observed decoupling is the result of a quantitative adjustment of the sector and not of an increase in economic or technological efficiency. In the absence of investments in farm modernization, value chain integration and resource optimization, the reduction of environmental pressures risks being accompanied by an economic weakening of the livestock sector.

Table 1 highlights an uneven dynamics of One Health pressures associated with cattle farming in Romania, driven by the interaction between livestock intensity, nutrient balances and the expansion of low-impact agricultural practices. By differentiating between absolute pressure levels and their relative, scale-adjusted dynamics, the comparison of the raw and normalized One Health Pressure Index values further refines this interpretation by elucidating the degree to which observed decoupling represents true structural change rather than artifacts of heterogeneous indicator magnitudes.

In the first part of the period under review, pressures are dominated by structural imbalances in nutrient balances, reflecting an inefficient use of agricultural resources and limited integration between livestock and crop sectors. Despite a comparatively moderate cattle number, these imbalances show a decreased potential for nutrient absorption at the agro-ecosystem level, with cumulative consequences on soil and water. As a result, the sector's structural reconfiguration—which is marked by a decline in livestock numbers and a steady rise in organic agricultural areas is what drives the reduction of pressures rather than an intensification of animal output. This history points to a phase of relative decoupling, where environmental demands are lessened without increasing the capacity for animal production.

The index's study reveals that the decoupling is passive rather than the outcome of technological optimization, with the decrease in pressures coming from extensification rather than from improved nutrient use efficiency or livestock farms' functional integration into agro-ecological cycles.

Therefore, it is discovered that the evolution of cattle herds in Romania was linked to livestock farm restructuring processes and the sector's size adjustment to economic and environmental constraints, which helped to lessen direct pressure on agricultural resources, particularly soil and agro-ecological systems. Nutrient surpluses decreased as cattle density decreased, as evidenced by a negative or near-equilibrium balance for both nitrogen and phosphorus. This helped to reduce the risks associated with excessive nutrient accumulation in soil and water, which had favorable effects on environmental quality and the security of agri-food systems.

In parallel, the expansion of agricultural areas managed organically was due to a gradual change in agricultural practices, with an indirect impact on the livestock sector. The increase in the share of organic farming thus contributes to reducing the cumulative pressures on agricultural ecosystems and supports production processes better integrated with the carrying capacity of the environment.

The simultaneous analysis of these indicators shows that the performance of the cattle breeding sector is no longer strictly dependent on the intensification of the use of inputs or the increase in animal density. On the contrary, the results indicate a process of decoupling between the level of livestock activity and the associated One Health pressures, manifested by the stabilization or reduction of the impact on the environment while maintaining the functionality of the sector.

This decoupling is indicative of Romanian cattle farming's structural shift to a less intensive model that is more in line with sustainability goals and more suited to ecological restrictions. According to this viewpoint, One Health pressures may be controlled by making changes to herd size, farming methods, and resource utilization rather than being an unavoidable consequence of raising animals.

5. Practical measures to stimulate active decoupling

In order to transform the identified passive decoupling into an active and sustainable process, measures aimed at increasing the efficiency of resource use and the functional integration of the livestock sector in agro-ecosystems are needed. In this regard, the following lines of action are required:

– modernising animal manure management systems, through technologies that allow for nutrient recycling and reducing losses to soil and water;

– closer integration of livestock and crop production, in order to close nutrient loops at farm and territory level;
– supporting mixed farms and those oriented towards high value-added production, compatible with One Health standards;
– strengthening the managerial capacity of farms, through professional training and access to economic and ecological planning tools.
These measures can transform the reduction of environmental pressures into a result of efficiency and innovation, and not exclusively of the restriction of economic activity.

CONCLUSIONS

The results of the investigation show that Romania's cattle breeding industry is in the early stages of decoupling from One Health demands. Without a zootechnical intensification, the observed developments show a relative reduction of environmental stresses, particularly by retaining low cattle density and good nutrient balance dynamics. The findings show that the structural reduction of livestock and the growth of low-pressure agricultural approaches, such as organic farming, determine the decoupling rather than an improvement in production efficiency. Instead of an active paradigm of technological or managerial change in the livestock industry, this configuration suggests a passive adaptation model based on the decrease of absolute pressures.
From the standpoint of One Health, this evolution reduces the hazards related to nutrient pollution and the overstress of agricultural ecosystems, which benefits the environment and public health. However, the long-term economic viability of the Romanian cattle industry is called into doubt by the lack of a clear correlation between the consolidation of livestock performance and the decrease of pressures.
In terms of agricultural policies, the results indicate the need to reorient public interventions from simple compensatory mechanisms to instruments that stimulate active decoupling, by: modernizing manure management systems; integrating livestock with crop production; supporting the transition to systems with higher added value and reduced impact.
Thus, the decoupling of One Health pressures in Romanian cattle farming is real but fragile, being supported by structural factors rather than deliberate managerial transformations. Strengthening this process requires a coherent strategic approach, which would simultaneously reduce pressures on ecosystem health and maintain the economic viability of the livestock sector.
The decoupling of One Health pressures in the Romanian cattle sector is real but fragile, being supported mainly by structural factors and the reduction of activity, not by profound technological or managerial transformations. Maintaining this balance in the long term requires a coherent strategy that harmonizes the objectives of environmental protection with those of economic performance. Without such an integrated approach, the risk is that the reduction of ecological pressures will be accompanied by the loss of competitiveness and economic viability of the livestock sector.

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EFFECTIVENESS OF WATER RESERVOIR MANAGEMENT MECHANISMS ON AGRO-PASTORALISTS' RESILIENCE TO CLIMATE CHANGE IN NORTHERN AND CENTRAL BENIN

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Abstract

This study assesses the effectiveness of water reservoir management mechanisms on the resilience of agro-pastoralists to climate change in northern and central Benin. The sample consists of 218 actors drawn from crop production, livestock, and fish farming value chains, complemented by institutional stakeholders. The evaluation was conducted using the Multi-Attribute Utility Theory (MAUT), which aggregates three performance dimensions—operational performance, governance and inclusion, and environmental performance—into a composite utility index. Indicators were normalized on a 0-1 scale and weighted using Principal Component Analysis for score aggregation. The results reveal a clear performance hierarchy: community-based management exhibits the highest effectiveness ($U \approx 0.77$), followed by co-management ($U \approx 0.55$) and individual management ($U \approx 0.35$). Participatory governance and environmental sustainability explain the superiority of the community-based model, whereas co-management remains constrained by insufficient ecological maintenance. The beta regression model confirms the superiority of collective regimes ($\beta = 1.594$; $p < 0.001$ for community-based management) and the positive influence of cooperative membership and education level on resilience. These findings indicate that resilience depends less on infrastructure than on the quality of collective governance. They support the promotion of participatory, inclusive, and institutionally strengthened management arrangements to sustainably enhance agro-pastoralists' adaptation to climate change.

Key words**:** *agro-pastoralists, Benin, multi-criteria analysis (MAUT), performance of management mechanisms, water reservoir*

INTRODUCTION

Climate change is intensifying rainfall variability, increasing the frequency of droughts, and disrupting the regularity of agricultural seasons in sub-Saharan Africa, thereby placing severe pressure on water-dependent agro-pastoral systems [20], [26]. In West Africa, these climatic dynamics translate into growing water insecurity, declining agricultural and pastoral productivity, and heightened vulnerability of rural households whose livelihoods rely on rainfed agriculture, livestock farming, and, increasingly, inland fisheries and aquaculture [17], [41].

In this context, water reservoirs (small dams and agro-pastoral reservoirs) constitute strategic infrastructures for climate change adaptation. They help secure access to water during the dry season, support the diversification of productive activities, and reduce exposure to climatic shocks [42], [49]. However, a substantial body of literature highlights that the mere physical availability of water does not guarantee sustained improvements in agricultural performance or user resilience [7], [29]. Outcomes largely depend on management mechanisms, access rules, user participation, and institutional

capacity to prevent conflicts and ensure infrastructure maintenance.

The literature on common-pool resource governance emphasizes the importance of local institutional arrangements—particularly collective management forms—in enhancing the effectiveness, equity, and sustainability of water systems [33], [38]. In West Africa, several studies show that participatory arrangements promote better coordination of uses, reduced conflicts, and greater environmental sustainability of water reservoirs [42], [12]. Nevertheless, the performance of these mechanisms remains highly heterogeneous across territorial contexts, types of activities, and users' organizational capacities.

In Benin, although water reservoirs play a central role in agro-pastoral systems in the northern and central regions, rigorous empirical analyses comparing the effectiveness of different management regimes (individual management, community-based management, and co-management) remain limited. In particular, few studies simultaneously integrate operational, institutional, and environmental dimensions within a systemic assessment of effectiveness and resilience.

This study aims to fill this gap by evaluating the comparative effectiveness of water reservoir management mechanisms and their contribution to agro-pastoralists' resilience to climate change, using a multicriteria analysis based on Multi-Attribute Utility Theory (MAUT) combined with an appropriate econometric modeling framework.

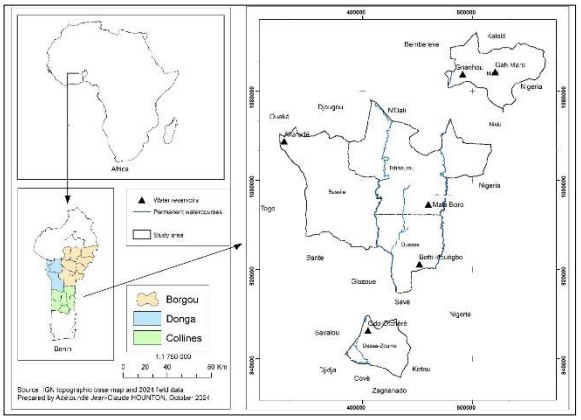
Literature review on water management and governance models in rural areas

The literature on rural water management reveals a marked evolution in analytical approaches, shifting from a primary focus on hydraulic infrastructure to increasing attention to governance mechanisms and institutional arrangements. Numerous studies emphasize that the sustainability of water services depends mainly on the coherence of management rules, financing and regulatory mechanisms, as well as on the effective participation of users, rather than on the mere physical availability of infrastructure [30], [47]. This shift has led to moving beyond binary opposition between community-based and public management toward more integrative frameworks, better suited to rural contexts in low- and middle-income countries. Recent typologies identify a plurality of management models, including individual management, community-based management, public management, and hybrid forms that combine institutional oversight with local participation [23], [45]. Individual management offers high flexibility but remains constrained by the lack of coordination, generating risks of use-related conflicts and environmental degradation [15]. Community-based management, in contrast, promotes local ownership, but its sustainability depends on the institutional context and the degree of professionalization of management arrangements [47]. In response to the limitations of "pure" models, the literature highlights the relevance of hybrid approaches and polycentric governance within the framework of integrated water resources management [28], [37].

MATERIALS AND METHODS

Study area

The study was conducted in five municipalities located in the Borgou, Collines, and Donga departments in northern and central Benin: Nikki, Tchaourou, Bassila, Dassa-Zoumé, and Ouèssè (Map 1).



Map 1. The study area

Source: Authors' compilation based on administrative boundaries of Benin and field survey data (2024)

These areas account for approximately 57% of the water reservoirs identified nationwide [39] and are characterized by a high density of farmers and cattle herders [1].

The municipalities were selected based on the perennial nature of the reservoirs during the dry season, their use for agricultural, pastoral, and fisheries purposes, and their age. Additional information on the study area is presented in Map 1.

Sampling, data collection, and statistical analysis

Six perennial and multifunctional water reservoirs were selected and stratified according to their storage capacity (small, medium, and large), with two reservoirs randomly drawn from each stratum. In each village, 35 agro-pastoral actors (farmers, livestock keepers, and fish farmers) were randomly selected from official agricultural service lists, in line with minimum statistical standards [25]. Institutional stakeholders were purposively selected based on their roles in reservoir management. Overall, the study is based on a sample of 218 individuals distributed across five municipalities.

Data were collected using smartphones through the KoboCollect platform [35]. Information covered reservoir uses, perceived performance, governance, financing and environmental management arrangements, as well as institutional rules and mechanisms. The analysis combined descriptive statistics with a multicriteria approach based on MAUT to construct a composite effectiveness score, following min–max normalization of the indicators. The determinants of this score were then estimated using a beta regression model with a logit link, incorporating the management regime and individual, institutional, and territorial control variables, while accounting for the spatial nesting of observations.

Justification and implementation of the MAUT-based multicriteria analysis

Evaluating the effectiveness of water reservoir management mechanisms requires an approach capable of integrating multiple interdependent and sometimes conflicting criteria. In this respect, multicriteria analysis constitutes a central decision-support tool in the fields of water and natural resource management [18]. Several methods are commonly used in the literature, including the Analytic Hierarchy Process (AHP), outranking methods such as ELECTRE and PROMETHEE, goal programming, and Multi-Attribute Utility Theory (MAUT) [3]. While AHP facilitates the hierarchical structuring of criteria, it remains sensitive to judgment subjectivity and rank reversal issues [9], [21]. Similarly, outranking methods and goal programming, although effective in handling conflicting objectives, often require complex formalization and parameterization [11], [31]. Despite these limitations, multicriteria approaches remain essential for comparing complex management options [13].

In this context, MAUT was selected due to its ability to incorporate uncertainty and explicitly model decision-makers' preferences through utility functions, while ensuring a coherent transformation of heterogeneous criteria onto a common scale [8], [40].

The methodological framework is based on the structuring of three identified performance dimensions-operational performance, governance and inclusion, and environmental performance-derived from field data. These dimensions were selected because they capture the key levers influencing the hydrological and productive resilience of agro-pastoralists. They are informed by data collected from agro-pastoralists and other relevant stakeholders. Each indicator x_{ij} is subsequently normalized on a 0–1 scale using a min–max transformation to ensure comparability across units. Following [5], for attributes to be maximized, normalized utility is computed using Equation (1), whereas for attributes to be minimized, an inverse transformation is applied using Equation (2).

$$U_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad \text{.....(1)}$$

$$U_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \quad \text{.....(2)}$$

Partial utilities are calculated for each dimension as the means of the normalized utilities of its sub-indicators m_k (Equation 3):

$$U_{ik} = \frac{1}{m_k}\sum_{j=1}^{m_k} w_k\, U_{ij} \quad \text{..... (3)}$$

where: k refers to the dimensions of availability, management, or environmental governance. The overall utility U_i of an alternative is then obtained through a weighted additive aggregation (Equation 4):

$$U_i = \sum_{k=1}^{K} w_k\, U_{ik} \text{ ..... (4)}$$

with $\sum w_k = 1$.

The weights w_k were assumed to be uniform and derived using Principal Component Analysis (PCA), in line with recent applications in agricultural systems, ensuring a balanced contribution of the evaluated dimensions [40]. On this basis, alternatives are ranked according to their overall performance, leading to the identification of the most appropriate management mode and the formulation of methodologically grounded recommendations. The entire process is summarized in Figure 1, which illustrates the successive steps of the methodological approach adopted.

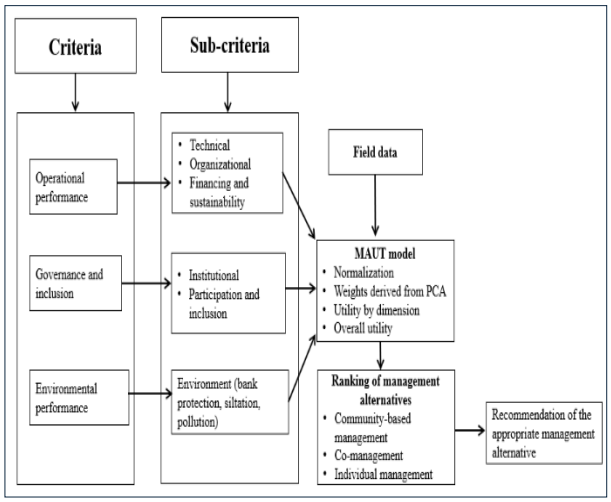


Fig. 1. Methodological framework for the multicriteria evaluation of water reservoir management alternatives (MAUT)

Source: Authors' elaboration based on MAUT framework

Justification and specification of the beta regression model

The utility score, a continuous variable strictly bounded between 0 and 1, cannot be adequately modelled using ordinary least squares due to the risk of out-of-range predictions and violations of classical assumptions [16]. Beta regression provides an appropriate alternative, as it allows for the modelling of asymmetric distributions, accounts for dispersion heterogeneity, and accommodates suitable link functions [14]. Its application is well documented in the analysis of environmental indices and management performance [19], [34], making it a robust and relevant framework for evaluating water reservoir management mechanisms.

The beta model with a logit link is specified in a general form as follows (Equation 5).

$$\text{logit}(U_i) = \beta_0 + \sum_{k=1}^{K} \beta_k\, X_{ik} \text{ .....(5)}$$

Here, β_0 denotes the intercept; β_k represents the regression coefficients; the set of explanatory variables; and the normalized utility of the reservoir management mechanism for observation i ($0 < U_i < 1$). The explanatory variables encompass the reservoir management mode (community-based management and co-management, with individual management as the reference category), institutional and organizational factors, individual characteristics of agro-pastoralists, physical characteristics of the reservoirs, and the territorial context. The detailed estimation results of the model are reported in Table 2.

RESULTS AND DISCUSSIONS

Analysis of the performance of management mechanisms by criteria

The results reveal a clear and consistent hierarchy in the performance of water reservoir management mechanisms, dominated by community-based management, followed by co-management and, lastly, individual management.

This hierarchy is evident from the overall criteria-based analysis, in which community-based management exhibits the highest average utility (U = 0.77), driven by near-maximal levels of governance and inclusion as well as strong environmental sustainability, while operational performance remains improvable (Fig. 2). This finding confirms that

the performance of hydrological systems depends less on infrastructure than on the quality of institutional arrangements, as demonstrated by [33] and [37] in their work on common-pool resource governance.

By contrast, co-management, although characterized by formally high governance scores, is constrained by weak environmental performance, reflecting incomplete coordination among actors and a deficit in ecological planning (Fig. 2). This observation is consistent with the analyses of [43] and [10]. Individual management displays the lowest overall performance, particularly along the environmental dimension (Fig. 2).

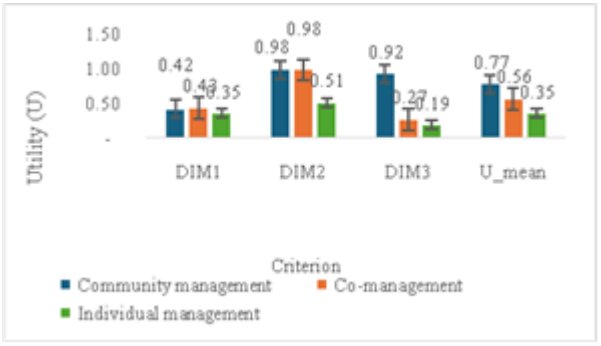


Fig. 2. Performance of water reservoir management alternatives by criterion and overall
Note: DIM1: Operational performance; DIM2: Governance and inclusion; DIM3: Environmental performance
Source: Authors' calculations based on field survey data (2025)

Fig. 2 confirms that the absence of collective rules exposes reservoirs to heightened risks of degradation [15], [48].

Analysis of the performance of water reservoir management mechanisms by activity and sub-criteria

The sub-criteria analysis (Table 1) shows that community-based management is the most effective option across all three activities, although the nature of its advantages varies across dimensions.

In agriculture and livestock production, the superiority of community-based management stems from the combination of fully operational governance arrangements and effective environmental practices, whereas co-management and individual management remain constrained by insufficient protection measures.

In fish farming, performance gaps are the most pronounced: only community-based management succeeds in jointly achieving operational efficiency, consolidated governance, and environmental protection, highlighting the strong dependence of this activity on water quality.

This finding is consistent with [36], who show that fish farming in small reservoirs is particularly sensitive to institutional failures, as well as with [6], which emphasize the central role of collective management in the sustainability of hydrological systems.

Table 1. Performance of water reservoir management mechanisms by activity and sub-criteria

Mechanisms/Activities	**Sub-criteria utility scores**						**Average utility (U)**
	DM1-1	DM1-2	DM1-3	DM2-1	DM2-2	DM3-1	
Agriculture							
Co-management	0.66	0.56	0.39	1	0.95	0.21	0.56
Community management	0.41	0.53	0.3	1	0.95	0.97	0.79
Individual management	0.06	0.75	0.36	0.5	0.49	0.28	0.41
Livestock							
Co-management	0.29	0.55	0.19	1	0.99	0.25	0.54
Community management	0.33	0.48	0.31	1	0.99	0.89	0.77
Individual management	0.34	0.47	0.17	0.5	0.55	0.16	0.35
Fish farming							
Co-management	0.5	0.43	0.15	1	0.93	0.48	0.62
Community management	0.5	0.65	0.47	1	0.93	0.89	0.81
Individual management	0.5	0.3	0.16	0.5	0.48	0	0.28

Note: DM1-1: Technical; DM1-2: Organizational; DM1-3: Financing and sustainability; DM2-1: Institutional; DM2-2: Participation and inclusion; DM3-1: Environmental.
Source: Authors' calculations based on field survey data (2025)

The performance of management mechanisms by activity and sub-criterion is presented in Table 1.

Individual utility profiles

The individual utility curves (Figure 4) reveal strong heterogeneity in agro-pastoralists' performance in water reservoir management. The dispersion of operational scores (U_DIM1) highlights marked differences in maintenance, irrigation efficiency, and the adoption of adaptation practices, confirming that access to infrastructure alone remains insufficient without targeted strengthening of technical and organizational capacities (Figure 3a). Governance and inclusion scores (U_DIM2) display a polarized pattern, with a majority of high-performing actors alongside a few local failures requiring institutional consolidation (Figure 3b). Environmental sustainability (U_DIM3) emerges as the most vulnerable dimension, characterized by sharp contrasts between active protection and near absence of actions (Figure 3c), consistent with the limitations of participatory approaches lacking structured learning processes highlighted by [4] and [28]. Finally, despite an overall increase in total utility (U_total), the persistence of low performance levels indicates that the transition toward fully resilient management remains incomplete (Figure 4d), with the highest-performing profiles combining effective governance, appropriate technical practices, and strong environmental engagement**.** The individual utility profiles across the evaluated dimensions are illustrated in Figure 3.

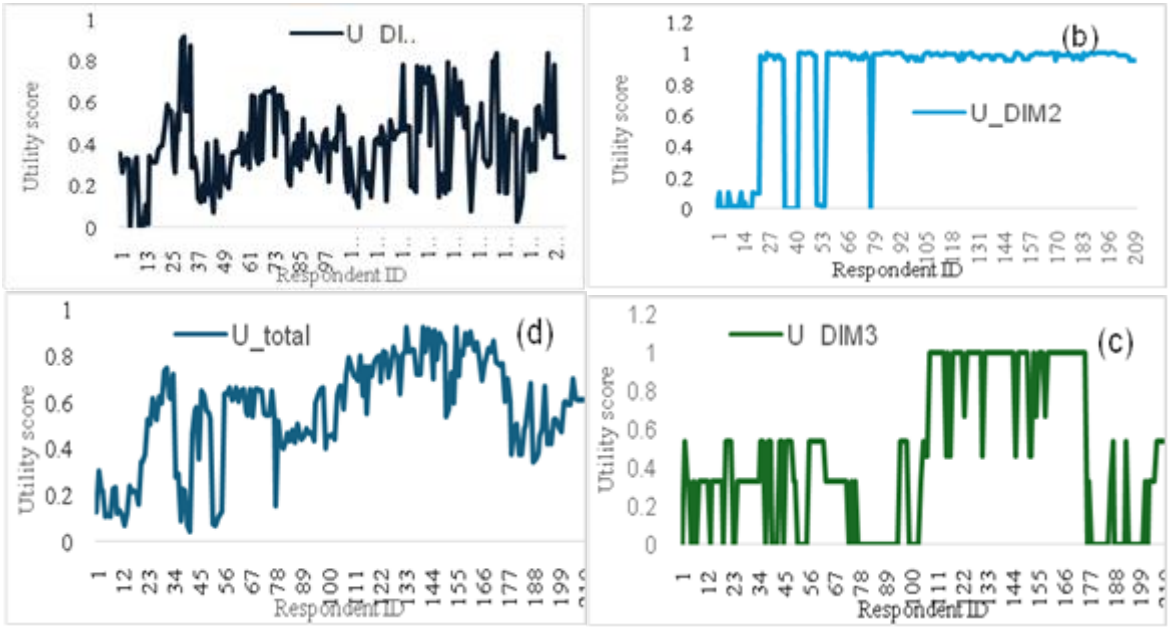


Fig. 3. Individual utility profiles across the evaluated dimensions
Source: Authors' calculations based on field survey data (2025).

Determinants of the effectiveness of management mechanisms

The beta regression results indicate that the effectiveness of water reservoir management mechanisms (Table 2) is primarily driven by institutional and organizational factors, while individual user characteristics play a marginal role. Overall model statistics indicate a good fit to the data. The precision parameter (φ = 19.637; $p < 0.01$) reflects low dispersion of utility values around their conditional mean, thereby enhancing the reliability of the estimates. The log-likelihood (LogLik = 191.88), together with relatively low AIC (–349.76) and BIC (–292.86) values, further confirms the quality of the model fit. The pseudo-R^2 of 0.758 indicates that approximately 76% of the variability in the management effectiveness index is explained by the model.

The absence of a significant effect of age, sex, or experience suggests that performance depends less on individual profiles than on the quality of collective rules and coordination

structures. This interpretation is consistent with the findings of [27], which show that participatory approaches influence livelihood sustainability and resilience far more strongly than individual characteristics.

Membership in an organized structure is also associated with higher performance of water reservoir management mechanisms, highlighting the role of collective organizations in structuring practices and enhancing management effectiveness. While [44] primarily emphasize the diversity and complexity of local institutional arrangements without isolating cooperatives as a measurable determinant, the present results provide complementary empirical evidence of a positive association between collective organization and the effectiveness of management mechanisms. However, this relationship should not be interpreted normatively, as the mere existence of formal organizations does not automatically guarantee improved performance. In this regard, [29], [38], [47], [4] stress that contemporary sustainability challenges exceed individual capacities and require structured collective action.

The results further show that formal education enhances the effectiveness of management mechanisms, whereas basic literacy is associated with lower effectiveness. This pattern suggests that performance gains depend less on the ability to read and write than on more structured skills, such as analytical reasoning, the processing of institutional information, and the negotiation and coordination capacities required in complex collective governance arrangements. This interpretation is consistent with the analyses of [2] and [4], as well as those of [28] and [32], which demonstrate that participation yields tangible outcomes only when supported by learning processes and capacity-building mechanisms. Conversely, the negative effect of literacy may reflect organizational dynamics in which information and power asymmetries undermine coordination when governance relies heavily on written procedures [22].

Table 2. Estimation results of the beta regression model

Variables	Coefficient	Standard Error	Statistics (Z)
(Intercept)	- 0.727**	0.251	- 2.899
Co-management (Yes =1)	0.982***	0.104	9.440
Community management (Yes =1)	1.594***	0.125	12.715
Cooperative membership (Yes =1)	0.482***	0.103	4.670
Age (Year)	- 0.001	0.004	- 0.252
Literacy (Yes = 1)	- 0.289*	0.151	- 1.908
Medium-sized reservoir (S2 = 1)	- 0.844***	0.108	- 7.845
Large reservoir (S3 = 1)	- 0.126	0.115	- 1.096
Experience in main activity (years)	0.005	0.006	0.970
Primary education (Yes = 1)	0.158*	0.088	1.796
Secondary education (Yes = 1)	0.233*	0.117	1.990
Sex (Male = 1)	0.180	0.146	1.237
Fish farming activity (Yes = 1)	0.129	0.119	1.081
Livestock farming activity (Yes = 1)	0.089	0.093	0.966
Agro-ecological zone 4 (ZAE4 = 1)	0.097	0.110	0.889
Agro-ecological zone 5 (ZAE5 = 1)	0.028	0.085	0.327
Precision parameter (φ)	19.637***	1.880	10.445
Log-likelihood (LogLik): 191.88	Pseudo-R^2: 0.758		
Akaike Information Criterion (AIC): -349.76	df.residual: 193		
Bayesian Information Criterion (BIC): -292.86	Number of observations: 218		

***** Significant at 10% ($p < 0.1$); ****** Significant at 5% ($p < 0.05$); ******* Significant at 1% ($p < 0.01$); df.residual: Residual Degrees of Freedom.

Source: Authors' calculations based on field survey data (2025)

The negative effect associated with medium-sized reservoirs suggests a mismatch between usage pressure and local institutional capacities, a finding consistent with [24] and

[36]. In contrast, the absence of a significant effect for large reservoirs confirms that resource abundance alone does not ensure better performance in the absence of robust governance arrangements [46].

Overall, these results confirm that resilience associated with water reservoirs primarily depends on the convergence of structured collective governance, effective coordination of uses, and active environmental strategies, thereby providing empirical support for common-pool resource theory in an agro-pastoral context.

Beyond these empirical findings, this study makes several contributions.

Methodologically, the application of the MAUT-based multicriteria approach to identify the most effective management mode for agro-pastoral and aquaculture water reservoirs in central and northern Benin represents an original contribution, as it goes beyond unidimensional cost–benefit analyses by integrating multiple dimensions of sustainable management.

Empirically, the study provides a quantitative comparative assessment of the effectiveness of water reservoir management mechanisms (community-based management, co-management, and individual management) in a Sahelian agro-pastoral context, highlighting the primacy of institutional arrangements over individual characteristics in shaping performance. Finally, the multi-sectoral analysis reveals that fish farming—being more sensitive to failures in collective governance than crop and livestock production—acts as a critical indicator of the limitations of individual and hybrid management modes. The beta regression results are presented in Table 2.

CONCLUSIONS

This study demonstrates that the effectiveness of water reservoir management mechanisms and the resilience of agro-pastoralists are primarily determined by the quality of local institutional arrangements. Collective, community-based, and collaborative management schemes constitute key levers for coordinating water uses and sustainably strengthening agro-pastoral systems. The findings confirm the better performance of multi-actor collaboration over individual management, while highlighting that its effectiveness depends on its translation into concrete environmental practices. More specifically, the empirical results show that water reservoirs managed under clear, shared, and socially legitimate rules exhibit significantly higher levels of agro-pastoral resilience, particularly in terms of secure access to water, reduced drought vulnerability, and sustainability of water uses. Community-based management emerges as the most effective mechanism when local communities are directly involved in rule-setting, monitoring of water uses, and maintenance of infrastructure, whereas co-management, although institutionally promising, remains constrained by coordination challenges, limited accountability, and uneven implementation of environmental practices. The econometric analysis further reveals that, beyond management regimes, individual characteristics such as cooperative membership and education level significantly enhance resilience, suggesting that capacity building and organizational strengthening are essential complementary components of effective water governance. These findings suggest that public water management policies in Northern and Central Benin would benefit from moving beyond uniform approaches by promoting differentiated governance arrangements tailored to local contexts and grounded in genuine agro-pastoralist participation. Ultimately, this research provides an original empirical contribution to the literature on the management of hydrological commons in a Sahelian context by employing a multicriteria evaluation framework that integrates operational, governance, and environmental dimensions, and by demonstrating that agro-pastoral resilience depends less on the mere availability of infrastructure than on the capacity of local institutions to sustainably organize collective action. Beyond this analysis of effectiveness and resilience, it is necessary to deepen the understanding of the effects of these

management mechanisms on the socio-territorial sustainability of these hydraulic infrastructures by examining their longer-term implications for the social, economic, and environmental dynamics of the territories concerned.

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FITTING THE LEAN PRINCIPLES INTO HORTICULTURAL BUSINESS – A CASE STUDY OF MODERN LETTUCE CULTIVATION

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Abstract

The aim of this study is to demonstrate how Lean philosophy, and methods can enhance operations in a non-typical production environment. Growing vegetables, especially lettuce and herbs, is a process in terms of production, but it has its distinctive features compared to, for example, assembly production. The research considering small and medium scale producers, like Finnish horticulture farmers, is totally absent. The novelty of this article lies in introducing the use of Lean to make horticulture processes more efficient and to minimize production loss.In Finland, the degree of domestic production of potted vegetables is almost 100%. Ensuring functionality and reducing waste throughout the supply chain are crucial. Finnish trade is highly consolidated, with two large retailing chains dominating the market. These large operators provide guidelines forprimary producers. In practice, the primary producer, i.e., the farmer, always tends to comply and, at the same time, adjust greenhouse production according to what needs to be delivered and when. This study introduces a case study of a transition process to continuous improvement, Kaizen, in a Finnish greenhouse vegetable-growing production company. This includes the selection of methods as well as changing the organizational culture. The company has gradually introduced various methods of continuous improvement to proceed with a more sustainable way of production, in which the researcher has become involved as an external facilitator. Especially, the qualitative study focuses on how the company creates value for the customers, the possibilities of various continuous improvement methods and their importance in greenhouse production and there is positive financial impact to use the methods.

Key words**:** *Lean, continuous improvement, horticulture management, primary production, process development*

INTRODUCTION

Productive and profitable agricultural enterprises are critical for countries' security of supply, the national economy, biodiversity and the prevention of climate change [50]. Besides the unforeseen changes and even crises, the agriculture sector has been facing continuous changes in its operational and business environment. This development has been especially challenging to small and medium-sized agricultural companies.

Horticultural companies in the Nordic countries are traditionally family-owned companies and have a unique identity which differs from other types of business [40]. Horticulture is the cultivation, processing, productization, trading and marketing of ornamental plants, vegetables, berries, fruits and mushrooms [48]. There is a gap in literature on the managerial point of view [11][12][23] of the horticultural side, and there is less concentration on social consequences in farming and family-owned companies [5].

Existing academic publications largely focus on cultivation development in Developing economies [2] [40]. There are ongoing discussions about Agriculture 4.0 and the kinds of technological innovations that can support the future of efficient sustainable farming [10][28]. The agricultural revolution is proceeding in a similar manner and terminology horticulture 4.0 is introduced by Sabine Ludwid-Ohm [29]. The industrial revolution has transitioned farming to mechanized methods and, more recently, to precision agriculture, such as greenhouse climate control, yield monitoring and guidance systems [2]. To adopt the technology and processes one must also have a management system in place.

Research focusing on European and Nordic greenhouse cultivation management is limited [30]. This raises the question, can the introduction of new management and

development practices impact positively the situation? This article demonstrates, through a case study, how the management of a horticulture enterprise can improve its operations by using methods of Lean philosophy.

In this manuscript we formulated two primary research questions:

(1)What role do Lean methods play in the development of greenhouse vegetable production processes?

(2)How can Lean management principles be effectively implemented in horticultural businesses to improve operations and development processes?

Motivation

Farming is traditionally labor-intensive work. In the year 2020, the labor costs of horticultural farming in Finland were nearly 30% of the total costs [15] The structural change has been ongoing for over a decade. In Finland the number of farms has halved compared to 2012 and the average size of the farms has grown [22]. Simultaneously, farmers are getting old, and young family members are not interested in taking over the farming business and developing the business [30][27]. However, most of the Nordic horticultural companies can still be counted as SMEs, with limited resources to invest and adapt new technologies to make their operations more effective.

The appeal of education in the agricultural sectors is constantly decreasing, as the short-termism of political decision-making makes it difficult to make future plans [46]. Because of the farmers' age and educational background, there is a risk of missing out on the opportunities of agriculture 4.0 or the process taking a long [30]. Traditional labor-intensive agriculture is transitioning to more cost efficient and productive environments due to the adoption of industrial production processes and working patterns. Agriculture 4.0 is introducing a lot of technological solutions to traceability to cover issues in food safety, food fraud and low quality. Autonomous farming is being implemented by making machines carry out independent processes, such as cultivation and harvesting, using satellite and GPS navigation. Farmers' role is changing, as they are experiencing many benefits from the new technologies, causing some to predict higher-tech futures [5][7][28]. Agriculture 4.0 is driven by the desire to avoid food waste, enable sustainable farming methods, adapt to climate change and allocate resources in a reasonable manner [49]

The average size of Finnish farms is still quite small and investments to new technology are expensive. Significant attention should also be paid to the industrialization of small farms to support small farms in adopting new technology [14][36]. In political decision-making and counseling, we should not put farmers in an unequal position because of farm size [5]. Studies on Swedish dairy farms have shown that various aspects of managerial capacity can significantly improve the efficiency and profitability of dairy farms [18]. Agriculture 4.0 requires an intelligence management system and requires farmers to have both an education background and the support to take farming to the next level [5][39]. Even when the size of the farm is small, enabling the farmer to adopt new technologies should be made possible, while underlining their need to understand their own business and farming processes [27]. The size of the farm or farmers changing role is not the only barrier to implementation of Agriculture 4.0. There is also a lack of skilled labor and economic barriers for high investment costs at the beginning. Management understanding of realistic capabilities where and how much they have resources to take farm forward [13][45].

The management of horticultural businesses has been notably under-researched, particularly in the context of Lean management principles [12]. This case study aims to address this research gap by exploring the application of Lean philosophy within the traditional Nordic horticultural environment. Utilizing qualitative research methods, the study seeks to demonstrate that Lean management can significantly enhance decision-making processes in the primary production sector, offering a framework for efficient and rapid decision-making.

Research Objectives

The research questions arise from the reality of the Finnish greenhouse growers and the special features they face compared to growers in other European countries [37]. The cultivation environment in northern countries is unique in terms of lighting and temperature compared to Central Europe [41]. The structure of Finnish trade is also very special compared to other European countries, as it is highly consolidated [25] and the degree of domestic production of potted vegetables is almost 100% [16]. The two large retail chains cover over 80% of the food retailing [1]. To answer address these issues, we built a road map in connection with the case study. The purpose of the roadmap is to demonstrate the impact of Lean methods in the operations of a greenhouse grower over several years and to build a model that gives academic contribution to greenhouse cultivation production to help other horticultural companies to start their Lean journey.

This paper presents a case study conducted between 2021 and 2024 in a large Finnish greenhouse company specializing in lettuce cultivation. The aim of implementing Lean methods was to improve the flow of production process in greenhouses and to minimize waste in production. The company was making a new strategy and business development plan for future and wanted to change its management system. As part of this transformation and a dissertation research project, the company decided to pilot the Lean management philosophy. Lean was chosen specifically to ensure that the development process would be driven internally by the company rather than outsourced to external consultants. Like any managerial system, Lean should be seen as a change in mindset and not as a project that starts and ends [4].

This paper is structured as follows: this Introduction is followed by the theoretical framework which first reviews the fourth revolution of agriculture and then covers Lean in management in general as well as lean methods which could offer a solution for getting over the barriers of development. Section three will present the research design and case study review, which introduces the study and road map for the case company together with a common model for other horticulture companies. The final section presents the conclusions and a summary and discusses and considers further research topics that are discussed and considered.

For the theoretical framework, existing research literature was retrieved from databases such as Scopus and Google Scholar. Additionally, citation networks were explored using the Connected Papers platform to identify relevant studies through reference tracking.

MATERIALS AND METHODS

As Lean philosophy and its methods are well documented in literature, this review covers overview of tools that could support development and efficiency in an agricultural environment.

Lean Philosophy and Methods

Toyota developed its production control system (TPS) under the leadership of production manager Taiichi Ohno. Based on TPS, Lean thinking was inspired by this philosophy of continuous improvement of production processes, causing many companies in various industrial and service areas to use its philosophy and methods [4]. The term Lean was introduced by Womack and Jones in their book Lean Thinking in the [51], and since then the western world has used this name for a management system that focuses on reducing productional waste, improving the flow of production and concentrating on produce based on customer demand. No large-scale investments are needed to utilize the Lean methodology and tools. The more the processes and learning are visualized to demonstrate what is happening in production or services, the easier it becomes to carry out improvement's development and "cherry pick" when identifying and eliminating waste [42].

The three central concepts of Lean thinking are reducing waste, creating added value for the customer and people working together [33]. Lean thinking consists of two levels: the strategic level of principles and the operational level of tools [13][21][26]. Lean thinking

provides a highly pragmatic means to proceed and learn from action instead of learning before acting. This is why Lean is viewed instrumentally, but the philosophy behind it should also be understood. Managers at different levels of the organization should commit to its manner of thinking and allow experimentation and failure as a means of viewing progress dynamically [13][43]. Since every company has its own starting point and as the Lean toolbox is full of different types of tools for finding root causes of productional problems, solving bottlenecks and improving communication, every company should find its own way of utilizing Lean.

Lean management employs various methodologies, the most well-known of which include Value Stream Mapping (VSM), 5S, Heijunka, Standard Operating Procedures (SOP), Kanban, and Plan-Do-Check-Act (PDCA) [3]. The utilization of these methods depends on the specific needs of the organization, with tools selected based on the initial conditions. The primary objective of Lean management is to reduce variability in production by eliminating activities that do not add value from the customer's perspective [30] [33]. By examining and standardizing processes through Lean management techniques, productivity and quality are enhanced, and costs are reduced.

Organizations often opt for Lean thinking when there is a sense of urgency. This happened at Kyrö Distillery during the Covid-19 pandemic [26]. Companies that do not have a direct example of the use of Lean philosophy in their own field should use external help. The importance of coaching and having support for your team is crucial. Organizations should use an external coach to receive answers to their questions, in addition to which an external coach helps to avoid returning to old habits [4]. Larger companies also use internal trained Lean coaches whose role is to support new parts of the organization in their efforts to take steps toward Lean. For example, the large Finnish teleoperator Elisa has approximately 300 internal coaches [43].

Lean In Horticulture

Since 2020, research on Lean management in agriculture has begun to emerge, primarily focusing on livestock and dairy farm operations[8][33][43]. As the green transition increasingly dominates public discourse, academic circles have also recognized the critical role of agricultural management [3]. The implementation of Lean management practices within horticulture, specifically in conventional greenhouse production, remains notably constrained. The most significant barriers to the adoption of Lean management and its methodologies in agriculture are the lack of knowledge, limited resources, and insufficient mastery of the techniques [36].

In agriculture, Lean tools have been more widely used in connection to livestock, with numerous examples presented by the Danish Susanne Pejstrup in her book Lean in Agriculture[17][30][37]. Case study examples from the Catalan pork sector show the positive impact of using Lean [38]. When it comes to cultivation, the case study on vertical farming featuring Liverpool crypt farm shows how the implementation of Value Stream Mapping already boosts environmental benefits, when plants form one part of the [14]. The national programs for implementing Lean more widely in the agricultural industry have been launched in the Nordic countries, for example in Sweden in 2010 when the Lean Landbruk was introduced [30]. However, these efforts have once again concentrated on livestock.

Melin and Barth studied the results of the program and discovered that the agricultural companies that adopted Lean thinking progressed at a very different pace compared to other companies even though they started at the same time [30][31]. This can be explained by an observation made by Hines and his group: To understand the Lean, you have to crucially understand the distinction of Lean thinking at the strategic level and Lean production at the operational level; otherwise, the selection of tools for the right part of the organization may fail [6].

Research Design

Though the author has been involved as a facilitator in the development process in an action research style [34], this research is

designed as a case study describing the long-term process of development of the managerial process. Case studies contribute to the development and refinement of theories by offering detailed empirical evidence and the method is flexible in terms of data collection, incorporating interviews, observations, and document analysis, which allows for the use of multiple sources of evidence. As defined by Michael D. Myers, a case study can be used either to discover things or to test and explain a particular topic [34]. In this case study, we aimed to explore and demonstrate the application of Lean methodologies within a horticultural cultivation environment. The focus was on examining how these methods were implemented during the study period, and how Lean philosophy supported the organization by maintaining existing quality standards and enhancing the flow of the production process. According to Myers, in business and management, the purpose of a case study is to make an original contribution of knowledge by using empirical data from real people in real organizations [34].

The designing of this study started in 2021, marked by the researcher's initial visit to the case study company. This visit facilitated a dialogue on continuous improvement and the preliminary steps the company could undertake to adopt a systematic approach to comprehending their processes and identifying appropriate tools. Over time, the company began to implement various Lean methodologies aimed at enhancing their production processes and inventory management. The researcher played a pivotal role in supporting and facilitating workshops, as well as assisting the management in progressing towards these improvements. By 2023, this iterative process had evolved into a well-defined model that consistently generated subsequent improvement proposals or implementations. Throughout the period from 2021 to 2024, numerous notes and reports were meticulously compiled. These documents were subsequently reviewed in the context of individual projects and their cumulative impact on overall productivity, with a particular focus on the optimization of working time. Decision-making was based on the premise that utilizing these methodologies could reduce process lead times, thereby saving man-hours. Consequently, the long-term financial performance was expected to improve. Simultaneously, employees were involved in the development of production processes and trained in new operational practices.

To establish a comprehensive understanding of the organization's initial context and prevailing organizational culture, a semi-structured interview was conducted with the company's management team at the beginning of the study. The management team and board members were involved, in total eight decision makers in the company. The semi-structured interview comprised a total of 69 questions, systematically divided into the following sections: company overview, processes and continuous improvement, customer promises, personnel, raw materials, trace and tracking, machines and maintenance, greenhouse shop floor, environment, and safety. This comprehensive approach facilitated the development of a clear and unambiguous structure for the case study.

RESULTS AND DISCUSSIONS

As stated earlier, Lean has both a strategic and an operational level. If the organization's management is not committed to changing its way of thinking and communication by increasing dialogue with employees, there is a risk that Lean will remain a project-based experiment [4].

Foundations of Operational and Organizational Development

The change must start from the basics. In the lettuce cultivation company, the change started inside the executive team. Run by the father together with his three sons, the cultivation enterprise turned 50 years in 2021. At that time, they understood that, although the company is a family business in its deepest sense, they also needed knowledge from outside the family to enable growth [35]. They started to build up new organizational practices and hired a CEO, a production manager and a

maintenance manager from outside from greenhouse cultivation business. This meant taking a risk but at the same time the family understood the arrangement to be a long-term investment. The family members remained part of the executive team and acted as the chair of the board [35].

The new executive team went through the semi-structured interview which also gave topics to think about. The semi-structure interview areas are defined in Table 1.

Table 1.Semi-structured interview topic and description.

Questionnaire area	Detail Description of Topic
Organization	Definition of organization. Roles and responsibilities
Processes and Continuous Improvement	The main process definitions. The lead times and measurement.
Customer Promiss	Key customer stakeholders and definitions. Detailed descriptions of documentation.
Personnel	How personnel are involved to decision making. The Annual clock to ensure maintenance of personnel competence.
Conditions	How the world's political situation has affected prices and energy supply.
Materials	Definition of production material specifications and detail definition of inventory management for raw materials and finished goods.
Traceability	Traceability definitions through supply chain. Markings and labelling.
Machinery	Maintenance in greenhouse and cultivation and advance maintenance of machines definitions.
Greenhouse Shop Floor	Descriptions of documentation of qty and massbalance in greenhouse shopfloor. Quality control and quality decision definition.
Environment	Sustainability and how is it measured and followed up.
Safety	Risk management. How the accidents are followed up and avoid.

Source: Authors' conception.

Figure 1 shows the Lean journey roadmap in the company. The methods employed were not selected at random; they were carefully discussed with the organization's managers to ensure they aligned with the company's requirements. In addition, the organization defined their customers' requirements and determined how they could offer the best service and products. The company's values, which emphasize developing operations and taking care of staff, hold an important position and will be realized throughout the company's Lean journey. Feedback from operators indicated that they feel that their voices have been heard and that their ideas are being implemented.

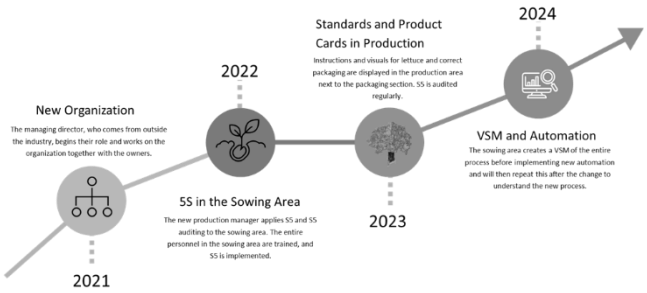


Fig. 1. A Four-Stage Road Map for the Case Study Farm
Source: Authors' own work.

Organized and Clean Sowing Area

The first actual Lean method was 5S, which was introduced in autumn 2022. It started as a two-day workshop, where every operator who works in the sowing area was trained for the concept of 5S [24][19]. A two-hour lecture was held in English, as most of the employees were not finish speakers. All the training materials were distributed to the participants. After the training, the team went to the sowing area and implemented the 5S in practice. The first S, Seiri, means removing all unnecessary items from the area. The items that are not needed should be completely removed, the items that are needed sometimes should be stored close and items that are needed daily should be placed in the workstation. This led to the removal of an old production machine because it was not being used. The second S, Seiton, took place next. The sowing area was organized, and the places for machines, pallets and materials as well as maintenance tools

were marked with attention tapes and paints. The third S, Seiso, started the second day of the workshop and included the actual cleaning of the area. The operators vacuumed and swept the area and wiped down the machines and shelves. The afternoon was spent on standardization, which is the fourth S, Seiketsu. The team agreed on working methods and schedules. Pictures of the workstations were taken and attached next to the workstations to show what the workstations should look like at the end of the shift. The participants themselves defined the kind of follow-up whiteboard they would have in the work area, how the area and 5S would be audited and by whom. The 5S audit document was distributed to the team, who then moved to phase five, Sitshuke, meaning commitment.

After three months, the facilitator interviewed the production manager and visited the sowing area one year later. The 5S was in place and the audit process was running. They had tried using applications for the audit during the first half a year but had then returned to a manual audit document, which now hangs on the wall. The employees said that seeing the document is more motivating and visual, and they appreciated the fact that there was no need to sign in to some system. During the 12 months, the changes were radical, but the process started to flow more smoothly. The production manager said that working overtime, which used to be more of a rule than an exception, had stopped. They had also noticed that there was more capacity which they could use or sell to their affiliates.

The organization also reported that they had found and fixed more bottle necks and that the tools had started to stay in their correct places. As the process had started to flow, they had noticed that there was more time in the day to do all the required maintenance and daily cleaning operations. As efficiency started to grow and variation in process was minimized, the company had also started to plan making investments in the sowing areas. There is now a clear process that can be automated without automating a process that involves a large amount of waste.

Standard Product Cards

The next method that was implemented was standardization of product cards [4] in production. This was done together with the sales team. Product requirements and definitions come from the customers. These definitions need to be delivered to every operator in production. When harvesting the lettuce, the operator needs to be able to see if the plant meets the requirements. That is why product cards, featuring pictures of the lettuce, such as frisée lettuce, were taken to the production area close to the operators. This allowed them to check the packaging variation and ensure that customer requirements were met. The visual product cards were part of the working instructions in production.

As customers defined the requirements of the product weight and packaging, the cards and instructions were also reviewed based on customer specifications.

The feedback, especially from employees on the shop floor, was that there is no longer uncertainty as to which package is correct, and which is not. The repacking and the other quality issues have decreased according to the sales manager.

Boost for the Next Process Development Rounds

As stated earlier, Lean is not a project or a program. Lean is a philosophy and can be understood as a journey aiming to make things better one by one [32]. In 2024, the company wanted to review the sowing area, this time by using the Value Stream Mapping method (VSM)[42]. The idea was to review the existing “as-is” process to improve the area again. 5S is running and sowing capacity can be distributed between two different greenhouse units. The improvement plan involves automating part of the process to reduce the number of working hours required. The robotics were added to the end of the production process and “to-be” process was implemented.

While reviewing the new “as-is” process, the team also identified other areas for improvement. After robotics were implemented the total lead time of the process was improved. This is a common phenomenon: as the process is visualized, it becomes clearer

[33]. Because Value Stream Mapping is an inexpensive, fast and simple means of visualizing the process, this provided the production manager with an excellent opportunity to elevate the process to the next level. The whole team was involved, and the ideas were reviewed. Upon developing the production process and conducting a new Value Stream Mapping (VSM) measurement, it was observed that the overall productivity per man-hour improved by 30%, and the lead time decreased by 9%. Consequently, a new standard time for the sowing process has been established, which can be further developed or adjusted in response to variability. Comparable research findings from horticulture in Nordic greenhouse production are not available. The overall resource utilization for the VSM study was reasonable, and the results will assist the company in benchmarking operations against specific metrics in the future. This demonstrates that the methodology tested in livestock farming [31] is also effective in horticultural plant production processes.

Implications for Applying Greenhouse Cultivation

After analyzing the roadmap in the case study and reviewing the literature, we defined the following model for other horticulture companies that want to embark on the Lean journey. The different phases, provided in years, can be defined as steps during which the way of thinking about the continuous improvement cycle is adopted. As Micheal Ballé has argued in his book The Lean Strategy, this requires a change in mindset [4]. It is not simply a project or program to implement.

The first step should include a review of the organization to ensure that resources are appropriately allocated. If this is not the case, the first step should be to appoint the right people and establish clear roles and responsibilities within the organization. The individuals in the team should be challenged to create team spirit, efficient work processes and a supportive structure with appropriate methods and tools [44]. The organization should be committed to a cycle of continuous improvement. This will support the adoption of the agriculture 4.0 opportunities in the future.

In the second step, the Lean tools that support the organization and its greenhouse operations should be selected. External help should be used if required. In this case study, it was easy to select either the 5S method or Value Stream Mapping (VSM) at the start. As the company's processes were already known, 5S was implemented first. However, if the work is being reviewed for the first time, it is recommended to start with a VSM and then proceed with 5S. Every organization is unique, which is why it is important to find the best tools for each organization [47].

In the third phase, a standard for the work should be created. Initially, it is enough to establish a standard for one workstation and review its effectiveness. Then, the process should be continued sequentially to the next area and workstation. Having a standard ensures that every operator works in the same manner at that workstation. This consistency will help employees and provide a baseline for future improvements. Visualizations and photographs should be used. Audits should be conducted as needed, and habits should be maintained [6]. The Fourth phase involves taking the Lean idea forward to the next area or using another tool to improve the work. The entire working team should remain in the same cycle and continuous feedback from the team should be sought. Lean continuous improvement is about minimizing waste, making waste reduction an engaging activity for employees. This is the most important step: keeping the team united and celebrating small victories and improvements.

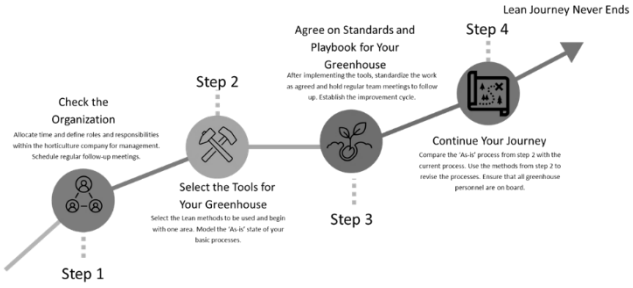


Fig. 2. A Suggestion for model for Horticulture Companies to Implement Lean Philosophy
Source: Authors' own work.

Impacts From an Economic Perspective

The case study shows that even small changes in production process cause significant improvement in flow which improves the financial performance of process.When the production process becomes more productive, it means that more output is generated with the same or fewer inputs. This improvement typically leads to lower unit costs, as fixed and variable costs are spread over a larger number of units. As a result, the company's operating margin improves because revenues remain stable or increase while costs decline. The cost reduction and lead time improvement show impact as increasing output of process and give opportunity to increase sales. Additionally, improved productivity reduces working capital and fixed assets, thereby lowering the capital employed and enhancing return on capital. This therefore frees up capital for potential investments. In our case study might be very marginal but in other environments this might open good opportunities.

Additionally, material needs decrease and occupational safety improves, although these changes are reflected more slowly in financial figures. It can therefore be concluded that the continuous Improvement cycle also drives economic productivity.

Table 2. Direct effects on financial figures

	Change %	
Operating expenditures	-30%	Decreased labour costs
Working capital	-9%	Decreased work in process (WIP)

Source: Interview of Company executive team members [35].

CONCLUSIONS

This case study represents the first academic investigation to examine a Finnish horticultural company through the lens of Lean management. The study spanned several years and focused on how Lean principles were applied in a real-world greenhouse production environment.

Two research questions guided the study. The first—whether Lean methods have a role in a horticultural agribusiness context—was clearly affirmed. The company, a family-owned enterprise, maintained its core leadership structure, with family members continuing in executive roles and chairing the board. Notably, the organization demonstrated openness and was bold enough to innovation by inviting external experts into its operations—an unconventional move in the traditionally insular horticultural sector. This decision proved transformative, as the newcomers introduced fresh perspectives and were empowered to implement novel ideas.

As Lean methods are very pragmatic and based on actions and visualizations, it was easy for operators and farmers to adopt this approach to working. The case study showed significant improvement in the sowing production process which means also a more sustainable way of working. Since horticulture companies are traditionally family-owned and have relatively flat and lean organizational structures, this type of continuous improvement approach effectively supports management [9]. Resourcing for development does not take much time, and it was observed that the methods were easy to adopt quickly, with results visible in the same day.

The operators gave positive feedback to management, feeling that their voices were heard and that they brought their knowledge to contribute to development of their own work.It was also noted that increasing visualization made familiarization with the work faster and easier, and quality errors decreased. There was immediate financial impact ondecreasing personnel costs and long-termeffect on EBITA and working capital. Employees in the sowing area were surveyed regarding their job satisfaction and asked to compare it to earlier conditions. According to their responses, overall job satisfaction had increased, and the work environment was considered more pleasant. Employees also indicated that the work area is easier to maintain.

For future research, it is necessary to investigate the operational metrics for horticulture that support operational management on the shop floor and how to set up common goals that are easy to communicate and follow in the operational environment of

greenhouses. In addition, there is potential for research on the integration of Lean Methods and Agriculture 4.0 and how they support one another. The focus should not only be on new technologies but also on how horticulture companies can utilize them in their organizations, ensuring that personnel are trained and guided towards new farming methods.

To answer the second research question is that there should be open dialog between the farmers and academia. The roadmap for implementing Lean methods, presented at the end of the empirical section, illustrates the response to the second research question. Farmers require support from policymakers and industry associations to adopt new technologies and develop processes [20]. Education should facilitate this development. It is essential to manage data generated by advanced systems in conjunction with maintaining healthy crops and to respond to this data before the crops exhibit any adverse reactions. This is a crucial aspect of the benefits offered by Agriculture 4.0.

The cycle of continuous improvement can be launched at several levels, but Lean practices can significantly help horticultural company owners visualize their processes, take steps to improve efficiency and eliminate unnecessary waste. As noted at the outset, the Finnish retail market is highly consolidated. Customer specifications from central purchasing organizations are decisive for primary producers, requiring continuous agility. Lean methodologies support the maintenance of continuous improvement and help validate the development and prove it to customer direction.

The roadmap developed in the case study can be applied to any greenhouse production environment. It has no limitations regarding plant production, whether it involves vegetable cultivation or ornamental plants. In the future research is required for more detailed for continuous improvement planning in horticulture production and how to implement it to cultivation planning and production measurement. The managerial point of view should be linked to the future research more tight and Lean management require the commitment of company owners and line managers.

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PREPARING RURAL COMMUNITIES FOR FUTURE TOURISM CHALLENGES: VIRTUAL REALITY AS A STRATEGIC TECHNOLOGY

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Abstract

This article develops a public policy–oriented conceptual model for using virtual reality (VR) as assisted, community-based access to tourism and cultural experiences for residents of rural Romania. The premise is that tourism participation based on physical travel often remains constrained by economic and digital barriers. The study integrates a narrative synthesis of the literature on the mechanisms of VR experience in tourism, constraints on tourism participation, and access equity (i.e., digital inequality), together with contextual indicators from official statistical sources (Eurostat; National Institute of Statistics of Romania), without collecting primary data. This integration is translated into an intervention model centred on distinctive VR mechanisms, particularly sense of presence, immersion and experiential learning. The model links these mechanisms to potential proximal outcomes, such as mediated participation in tourism, cultural exposure and assisted digital use, treating VR as an alternative pathway to tourism experiences under limited physical mobility. The article proposes three pilotable institutional formats: rural libraries, community cultural centres and schools as digital educational hubs, alongside operational rules, risk mitigation measures and minimal evaluation indicators. The contribution lies in shifting the emphasis from individual VR adoption to an institutional design that could support scalable and evaluable interventions in rural areas.

Key words: *rural Romania, tourism access, digital transformation, virtual reality, policy-oriented model*

INTRODUCTION

Tourism has traditionally been one of the most visible ways in which individuals broaden their cultural, social and economic horizons. It facilitates contact with other places, norms and practices, supports informal learning and can contribute to wellbeing as well as to strengthening community cohesion. At the macro level, tourism is recognised as a field of particular relevance to sustainable development, and is repeatedly integrated into international agendas aimed at reducing access gaps in opportunities between groups and territories, including between urban and rural areas [38].

However, the potential benefits of tourism are not evenly distributed. In practice, access to travel remains strongly conditioned by material resources and by the household budget's 'room for manoeuvre' after essential expenditures have been covered. In Romania, official data from the National Institute of Statistics (NIS) indicate that, in 2024, average monthly household expenditure accounted for a very high share of total income (approximately 85%) [27], suggesting limited flexibility for discretionary spending. Moreover, the structure of consumption expenditure shows substantial shares allocated to food and to housing/utilities, while areas such as education or travel remain marginal within the current household budget [27]. In this context, tourism may become a sporadic activity, or even inaccessible, for a significant proportion of the population, not due to a lack of interest, but because of persistent economic constraints associated with income levels and the cost of living.

These constraints tend to be felt more acutely in rural areas, where income differentials relative to urban areas are persistent. For 2024, NIS indicators suggest a substantial urban–rural gap, both in household income and in income per person [27].

Beyond the strictly financial dimension, limited access to tourism mobility may have wider implications, as it reduces direct exposure to models of economic organisation, services, infrastructures and practices observable in other regions. It may also diminish cultural capital and opportunities for experiential learning, and intensify a sense of 'distance' from the technological and cultural transformations that become more visible in urban centres or international destinations. In terms of local development, the absence of contact with diverse examples, such as tourism entrepreneurship initiatives, digitalisation or heritage valorisation, may constrain processes of inspiration, imitation and incremental innovation at community level, thereby reinforcing narrower repertoires of reference.

In parallel, over the past two decades tourism has been strongly shaped by digitalisation, and the ways in which destinations are searched, planned and evaluated have increasingly come to rely on digital content, online platforms and technologically mediated experiences [3, 4].

Nevertheless, digitalisation does not remove the fundamental constraint posed by the cost of physical travel, including transport, accommodation, food, and the time required. Indicators of tourism participation among Romanian residents show that a substantial share of the population does not engage in tourism activities, which points to a persistent access gap even in a context where information about destinations is abundant. Eurostat data indicate that, in 2024, fewer than three in ten residents of Romania aged 15 and over participated in tourism, whereas in other EU Member States at least seven in ten residents took a tourism trip, with values of 84% in the Netherlands and 76% in Austria [12]. Thus, in Romania, the number of people who do not participate in tourism clearly exceeds the number who do [12].

Within this framing, the question arises as to whether immersive technologies such as virtual reality can intervene and provide an alternative and complementary form of access to tourism and cultural content for communities with limited mobility.

Virtual reality (VR) is a technology that enables users to explore computer-generated three-dimensional (3D) spaces, commonly referred to as virtual environments (VEs), and to develop a sense of immersion and presence. In current use, VR is most frequently accessed through head-mounted display (HMD) devices such as the Oculus Quest or HTC Vive Pro [15, 1, 31].

In tourism and hospitality, VR has been discussed as a tool for destination visualisations at the pre-travel stage, as well as for cultural interpretation, education, marketing, and service design. Recent literature reviews highlight the diversity of applications of this technology and emerging directions for research [9].

From an affordability perspective, VR has a relevant distinctive feature in that a substantial share of costs is front-loaded, through the acquisition of equipment and customised content, whereas physical travel entails recurring expenditure for each trip. An industry insight report notes, based on an estimate attributed to BCB Group, a leading crypto banking group, that a physical itinerary to global landmarks such as the Statue of Liberty or the Great Wall of China could amount to approximately USD 7,600 (flights, transfers and attraction entry fees), whereas virtual access would cost just over USD 2 [5].

Although VR cannot fully reproduce the social, sensory and economic dimensions of 'on-site' tourism, it can function as a form of 'virtual visitation' with educational and recreational value.

In Romania, although infrastructure indicators show substantial fixed internet penetration in rural areas, around 75 connections per 100 households [24], this does not guarantee effective technology use at the individual level. European Commission data on digital skills indicate low levels; in rural areas, the share of people with digital skills above the basic level is only around 5% [10].

Consequently, the realistic premise is not "VR at home", but "VR as assisted community access", delivered through local access points such as libraries, community cultural centres,

or educational hubs, where costs, support, and skills can be shared and supported.

On this basis, the present article aims to open an exploratory line of inquiry into VR mediated tourism in rural Romania, without collecting primary data, but anchored in relevant secondary data drawn from official sources such as the National Institute of Statistics of Romania and Eurostat (the Statistical Office of the European Union), in order to substantiate the need for, and the timeliness of, an intervention model.

In the literature, VR is often discussed from the perspective of the general consumer, or of the destination as a marketing actor. More rarely, however, it is systematically examined as an access equity instrument for rural communities facing economic and geographic constraints, delivered through community infrastructures.

Accordingly, this article formulates the following research question:

***RQ**: How can a community-based access model for virtual reality (VR) be designed to expand access to virtual tourism experiences for residents of rural Romania, under conditions of economic and digital constraints?*

The main contributions are threefold. (1) The article positions virtual reality (VR) as an alternative and complementary form of mobility to physical travel, as a premise for expanding access for residents of rural Romania to VR mediated virtual tourism experiences and cultural exposure. (2) The article proposes a conceptual model that links economic and digital constraints to the mechanisms of VR experience, including immersion and presence, learning, and guided exploration, and to proximal outcomes such as perceived access to virtual tourism experiences, digital literacy, and cultural openness. (3) The article advances a policy and practice-oriented implementation model based on assisted community access delivered through local infrastructures, proposing three pilot formats, rural libraries, community cultural centres, and schools as educational hubs, while outlining a research agenda for subsequent testing.

Literature-based conceptual framing

VR for virtual visitation, the pre-trip phase, education, and cultural interpretation

The literature positions virtual reality (VR) as a technology capable of mediating tourism experiences through immersion and a sense of presence, with applications on both the demand side, supporting the formation of tourist expectations and evaluations, and the supply side, as a set of tools for destinations and providers. An early reference point is Guttentag's synthesis (2010), which systematises the uses of VR in tourism and explicitly discusses the conditions under which it can function as a substitutive experience, as well as the limits of substitution, for example the absence of certain social and sensory dimensions of physical travel [15].

Subsequently, a sustained stream of research has highlighted the relevance of VR in the pre-trip phase, where it can support information seeking, anticipation, and the formation of attitudes towards destinations. Tussyadiah and colleagues (2018) show empirically that a sense of presence in VR is associated with attitudinal change and visitation intentions, suggesting a persuasive role for VR in destination communication and marketing [33]. In the same vein, reviews of the field confirm that a substantial share of studies focuses on the use of VR for promotion and communication in the pre travel stage, and recommend distinguishing between non immersive, semi-immersive, and fully immersive systems [1].

Complementarily, Skard and colleagues (2021) highlight psychological mechanisms such as the stimulation of mental imagery and affective anticipation, or happiness forecasting, which may influence travel intentions [32].

Beyond marketing, VR is also discussed as a form of virtual visitation, with educational and interpretative functions relevant to museums and heritage settings. Within this line of research, the integration of VR, sometimes alongside AR and other technologies, is examined through the lens of value co creation, in the sense that the experience is designed to generate benefits for both organisations and visitors through the visitor's active

engagement with content, in relation to the institution, interaction, and personalisation, rather than through passive consumption alone. Moreover, from the perspective of reducing access barriers within the same cultural context, VR may become a viable instrument when a physical visit is not possible for various reasons [20]. Effective use of these technologies can support the value created particularly at the pre visit, or pre trip, stage [13], as well as during the on-site and post visit stages, resulting for visitors in a memorable experience that is better tailored to their interests [20].

Constraints, equity, and accessibility in tourism

The constraints framework provides a useful basis for interpreting why certain groups participate less frequently in leisure activities and, by extension, in tourism. The classic leisure constraints model distinguishes between intrapersonal, interpersonal and structural constraints and subsequent developments order these hierarchically, from the most proximal, intrapersonal constraints to the most distal, structural constraints. Within this logic, even when a preference for, or motivation to engage in, an activity is present, structural constraints, for example time, financial resources, and access, may continue to intervene between preference and participation, limiting or even preventing the actual undertaking of travel [6, 7, 14].

In tourism, the equity dimension is also discussed through the lens of social tourism and inclusion policies, which start from the premise that certain population groups, for example people on low incomes or in situations of vulnerability, face systematic barriers to participation in tourism activities. McCabe (2009), for instance, explicitly analyses the barriers encountered by low-income groups and places holiday participation within a broader discussion of the personal and relational benefits of tourism, for example time spent together as a family and the opportunity to visit new places and try different activities, in relation to the social policy agenda [22]. These perspectives are relevant to rural areas not in order to impose a uniform social label, but as a context characterised by internal heterogeneity, in which economic constraints, such as more pressured household budgets, geographic constraints, such as greater distance from transport nodes and higher travel costs, and institutional constraints, such as more limited access to cultural infrastructures and services, may accumulate. In addition, the accessible tourism literature shows that 'access' depends to a large extent on the integrated design of tourism products and services, as well as consumption environments, especially the built environment and supporting infrastructures and information, so that participation is feasible for diverse categories of users [8].

Within the rationale of the present article, VR is not positioned as a 'substitute' for tourism, but as a potentially complementary measure for reducing certain structural constraints, related to costs, limited digital skills, and/or distance, for people living in rural areas, thereby enabling some degree of access to mediated tourism and cultural experiences.

Access to technology does not guarantee digital inclusion

A major risk of techno optimistic arguments is the assumption that access to technology automatically produces inclusion. The digital divide and digital inequality literature challenges this premise. Digital inequalities are not limited to access to infrastructure and devices, but also include differences in skills, including the practical ability to use equipment and applications, differences in the types and frequency of use, as well as inequalities in the outcomes of digital technology use, for instance access to employment opportunities, the ability to conduct commercial transactions on more favourable terms, or the attainment of measurable socio economic benefits [34, 35]. Helsper (2012) proposes the Corresponding Fields Model for Digital Exclusion, which hypothesises a bidirectional relationship between social exclusion and digital exclusion across corresponding economic, cultural, social, and personal fields. More precisely, offline disadvantage is expected to be associated with online disadvantage in the corresponding field, and vice versa. The social

to digital link is mediated by access, skills, and attitudes, whereas any digital to social gains depends on relevance and the quality of the experience, ownership, understood as control and empowerment, and sustainability [17]. This implies that providing connectivity is not sufficient. The resources and skills that make technology relevant and usable must also be addressed.

For a 'VR as assisted community access' model aimed at rural residents, this means that 'access' should be conceived as assisted and institutionalised access, rather than as individual acquisition alone. The cost of equipment, maintenance, hygiene, technical support, content selection, and facilitation of use become essential components. In this respect, the literature on the role of public institutions, particularly public libraries, in digital inclusion shows that they can function as nodes for access, digital literacy, and community support, reducing gaps between policy and the effective use of digital devices [19, 37].

Building on these three strands of literature, VR in tourism, equity and constraints on participation, and digital inequality, the next section develops the concept of 'alternative mobility' through VR and operationalises it in a conceptual model of community intervention centred on rural access points, namely rural libraries, community cultural centres and schools as digital educational hubs (Figure 1).

Conceptual model, VR as alternative mobility for tourism

From physical mobility to mediated experiential access to tourism

In mobilities research, tourism is understood not only as movement between two points, but as an assemblage of practices, infrastructures, images, and social relations that make it possible to 'be in the world' through movement, or through forms of being connected at a distance. The mobilities paradigm emphasises that the rights and capacities to travel are profoundly unequal [30]. At the same time, tourism sits at the intersection of mobilities and technology, and research on tourism mobilities shows that new technologies reconfigure modes of access to, representation of, and experience of destinations [16].

On this foundation, in this article we define alternative mobility as experiential, immersive access to tourism and cultural content through VR when physical mobility is structurally constrained. The concept does not assume that VR becomes a complete substitute for tourism. Rather, it may function as a complementary channel of access and symbolic, educational, and emotional participation in tourism experiences for residents of rural areas. This delineation is consistent with the VR in tourism literature, which explicitly discusses the possibility of substitution in certain contexts and its limits [15], as well as with more recent arguments that VR is more realistically conceptualised as a tourism niche or a complementary tool in specific situations, rather than a full replacement for conventional tourism [36].

The proposed model - inputs, intervention, mechanisms, outcomes and risks

To anchor the concept within the article's rationale, economic and digital constraints, together with community level feasibility, we propose a simplified conceptual model (Figure 1), which explains the mechanisms through which VR might support relevant outcomes in rural communities, without assuming automatic inclusion or uniform effects.

In the model, the central mechanism that differentiates VR from other media is a sense of presence, understood as the subjective experience of being there [33]. This sense of presence is supported by perceived realism and the immersive character of the three-dimensional, 3D, virtual environment, which can generate an 'almost there' effect in destination exploration [33, 28].

Once activated, this mechanism makes VR experiences more engaging than non-immersive forms of representation such as images or video materials [15]. This increased engagement may amplify curiosity and emotional involvement and, in turn, influence preferences and intentions related to the tourism content explored in VR [21].

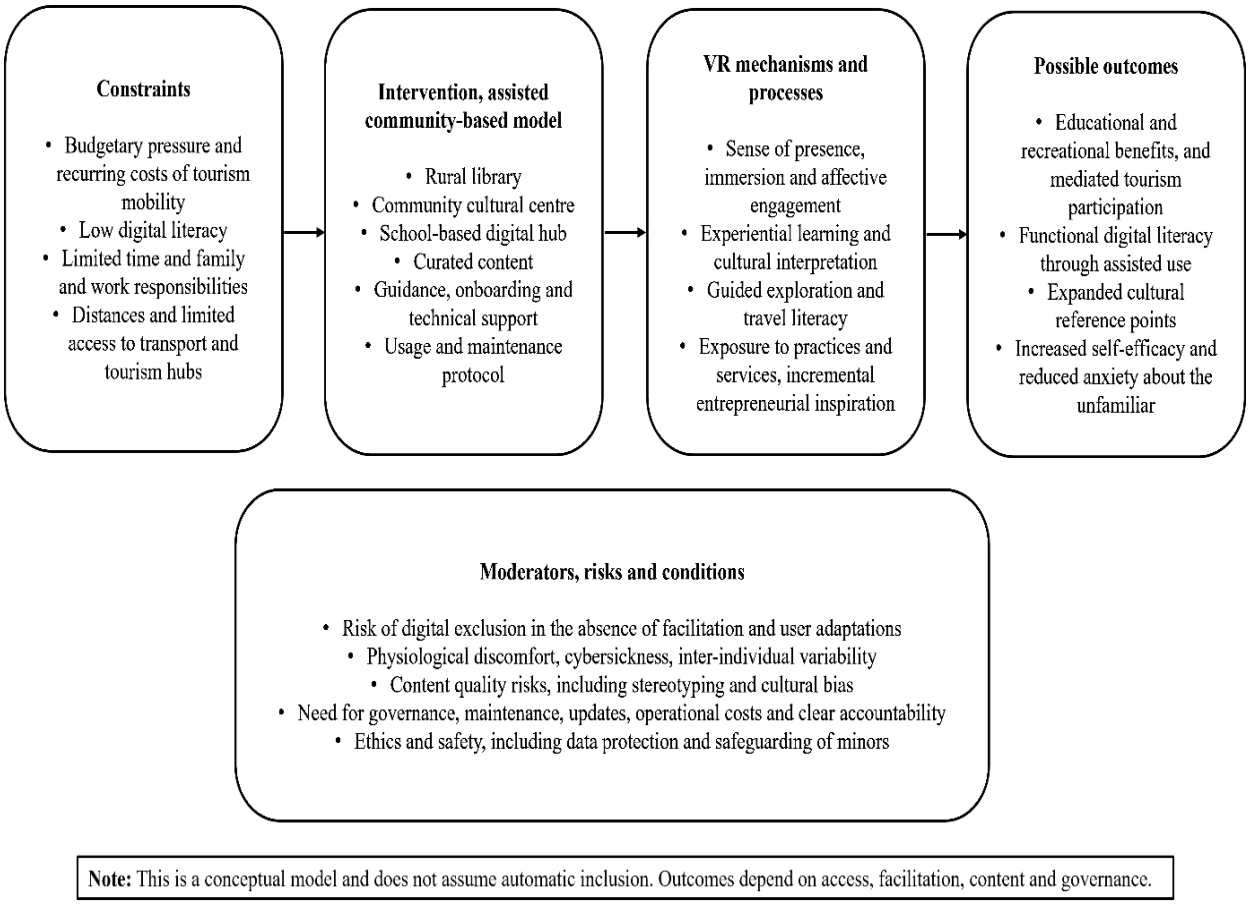


Fig. 1. Conceptual model for VR-assisted community access to tourism for Romanian rural residents
Source: Own conception.

At the empirical level, tourism research supports this logic, indicating that the intensity of presence experienced in VR may be associated with attitudinal change and intentions to visit destinations encountered in immersive environments, confirming the relevance of sense of presence as a key mechanism in tourism experiences mediated by this technology [33]. Complementarily, on the educational and interpretative dimension, research on the use of immersive technologies in cultural heritage contexts suggests that such experiences can enrich the visitor experience by increasing active engagement in content exploration. This engagement may take the form of navigation, interaction with interpretative elements, and decision making throughout the experience, which may facilitate learning about the meanings, context, and cultural values of the sites presented [20]. As a result, potential effects may be reflected in post experience evaluations, including satisfaction and overall impressions of the virtual visit, intentions to revisit, and the sharing of positive word-of-mouth [20]. In addition, studies in experiential education indicate that immersion can support situated learning when the intervention is designed and structured explicitly in pedagogical terms [29]. At the same time, the model explicitly incorporates the premise that access to technology does not equate to digital inclusion. Digital inequality theory shows that differences between individuals and groups are not only a matter of infrastructure and devices, but also of skills, patterns of use, and the benefits derived [35]. The Corresponding Fields Model for Digital Exclusion suggests that social and digital exclusion can reinforce one another [17]. Therefore, the proposed intervention is institutionalised and assisted through community access points and facilitation, so that technical access can be translated into functional access and effective use.

Health and usability risks are treated as structural limitations of the intervention. The literature on the use of head mounted display, HMD, devices recognise cybersickness as a relevant barrier and discusses factors that increase its likelihood, for example latency, prolonged exposure, and intense visual motion, as well as design and session management measures [2].

Accordingly, 'alternative mobility' through VR is conditional on design quality, the duration and organisation of use, and the support provided to users, conditions that are reflected in the facilitation components and the implementation section of the article.

MATERIALS AND METHODS

This article adopts a conceptual, public policy-oriented design, without collecting primary data.

The methodology combines, (a) a guided narrative review of the relevant literature, and (b) a descriptive context analysis based on official secondary data, NIS and Eurostat, and publicly available datasets.

These data are used to document rural residents' access limitations with regard to physical tourism and to argue for the feasibility of a 'VR as assisted community access' model, through which they can access virtual visitation experiences and related tourism and cultural content without physical travel. The conceptual model was developed following [18] structured approach to building conceptual frameworks, guiding the identification of components, mechanisms and potential outcomes of a VR-assisted community-based intervention in rural Romania.

Mini protocol for the literature review

The review was conducted through a concise protocol, using searches across databases and academic search engines commonly used in tourism and the social sciences, such as Scopus, Web of Science and Google Scholar. Searches combined English language terms grouped into three thematic strands:

(1)VR and tourism, virtual reality, VR tourism, virtual visitation, pre trip, presence,

(2)accessibility and equity in tourism, tourism constraints, social tourism, accessibility, equity, and

(3)digital inequality, digital divide, rural connectivity, digital inclusion. The selection focused primarily on peer reviewed journal articles, academic books, and relevant chapters, prioritising conceptual works and reviews that substantiate the mechanisms of VR experience and explanatory frameworks for constraints and digital exclusion.

Non-academic sources and works without direct relevance to the article's objective were excluded.

The review is narrative and oriented towards conceptual model development, it does not aim to exhaust the literature, but rather to integrate coherently the theoretical lines required for the argument.

Descriptive contextual analysis based on secondary data

The contextual component used official indicators drawn from public sources, NIS, Eurostat and ANCOM, covering, (a) household income and expenditure, (b) indicators of tourism participation in Romania, and (c) connectivity and digital skills. Indicators were treated descriptively, levels and shares, and compared where the sources allow, following the logic, budget pressure, tourism participation, digital feasibility. Findings are not interpreted causally, but as a contextual diagnosis that supports the conceptual model and the implementation recommendations proposed in this study.

The period 2023 to 2024 was selected to ensure reporting as close as possible to the present and thus higher relevance to the article's topic.

For 2025, some of the required statistical series have not yet been fully published or are not available in a comparable form, which is why 2025 was not included in the present analysis.

RESULTS AND DISCUSSIONS

On 1 January 2025, Romania's resident population was distributed almost evenly between urban and rural areas, with approximately 51.3% living in urban areas and 48.7% in rural areas (Table 1).

Table 1. Romania's resident population on 1 January 2025

Indicator	Unit	Residence area	Value
Resident population on 1 January, 2025	Number of persons	Urban	9,770,366
Resident population on 1 January, 2025	Number of persons	Rural	9,272,785

Source: Calculation based on NIS Tempo Online 105A [26].

This structure indicates that a very substantial share of the population lives in rural localities, where access to opportunities, services, and digital infrastructures is typically more limited than in cities. In this respect, the proposal of a VR model tailored to rural areas is supported both by the size of the target group and by the need to address access barriers in resource constrained settings.

Table 2 summarises the level and composition of monthly income and expenditure per person in rural Romania for 2023 and 2024.

Table 2. Average monthly income and expenditure per person in rural Romania

Average monthly income and expenditure per person in rural Romania		
	2023	**2024**
Total income, average monthly per person (lei)	2,277.69	2,612.69
Total expenditure, average monthly per person (lei)	2,005.77	2,247.17

Share of total expenditure, by expenditure categories (%)		
	2023	**2024**
Monetary expenditure, of which:	87.9	88.4
Consumption expenditure, of which on:	56.6	55.4
(a) food and beverages consumed	18.6	17.9
(b) purchase of non-food goods	26	25.8
(c) payment for services	12	11.7
Taxes, contributions, membership fees and other charges	26.2	27.2
Value of consumption of food and non-food products from own resources	12.1	11.6

Note: As an order of magnitude, RON 2,612.69 corresponds to approximately EUR 513.35, using the National Bank of Romania exchange rate on 16 January 2026 of RON 5.0894 per euro.

Source: NIS, Press Release, June 10, 2025 [27].

Over the period analysed, average monthly income per person increased from 2,277.69 lei to 2,612.69 lei, up 14.7%, while total expenditure rose from 2,005.77 lei to 2,247.17 lei, up 12.0%. The difference between income and expenditure remains positive, yet the consumption profile indicates a budget still strongly constrained by current needs and recurring obligations.

From a structural perspective, monetary expenditure accounts for approximately 88% of the total in both years, 87.9% in 2023 and 88.4% in 2024, while 'consumption', food, non-food goods, and services, totals 56.6% in 2023 and 55.4% in 2024. Within consumption, the share of food and beverages consumed declines slightly, from 18.6% to 17.9%, as do services, from 12.0% to 11.7%, while taxes, contributions, and other mandatory payments increase, from 26.2% to 27.2% and remain the largest consumption category in both years. The value of consumption from own resources also remains significant, from 12.1% to 11.6%, suggesting the persistence of self-consumption practices in rural areas.

Lower participation in travel among rural residents can also be interpreted through a complementary lens by considering the distribution of household consumption spending across categories (Figure 2).

Although the figure (Figure 2) does not provide an explicit rural breakdown, it captures how households generally allocate their monthly expenditure across the main consumption categories. Within this profile, spending on hotels, cafés, and restaurants is modest, at around 2% in both 2023 and 2024, pointing to limited scope for financing tourism related activities, including travel, stays, and out of home consumption. A similar pattern is observed for education, where average monthly spending is around 0.6% of total average monthly consumption expenditure per household, leaving little budgetary room for investment in human capital and, indirectly, for building the skills needed to access digital opportunities.

This structure supports the conclusion that, beyond income levels, budget constraints are reflected in the prioritisation of essential spending, at the expense of components associated with tourism mobility, recreation, and educational development.

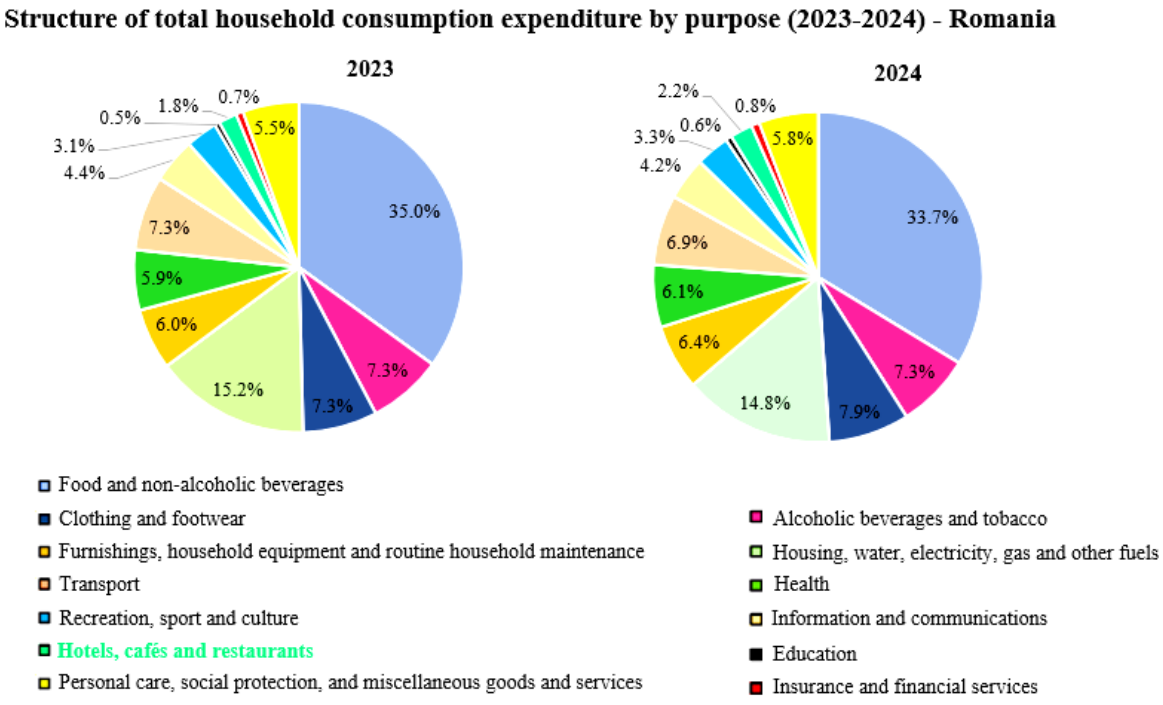


Fig. 2. Structure of total household consumption expenditure by purpose, Romania, 2023 and 2024
Source: NIS, Press Release, June 10, 2025 [27].

With regard to digital inclusion, it is important to emphasise that high levels of connectivity do not automatically translate into digital skills. Although Romania benefits from high quality internet infrastructure (Table 3), a household connection does not necessarily mean that its members possess the skills and operational capabilities required for relevant forms of digital use, such as searching for and critically evaluating information, using online services, educational, administrative, or financial, or participating in forms of learning and exploration mediated by technology.

Table 3. Fixed internet access indicators in rural Romania (ANCOM), 2023 - 2024

Indicator	2023	2024
Fixed internet penetration per 100 households (rural)	72%	75%
Annual growth rate of fixed internet connections (rural)	5%	5%

Source: ANCOM, 2024 and ANCOM, 2025 [24, 25]

This argument is further supported by Digital Economy and Society Index (DESI) data for rural Romania. According to the digital skills indicators, the share of people with at least basic digital skills remains low, although it is increasing, from 18.3% in DESI 2023 to 20.99% in DESI 2024 (European Commission, n.d.) [10]. Similarly, the share of those with digital skills above the basic level remains very small, at 3.67% in 2023, DESI 2023, and 5.08% in 2024, DESI 2024 (European Commission, n.d.) (Figure 3).

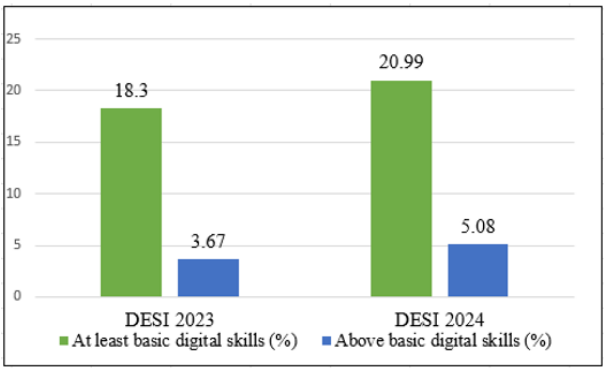


Fig. 3. Digital skills indicators, rural Romania (DESI 2023-2024)
Source: European Commission, n.d. [10].

In methodological terms, DESI digital skills indicators classify according to reported digital activities across five areas, namely information and data literacy, communication and

collaboration, digital content creation, safety, and problem solving, for example managing applications or installing software. The category, at least basic digital skills, implies a minimum functional level across all five areas, while above basic indicates a somewhat more advanced and more consistent repertoire of use across the same five areas [10].

In relation to the topic of the article, this distinction between access, connectivity, and skills, digital skills, is essential for two reasons. On the one hand, the relatively high level of fixed internet penetration in rural areas, 72% in 2023 and 75% in 2024 (Table 3), indicates the existence of a minimum infrastructure that can support the implementation of an assisted, community anchored VR model. On the other hand, the low values of digital skills measured by DESI show that the mere availability of a connection does not automatically translate into relevant digital use, nor into observable benefits in everyday life, such as digital learning, or leveraging economic and social opportunities mediated by technology. In this sense, the proposed intervention is justified precisely as a mechanism that links existing infrastructure to the gradual development of usage capacities through guided, repeated exposure and practical support.

Furthermore, Eurostat data indicate that, in rural Romania, internet use is strongly oriented towards mobile phones, with 83.23% of people aged 16 to 74 who use the internet accessing it via a mobile phone or smartphone (Figure 4).

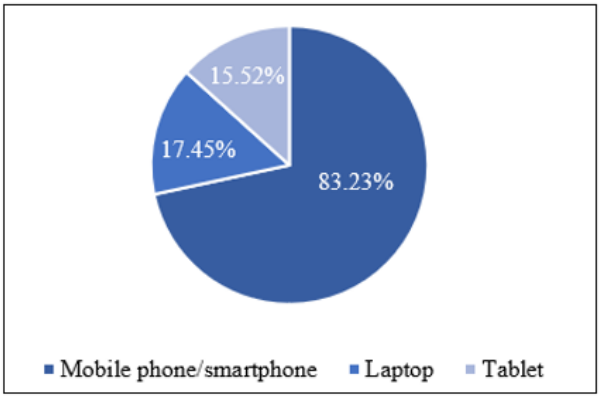


Fig. 4. Individuals (16–74) using the internet on various devices, Romania rural areas, 2023
Source: Eurostat, 2024 [11].

In practice, this mobile first profile may limit the quality and comfort of more complex immersive experiences. An assisted community-based VR model can therefore provide access to suitable equipment, a comfortable setting for use, and facilitation that transforms occasional digital content consumption into a structured experience of exploration and learning.

Along the same lines, Eurostat indicators on online activities show that, in 2023, the most frequently reported use in rural areas is reading news online, 47.80% (Figure 5).

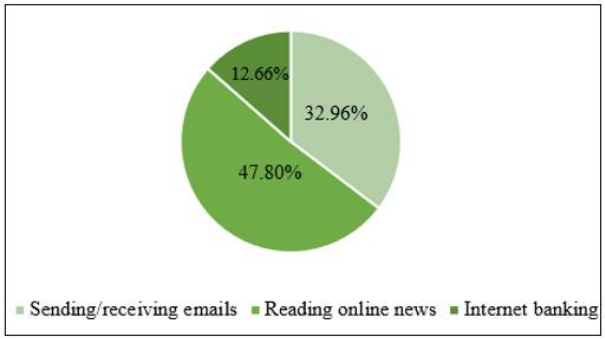


Fig. 5. Individuals (16–74) using the internet for different activities, Romania rural areas, 2023
Source: Eurostat, 2024 [11].

This distribution indicates a predominantly passive, informational use of the internet, content consumption, not an active or skills-oriented use, such as online learning, content creation, or the use of more complex digital services. In relation to the article's topic, such a profile can function as an indirect indicator that the digital environment is used mainly for everyday information, not for activities that might broaden the experiential horizon, for example guided cultural exploration, or support the accumulation of transferable skills. Therefore, the assisted VR intervention is relevant not only as a complementary option to tourism experiences that are otherwise difficult to access, but also as a mechanism for moving from simple digital consumption to richer, supported, and formative forms of use.

Another factor supporting the relevance of the assisted VR model is Romania's position in Eurostat statistics on tourism participation, tourism propensity, defined as the share of the population aged 15 and over who undertook at least one personal tourism trip with at least one

overnight stay in a given reference year (Eurostat, 2025). In 2024, the tourism participation rate at EU level was approximately 65%. Romania, however, sits at the lower end of the distribution, with 28% of the population participating in tourism, compared with values above 80% in countries such as the Netherlands (Eurostat, 2025). At the same time, Romania records a very low share of international only participation, foreign only, at around 2.8%, indicating reduced exposure to tourism experiences outside the country (Eurostat, 2025). Participation is dominated by domestic trips, suggesting that cross border mobility remains constrained for a substantial share of the population (Figure 6).

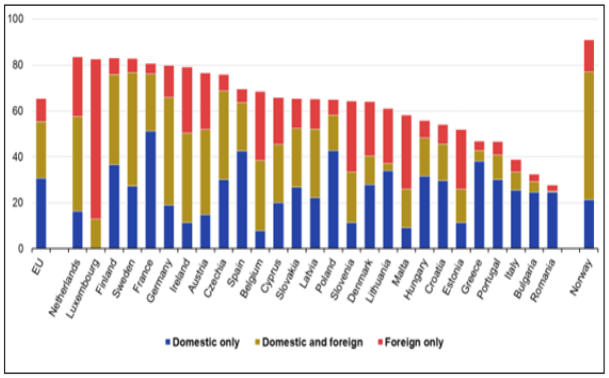


Fig. 6. EU tourism participation rate (15+), domestic vs international, 2024 (%)
Source: Eurostat, 2025 [12].

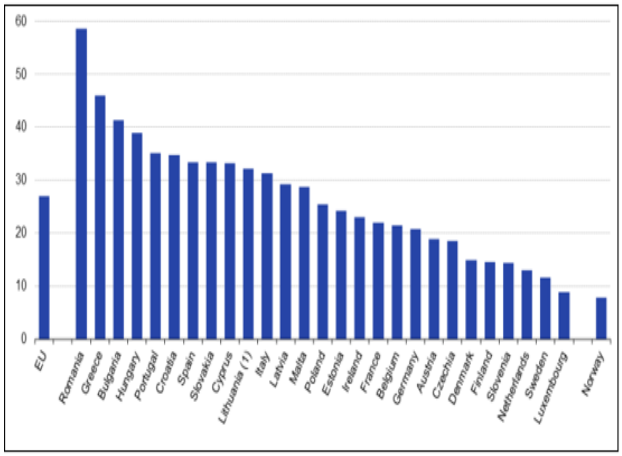


Fig. 7. Share of the EU population unable to afford a one-week annual holiday, 2024 (%)
Source: Eurostat, 2025 [12].

Another indicator related to tourism participation, with direct relevance for interpreting economic barriers, shows that, in 2024, Romania ranked among the highest in the share of people who cannot afford a one-week holiday each year (Eurostat, 2025) (Figure 7).

Although these results (Figures 6 and 7) do not distinguish between urban and rural areas, they highlight Romania's generally low level of tourism participation compared with other EU Member States. Moreover, the association between low tourism participation and financial constraints strengthens the case for complementary solutions with lower costs and greater accessibility.

Implementation architecture for community-based VR infrastructure for rural residents for tourism and educational purposes

For VR to function as a form of 'alternative mobility' to physical tourism among rural residents, implementation should be designed as assisted community access, not as individual acquisition. Even if the cost of VR equipment is, in many cases, on the order of a few hundred euros [23] and is largely incurred at the point of purchase, the technological ecosystem, software, applications, standards, and performance requirements, evolves rapidly, and users may face difficulties in installing, updating, and using content autonomously, including due to recurring costs or limited digital skills. Beyond this consideration, effective VR use requires a period of familiarisation and learning, navigation, interaction, settings, and safety, which makes guidance and facilitation relevant in ensuring that the experience is accessible, safe, and satisfactory. Given that digital skills in rural areas tend to focus on routine mobile phone use and basic applications, such as calls and email [11], and are less developed in relation to immersive applications or technical configurations, the models below are built on a pragmatic rationale.

This rationale aims to reduce per user costs through sharing, expand participation in tourism experiences among residents for whom physical travel remains prohibitive, and embed VR within an institutional setting, a library, a community cultural centre, or a school, so that

use is safe, easy to learn, repeatable, and evaluable.

Model 1: Rural library – "VR corner" (public, scheduled access)

Concept - the establishment of a VR corner within the communal library, offering short, scheduled sessions facilitated by trained staff. The library functions as a neutral and familiar access point for the local community.

Resources (indicative) - initial investment (CAPEX): 1–2 standalone headsets (or 1 headset and a PC), accessories and hygiene consumables, a dedicated space (approximately 2–3 m²), and introductory materials (posters, user instructions). Operational costs (OPEX): maintenance, replacement of consumables, content updates, and facilitator time.

Actors - local municipality (funding and coordination), librarian/facilitator, county library (methodological support), university/NGO (training and evaluation), local private sponsor (co-financing).

Rules of use and inclusion - scheduled bookings (e.g. 15–20 minutes per slot), assisted sessions for older adults, the option of an accompanying person, booking without a smartphone (at the desk or by phone), hygiene protocols and breaks to reduce discomfort. Content can be organised into a thematic catalogue (e.g. virtual tours, museums, heritage, nature), with dedicated packages (such as "Europe in 30 minutes").

Evaluation - number of unique users and return rate, user satisfaction (short questionnaire), incidents (e.g. discomfort or cybersickness), perceived progress in digital skills, and intention for subsequent tourism-related exploration (virtual and/or physical).

Model 2: Cultural centre / community hall – "VR sessions & community events"

Concept - the use of VR as a community event format, through guided thematic sessions, 360° projections (where applicable), and "exploration evenings" (for example, "world museums", "historic cities", "national parks"), complemented by a post-experience discussion component.

Resources (indicative) - initial investment (CAPEX): 2–4 headsets (for rapid rotation) or a combination of headsets and screen/projection (for group use). Operational costs (OPEX): facilitator time, event logistics, hygiene measures, content licences and updates.

Actors - local authority (logistics), cultural centre/community hall (space and organisation), cultural or educational NGO (content curation and selection), DMO/tourism partners (content and supporting materials), private sponsor (equipment).

Rules and inclusion - free-access events or events with a symbolic fee, short time slots (5–10 minutes) to reduce discomfort, adaptations for people with reduced mobility (for example, seated use and assistance), as well as sessions dedicated to families.

Evaluation - event attendance, qualitative feedback, user profiles (age, digital experience), perceptions of cultural access, and the identification of relevant themes for future sessions.

Model 3: Digital hub in school / after-school – "VR for tourism & career inspiration"

Concept - integrating VR into educational and guidance activities, for example in geography, history, and heritage, complemented by career inspiration modules (virtual visits to modern farms, exhibitions, factories, universities, or laboratories), with the aim of broadening students' range of options and their aspirational horizon.

Resources (indicative) - initial investment (CAPEX): 2–3 headsets and storage and management infrastructure, within an appropriate and safe space. Operational costs (OPEX): allocated teaching time, IT support, and content updates.

Actors - school (implementation), school inspectorate/local authority (funding), teachers (curricular integration), NGO/university (training and evaluation), regional economic partners (content for "career tours").

Rules and inclusion - parental consent, short and structured sessions, use in small groups, non-VR alternatives for sensitive students (360° video on screen), and equal access for pupils without digital resources at home.

Evaluation - educational indicators (interest, engagement), digital skills, teacher feedback,

exploration intentions (real-world and/or online visits), and levels of parental acceptance.

These three models are complementary in that the library optimises individual and repeatable access, the cultural centre strengthens the community dimension, and the school prioritises the educational and guidance component. Within this architecture, VR can be operationalised as a local intervention that is governable, measurable, and adaptable, and suitable for pilot testing and gradual scaling.

This article proposes a conceptual repositioning of virtual reality in tourism as an alternative and complementary form of experiential access to tourism-related content, particularly relevant for rural residents facing structural constraints related to cost, digital provision, levels of technological skills, time, and distance.

VR is proposed as a channel for symbolic and educational participation in tourism experiences, insofar as its distinctive mechanisms, particularly the sense of presence and immersion, support the emotional engagement that fosters involvement, exploration, and learning. At the same time, a clear delineation of the limits of substitution remains essential, as VR does not fully replicate the social, sensory, and economic dimensions of on-site tourism, and its utility must be evaluated realistically in relation to the objectives of the intervention and the profile of the users.

From a theoretical perspective, the proposed approach links three strands of literature that are often discussed separately: (a) the mechanisms of VR experience in tourism, through a sense of presence, engagement, and the shaping of preferences and intentions [33, 21, 28], (b) participation constraints and the equity dimension of access [22], and (c) digital inequality, which highlights that technical access is not sufficient for inclusion [35]. The contribution lies in articulating these elements into a conceptual intervention model. In rural communities, the issue is not typically a lack of information about tourism destinations, since a mobile phone provides rapid access to basic information and simple online searches, but rather that interest often remains at the level of intention and does not translate into actual tourism participation, due to budget pressures and, implicitly, the costs associated with physical mobility. In this sense, VR may function as a mechanism for reducing certain structural constraints, yet its effectiveness depends on how the intervention is designed to ensure functional access and effective use, not merely technological availability through, for example, providing a computer via a social programme.

An important outcome of the discussion is that the feasibility of VR as an access tool in rural areas depends less on the technology's notional availability and more on the institutional design of implementation. The assumption of widespread at-home VR use is unlikely in circumstances where digital skills are often restricted to basic uses, and where costs and maintenance requirements can create recurring friction. Consequently, the recommended model, namely assisted community access, reframes the issue as a governable form of local infrastructure, supported by rules, facilitation, and indicators. The public library, the community cultural centre, and the school were not selected arbitrarily, as they are institutions with already legitimate public functions in information provision, learning, and culture. They can simultaneously reduce the cost per user, the skills barrier, and usage risks (hygiene, safety, cybersickness) through the involvement of multiple decision-makers at political and social levels. Moreover, this architecture could enable a shift from an occasional intervention to one that is repeatable and evaluable, which is a minimum condition for formulating and sustaining public policy. In policy terms, the three proposed models suggest that VR can be treated as a low-risk, low-threshold local intervention aimed at expanding access to mediated cultural and tourism experiences, provided that inclusion mechanisms are explicitly built in, such as booking without a smartphone, assisted sessions, and non-VR alternatives. They also require risk management measures, including short session durations, breaks, the selection of low-motion content, and hygiene protocols, as

well as a minimal governance framework that clarifies responsibilities, maintenance, updates, and data protection, including for minors. In particular, the educational component serves a dual function, since, on the one hand, VR can support learning by providing an interactive and dynamic space for presenting information, and, on the other hand, it can generate cultural exposure and horizons of exploration that would otherwise remain inaccessible. In rural areas, this dimension could go beyond cultural valorisation and influence aspirations, reference repertoires, and digital literacy. The discussion must, nevertheless, remain attentive to at least two risks. The first is the risk of reproducing digital exclusion, since, if access to VR is configured without facilitation, without adaptations for vulnerable users, and without alternatives, the intervention may primarily benefit those who are already digitally literate. The second is the risk of technological reductionism, whereby VR is presented as a sufficient response to structural inequalities, even though it does not directly alter the material conditions that sustain them, such as income levels, recurring costs, and access to mobility. VR may broaden horizons and support mediated participation in tourism, but it cannot replace measures or policies that reduce economic and infrastructural barriers. For this reason, VR should be positioned as a complementary instrument within a portfolio of cultural, educational, and social measures, instead of a stand-alone intervention. This study has limitations inherent to its design. As a conceptual study based on secondary data, it cannot estimate causal effects, nor can it empirically validate acceptance, actual use, or the cost-effectiveness of the proposed models. The resources required to implement such a programme or policy are presented in indicative terms, and the proposed evaluation indicators remain proxy measures that require Operationalisation and appropriate measurement instruments. Moreover, the analysis of content curation, quality, and local relevance, as well as considerations relating to ethics, data protection, children's safety, and cultural bias, remains at the level of principle and requires further strengthening in subsequent stages.

The research agenda derived from this framework should be applied and phased. A key priority is to run local pilots of the three institutional formats, namely the public library, the community cultural centre, and the school, alongside an evaluation of operational performance using indicators such as unique users, repeat visits, satisfaction, drop-out, cybersickness incidents, and comparisons across facilitation levels, from full guidance to minimal support or on-demand assistance. In parallel, acceptance and usability analyses are needed across age groups, with particular attention to technology anxiety, support needs, and content preferences. For the educational component, pre- and post-intervention effects on curiosity, knowledge, and cultural awareness can be tested. Another strand involves clarifying VR's role as a complementary instrument or, under certain conditions, as a substitute for people facing high levels of constraint, together with cost-effectiveness analyses (CAPEX and OPEX) and the exploration of public–private funding models. Finally, research should incorporate criteria for content selection and validation, as well as ethical guidelines on safety, data protection, and inclusion.

CONCLUSIONS

This article began from a contextual observation. For many rural residents in Romania, access to travel, particularly international travel, is constrained by persistent economic pressures. Official statistics indicate substantial household budget strain, in the sense that routine expenditures absorb a very large share of income. Under these conditions, a plausible hypothesis is that tourism participation occurs rarely, or not at all, largely because there is limited discretionary capacity to cover the costs associated with physical mobility, including forms of tourism linked to recreation and informal learning. Against this background, the central aim of the study was to explore whether VR might offer, at least in part, an alternative form of access to tourism

and cultural experiences, without claiming to replace physical travel. Exposure to different ways of living, practices, and solutions from other regions can provide sources of inspiration and may foster attitudinal change and everyday initiative. The article's main contribution is conceptual and public policy-oriented, as it shifts the discussion from "VR at home" to "VR as assisted community access". Rather than focusing on individual acquisition, it proposes three institutional formats that are straightforward to pilot: the public library, the community cultural centre, and the school. These formats can reduce the cost per user, lower the digital skills barrier through facilitation, and manage risks such as hygiene, safety, and cybersickness. At the same time, the article delineates the limits of VR. It may support mediated participation and learning, but it does not automatically increase incomes or remove the material barriers to physical mobility, which is why it should be treated as a complementary instrument, as opposed to a stand-alone solution. In closing, the article outlines a direction for applied research centred on local pilots, so that the conceptual model can become a practical starting point for realistic interventions, calibrated to the needs and resources of rural communities.

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CLIMATOTHERAPY TOURISM DEVELOPMENT PROSPECTS IN RURAL REGIONS: THE BULGARIAN CASE STUDY

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Abstract

The tourism industry forms a big part of the world Gross Domestic Product and is an important industry in terms of employment giving livelihood to more than 357 million people worldwide. Health tourism is one of the fastest growing parts of the tourism industry which indicates the global health tourism market at $24.1bn in 2023 and annual increase worldwide to reach 17% till 2030, according to PwC. Health tourism is one of the prioritized forms of tourism in Bulgaria according to the National Strategy for sustainable development of tourism in Bulgaria, 2014-2030. One of the forms of health tourism, which has great traditions in Bulgaria, is climatotherapy tourism. This type of tourism has multidisciplinary nature and is also connected with use not only of the atmosphere conditions of the region, but also of all natural resources of the place – mineral water, healing mud, solar conditions etc. Therefore, the main purpose of the current article is to investigate climatotherapy tourism development perspectives in Bulgarian rural regions taking into consideration the southern Bulgarian Black Sea coast. Within the current study a specific questionnaire is designed to reveal the opinion about climatotherapy tourism prospects from the main stakeholder's point of view: business entrepreneurs, representatives of municipalities and the local communities. The main results show that climatotherapy tourism has highly positive development perspectives, but most importantly it has a great potential to improve livelihood and local community well-being in rural regions. Though, national strategic approach, local government support and specifically qualified employees are also needed in terms of climatotherapy positive development perspectives.

Key words**:** *climatotherapy tourism, health tourism, rural tourism, rural regions, Bulgarian Black Sea coast.*

INTRODUCTION

Health tourism is one of the promising types of tourism in terms of sustainable growth rate in its development in recent years. According to global data, global health tourism market generated $24.1bn in 2023 and the annual increase rate worldwide is predicted to reach 17% till 2030. The annual growth in recent years is between 10% and 12% based on the number of visitors for the purpose of health tourism [10], and within the EU the growth on the same indicator on an annual basis varies between 12% and 15% [21]. Health tourism manifests itself in various subtypes and forms, the most frequently affected being medical, SPA and wellness tourism and climatotherapy tourism. One of the oldest historically specialized types of tourism within health tourism is climatotherapy [2]. Information about its practice has existed since 3 thousand BC during the development of Ayurvedic medicine. In Bulgaria there is also information about the active practice of climatotherapy tourism since the 50s of the 20th century, when Bulgarian doctors used climatotherapy for medical purposes [31]. In terms of domestic tourism, climatotherapy tourism was used long before this for medical and health purposes, mainly for respiratory problems prevention. Climatotherapy tourism is not based solely on the so-called aerotherapy, based on the specific chemical composition of the air, but is a much more complex type of tourism. It also includes the use of all climatic features of the tourist area, including natural ones such as healing mineral springs, healing mud, etc., which emphasizes its broad scope. There are nearly 90 certified climatic resorts in Bulgaria, the majority of which are located in rural and ecologically clean regions. Given the complex economic situation and the provision of

livelihoods for the local community in these regions, the development of climatotherapy tourism could have a beneficial effect on rural regions and communities in Bulgaria [26]. Therefore, the main research objective of this article is to examine the assessment of stakeholders towards the opportunities for climatotherapy tourism development in rural regions, on the basis of which to assess the prospects for the development of this specialized type of health tourism.

Literature review

Climatotherapy is one of the oldest and time-proven ways to treat various diseases through climatic and natural conditions.

Table 1. Chronology of research on climatotherapy tourism

Terms	Study contribution
1970s (Besancenot et al., 1978 [4]; Crowe et al., 1977 [6]; Danilova, 1974 [7])	Climate impact on economic sectors with a focus on tourism.
1980s (McBoyl et al., 1987 [17]; Mieczkowski, 1985 [18])	Decline in research activity and interest in climatotherapy tourism.
1990s (Wall et al., 1996 [29]; Harrison et al.; 1998 [11])	Renewed interest in climate tourism as a result of global climate change.
1999 Commission on Climate, Tourism and Recreation [5]	Establishment of the first specialized international research group in the field of tourism climatology with annual international conferences since 2003.
21st century to present	A multidisciplinary approach to understanding the relationship between climate and tourism. Observing, studying and monitoring the two-way relationship between climate and tourism. Improving services in climate tourism and helping local communities to benefit from climatotherapy integration.

Source: Created by the author.

Information about this healing method of influencing the body has been available since the time of Hippocrates, who believed that diseases occur when the so-called homeostasis is disturbed - the balance between several fluids, and this can be corrected by another fluid such as water, for example [8].

Over time, climatotherapy and climatotherapy tourism have been studied by various specialists and scientific organizations, with studies aimed at improving knowledge about climatotherapy tourism and promoting the positive effects of its practice [20]. Specialized studies date back to the 1970s and have developed significantly in scope and focus over the years.

Table 1 presents a short synthesis regarding the chronology of the research literature in teh field of climatotherapy tourism.

Climatotherapy tourism is based on the use of the healing effect of the climate in a given region. The components of the local climate that are important are: *temperature, sunlight, wind, humidity, infrared* and *ultraviolet radiation* [23] According to their specific combination, they can have a beneficial effect on the body and counteract various diseases. [19].

Regarding the positioning of this specialized type of tourism, there are two main opinions.

- *Climatotherapy tourism is part of health tourism*, where together with balneological tourism, both types of factors are used for the healing effect of the body - treatment with mineral waters is complemented by the beneficial effects of the local climate [32].
- Climatotherapy tourism is a subtype of medical tourism based on thermal treatment (a method that uses the benefits of heat for the human body), the latter being divided into: hydrotherapy, climatotherapy, heliotherapy, aerotherapy, thalassotherapy, aromatherapy [22].

According to the choice of an area with a favorable climate for practicing climate-therapeutic tourism, the so-called climatotherapy resorts are distinguished, and they are zoned into four main types:

-areas along the coast, where the focus of climate treatment is thalassotherapy;

-areas around thermal springs, where the focus of climate treatment is balneotherapy;

-mountain areas in windless areas, where treatment is practiced at high altitude;
-areas with a favorable climate, where the focus is the complex healing effect of the climate [13].
Bulgaria has an environment conducive to the development of health tourism, respectively climatotherapy tourism as a subtype of health tourism.
There is a diversity of thermal mineral waters and mud healing deposits, a temperate continental climate with four seasons, marine and mountainous natural features, and the country is among the leaders in such natural tourist resources in Europe [12].
In relation to the prospects for the development of this type of tourism in the EU, health and medical tourism is the sector that is developing in the world during the crisis with a growth of 10-12% per year and the trend is sustainable [16].
In addition, the aging population in the EU from a demographic point of view has a growing need for medical services, with Italy, Greece and Germany among the leading countries in this indicator with the highest percentage of the population over 60 years of age [15]. This information explains the decision of the Bulgarian authorities to indicate health tourism as one of the priority types of tourism in the Strategy for Sustainable Development of Tourism in Bulgaria 2014-2030 [27].
Climatotherapy tourism as a subtype of health tourism has a long tradition of practice in Bulgaria. According to specialists in this field, Bulgarian dermatologists were among the first to use climate treatment to alleviate the condition of patients with psoriasis – the beginning dates back to the 1950s in our *coastal regions* [14].
According to official Bulgarian documents, the country has 89 climatotherapy resorts in total – 55 climatotherapy mountain resorts and 34 climatotherapy sea resorts [24].
In relation to the latter, the main competitive advantages are the unique climatic conditions and the diversity of mineral water in terms of chemical composition, temperature and properties, which makes its impact wide-ranging.
Climatic treatment areas in Bulgaria are concentrated mainly on the Black Sea coast and in the mountain resorts of the Rhodopes, Rila and Pirin.
Among the leading climatic resorts are Tuzla (the sun and sea water, as well as a mineral spring with water suitable for people with psoriasis; there is a mud bath, as well as estuary water), Balchik (sea water is particularly suitable for the treatment of psoriasis and atopic dermatitis), Belmeken (the mountain is a very good place for people with allergic dermatitis).
Sea climatotherapy tourism is based on aerotherapy and thalassotherapy, originating from the therapeutic use of sea water, sea products such as algae and sea mud, and the sea climate for a healing effect [30].
The name comes from the Greek words thalassa ("sea") and therapia ("treatment"), created by the Frenchman Dr. Jacques de la Bonnardière in the 1960s. [9].
The basic principle of thalassotherapy is the similarity between sea water and human plasma in terms of mineral content. Immersion in sea water, application of sea mud and residence in marine climate zones helps the body absorb important trace elements such as magnesium, potassium, calcium, sodium and iodide through the skin and respiratory tract.
The results are aimed at skin diseases, arthritis, arthrosis, rheumatism, chronic lung and allergic diseases, psoriasis, etc.
There is also information about the beneficial effect of thalassotherapy in depression, stress and mental fatigue [25].
The main resorts for sea climatotherapy tourism are Varna, Golden Sands, St. St. Constantine and Elena and Albena, where sea aerotherapy, thalassotherapy and balneotherapy are combined.
In Nessebar, Sozopol and Balchik, sea *climatotherapy tourism is combined with rural and cultural tourism.* Medical and health centers that apply sea climatotherapy tourism are located in the resorts of St. St. Constantine and Elena, Riviera, Golden Sands and Albena.

Bulgaria has a total of 34 climatotherapy sea resorts, 18 of which are of national importance [24], as shown in Table 2.

Table 2. Climatotherapy sea resorts of national importance in Bulgaria

Climatotherapy seaside resort	Year
Albena	2005
Ahtopol	1972
Balchik	1957
Burgas	1953
Varna	1950
Dyuni	2005
Golden sands	2005
Kiten	1967
Nessebar	1954
Obzor	1967
Pomorie	1953
Primorsko	1967
St. St. Constantine and Elena	2005
Sunny beach	2005
Sozopol	1967
Tuzla	1965
Tsarevo	1967

Source: Created by the author.

Mountain climatotherapy tourism is based on intense UV radiation, a large amount of negative air ions, lower temperatures, reduced atmospheric pressure, which has a pronounced tonic and healing effect [3]. Climatotherapy can be practiced in all four zones of the mountain areas - high mountain, mid-mountain, transitional zone and low mountain zone, which helps for sustainable use of the natural resources. [1] The transitional zone is most used for these purposes, since the environment has milder conditions than those in the high mountain and mid-mountain zones, but with more pronounced healing properties than the low mountain zone. The results of climatotherapy in mountain areas are aimed at chronic bronchitis, bronchial asthma, lung diseases, endocrine diseases, obesity, cardiovascular diseases, skin diseases such as neurodermatitis, chronic urticaria, etc. The specific feature of climatotherapy tourism in mountain areas is the application of a terrain approach – moderate movement in the natural environment combined with strictly dosed climbs on mountain trails with different slopes [16]. Very often, mountain climatotherapy tourism is combined with practicing outdoor sports, hiking routes, as well as *rural, cultural* and *educational tourism* during the favorable months of the year.

Recognized mountain climatotherapy resorts of national importance are the Borovets resort, the town of Kotel, the Pamporovo resort and the Yundola village, Velingrad municipality. [28] Bulgaria has a total of 55 climatotherapy mountain resorts, only five of which are of national importance [24].

Table 3. Climatotherapy mountain resorts of national importance in Bulgaria

Climatotherapy mountain resort	Year
Borovets	2005
Samokov	1967
Kotel	1967
Pamporovo	1967
Yundola	1967

Source: Created by the author.

MATERIALS AND METHODS

After making a literature review of the topic we can conclude that the climatotherapy tourism development in Bulgaria has established traditions and is based on objective climatic conditions of the country. The research **methodology** in this paper is based on the following scientific research tasks:

- *Questionnaire development for investigation* of the perspectives for climatotherapy tourism development in Bulgaria.
- *Database creation* for quantitative processing of information.
- *Results analysis* in order to reveal the respondent's evaluation of climatotherapy tourism development prospects in Bulgaria.
- *Results* d*iscussion* to highlight key conclusions and provide guidelines for the future successful climatotherapy tourism development in Bulgaria.

The subject of this study is the climatotherapy tourism development prospects in rural regions.

The **object of the study** is the climatotherapy tourism on the southern Bulgarian Black Sea coast, where 11 from the 18 climatotherapy sea resorts of national importance in Bulgaria are located.

The **purpose of this research** is based on empirical study to investigate the climatotherapy tourism development prospects in Bulgarian rural regions.

The **scientific methods** used in this study can be grouped as observation, analysis and synthesis, questionnaire survey, comparative analysis, descriptive and discriminative statistical methods.

The **questionnaire** as a research tool is conducted based on an online survey. The respondents are targeted as climatotherapy tourism development stakeholders – business entrepreneurs in the tourism industry, representatives of municipalities located on the Bulgarian Black Sea coast and the local communities. The time period of the online questionnaire was set from 14.07.2025 till 15.09.2025. The digital platform instrument for the research purpose is collected to be Google Forms.

The current paper has some research limitations as follows:

- *Geographical scope* – the respondents are located on the Bulgarian Black Sea coast giving their opinion about climatotherapy tourism development prospects considering their business, municipality and/or local community.
- *National scope* – the current investigation involves only Bulgarian representatives of the business entrepreneurs and local communities on the Bulgarian Black Sea coast.
- *Time scope* – the study is conducted from 14.07.2025 till 15.09.2025 considering the seasonal tourism activities on the Bulgarian Black Sea coast.

The process of **collecting the empirical data** was structured in **3 phases**.

In the first one the questionnaire was designed in Google Forms as an anonymous targeted study. The survey consists of 7 closed-ended questions with predetermined answer choices. By 3 of them an open-ended option is also included in order to give the respondents the possibility to add personal opinion. The further structure of the survey questions is 4 choices of given options and 3 multiple choice questions. The topics of the questionnaire cover as follows: climatotherapy tourism potential in Bulgaria and in rural regions, climatotherapy tourism obstacles and favoring factors, positive and negative impact of the climatotherapy tourism, perspectives for climatotherapy tourism development in rural regions.

In the second phase of the empirical study the questionnaires were distributed to targeted respondents on a multi-channel' basis using:

- Official contact persons from the six municipalities located on the southern Bulgarian Black Sea coast – *Nessebar, Pomorie, Burgas, Sozopol, Primorsko, Tzarevo*.
- Official contact persons of business entrepreneurs, published in the official digital tourist platforms of the mentioned six municipalities.
- Representatives of the local communities through the official municipality pages in social media Face Book and tourism related non-profit organizations to their members.

In the third phase the collected data was distributed and aggregated for the statistical analysis purpose. Tables and figures were designed for the purpose of visualizing the processed data.

RESULTS AND DISCUSSIONS

After conducting the survey, it was found that for the purposes of the study, the questionnaires of 196 respondents can be used. The respondents' opinion about the climatotherapy tourism potential to attract more tourists to Bulgaria shows a highly positive attitude (Figure 1).

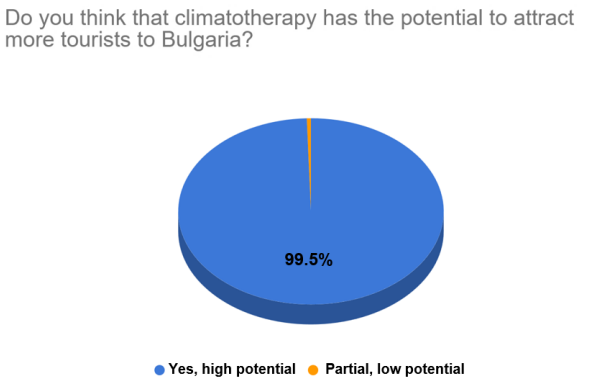


Fig. 1. Survey respondents' structure in terms of climatotherapy tourism development potential in Bulgaria.
Source: Created by the author.

More than 99% of the research respondents testify that this type of specialized form of tourism has great potential in Bulgaria in order higher tourists flow to the country.

Only one person from the 196 survey participants believes that the potential is only partial and none of the respondents believes that climatotherapy tourism has no actual potential in Bulgaria in order to attract more tourists to the country (Figure 1).

The climatotherapy tourism has established roots in Bulgaria dating back from the 60's of the 20th century, which can be seen from the previous paragraph' investigation. Taking into consideration that currently this form of tourism is no longer highlighted in Bulgaria's tourism portfolio, the next question aims to reveal the existing obstacles to climatotherapy tourism development in the country. The greatest share of the survey respondents thinks that there is a low awareness among the domestic and incoming international tourists. Major share of the respondents believe that obstacles can be seen also in the lack of qualified employees and the insufficient tourism infrastructure for this type of specialized tourism. There is also a notable share from the survey participants that believe there's poor regulatory framework and this hinders the climatotherapy tourism development in Bulgaria (Figure 2).

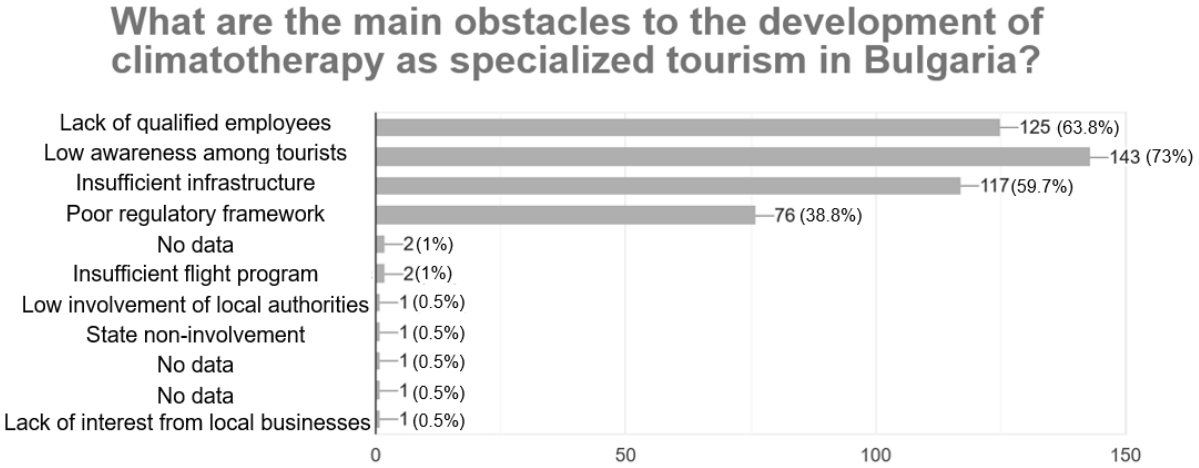


Fig. 2. Survey respondents' opinion about main obstacles to the climatotherapy tourism development in Bulgaria.
Source: Created by the author.

More importantly for the current study, the respondent's opinion about the climatotherapy tourism development prospects in the Bulgarian rural areas is also very positive. The majority of survey respondents (nearly 94%) strongly agree with the statement that climatotherapy tourism is applicable in the Bulgarian rural areas and has good development perspectives.

The other 6.1% of the respondents cannot give a clear opinion, which is also indicative in terms no negative perspectives about climatotherapy tourism application in the Bulgarian rural areas can be predicted (Fig. 3).

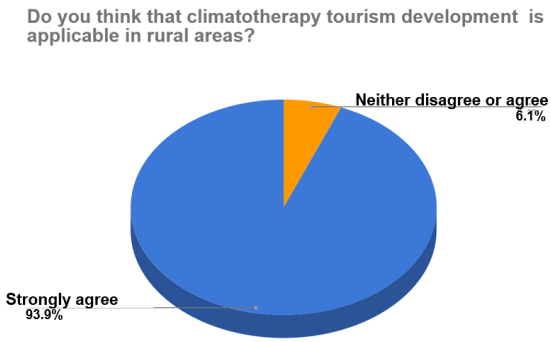


Fig. 3. Survey respondents' structure in terms of climatotherapy tourism application possibilities in the Bulgarian rural areas.
Source: Created by the author.

Notably, in relation to the positive respondents attitude, the participants' willingness of involvement in climatotherapy development

can be defined as remarkable. Obviously, the greatest share of the survey respondents are business entrepreneurs – almost 59% of the questionnaire participants. They demonstrate positive willingness to actively develop and/ or integrate climatotherapy tourism in their product list. More than a quarter (27%) witness they would be supporting climatotherapy tourism in rural areas as an active local community. Nearly 14% of the survey respondents show their advocacy for this statement as a supporting local authority (Figure 4).

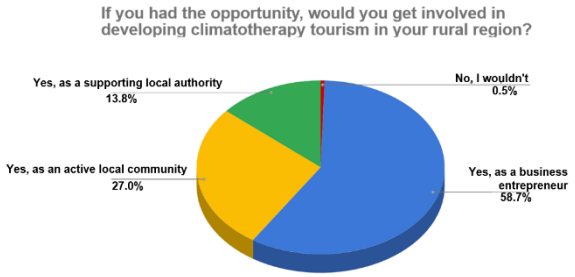


Fig. 4. Respondents' opinion in terms of willingness for climatotherapy rural tourism participation.
Source: Created by the author.

The reasons for supporting the climatotherapy tourism development in rural areas can be variable, but for the purpose of this study they are grouped as social and/or economic benefits. Comparing both groups, the better acceptance can be found in the economic benefits (nearly 21% compared to only 2% for social benefits). Though, the greatest share of the survey respondents see synergistic effect of climatotherapy tourism development in rural areas – 77% from the questionnaire participants believe it has both, social and economic benefits (Fig. 5).

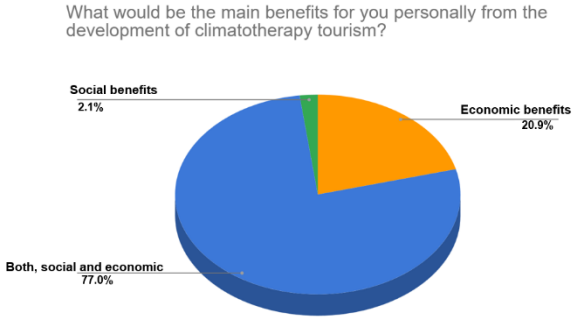


Fig. 5. Survey respondents' structure in terms of climatotherapy tourism benefits perception.
Source: Created by the author.

Giving a more precise definition about climatotherapy tourism development potential for improving rural region life and wellbeing, the next question gives insights in this field. Nearly 71% of the survey respondents believe that this form of tourism development would significantly improve the economic well-being of rural regions' people. Almost equally, respectively 64,8% and 63,8%, think that climatotherapy tourism development will expand their social contacts and improve the local community well-being. More than 45% of the questionnaire participants see the climatotherapy tourism development as a perspective for cultural prosperity. There are quite a few who believe that this form of tourism would help improve biodiversity conservation in rural regions (Fig. 6).

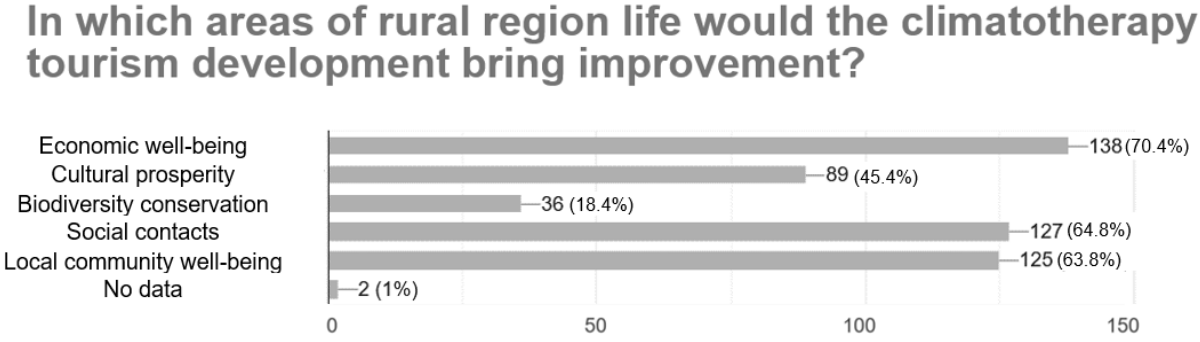


Fig. 6. Respondents' opinion in terms of willingness for climatotherapy rural tourism participation.
Source: Created by the author.

The climatotherapy tourism development prospects can be generally defined as positive. Only one person thinks there are no successful development perspectives. The majority of the survey respondents see the future focus of this form of tourism on health and prevention – respectively 71.4% and 70.9% of the questionnaire participants. A great share of the survey respondents believes there is definitely a successful development prospect, but they focus the perspectives on the local community (66.8%) and the opportunity for an active participation of local people in the successful climatotherapy tourism development. Another significant share of the questionnaire participants (62.8%) sees climatotherapy tourism as successful in the meaning of an alternative of mass tourism and as a possibility for refocusing Bulgaria's profile as a tourist destination into new niche tourism types of activities and forms of tourism (Fig. 7).

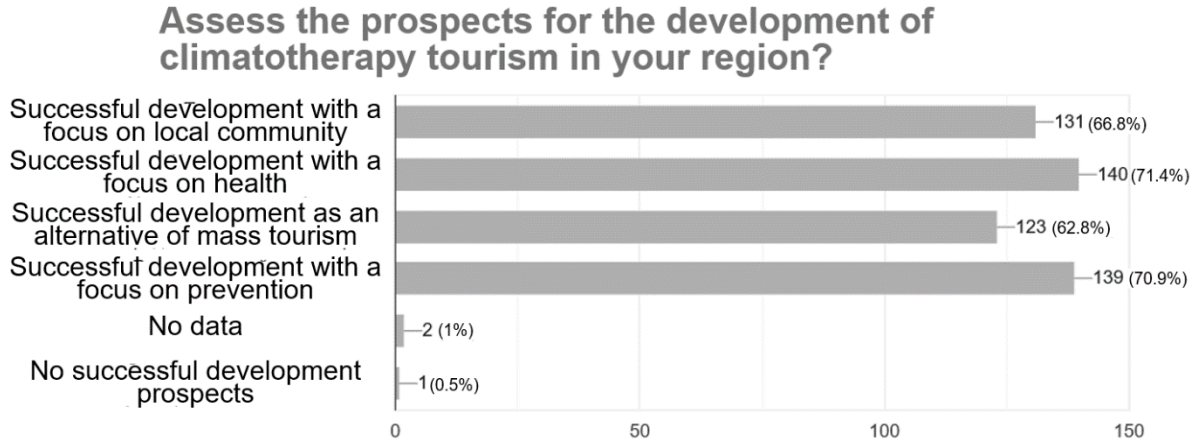


Fig. 7. Respondents' opinion about climatotherapy development prospects in rural regions.
Source: Created by the author.

CONCLUSIONS

After the conducted study among stakeholders in terms of climatotherapy development perspectives in the Bulgarian rural regions the following conclusions can be highlighted as most important:

- The potential of climatotherapy tourism to attract more tourists to Bulgaria can be generally assessed as highly positive. Taking in consideration that more than 99% of the respondents testify their positive opinion, it can be acknowledged that this type of specialized tourism has great potential in Bulgaria in general. This statement can be directed to both – domestic and international tourist flows.
- It is notable that the climatotherapy tourism has established practices in Bulgaria dating back from the 60's of the 20th century, but nowadays this form of tourism is no longer actively used in the country's tourism portfolio. According to the perceived climatotherapy development obstacles, the main barriers can be found in the low awareness among domestic and incoming international tourists. Therefore, it can be recommended that an information campaign should be conducted in order to advertise the positive aspects of climatotherapy tourism for the tourists. Further, the information can be also directed to other stakeholders as tourist companies, local communities and business.
- Additionally, a notable share of the respondents believes that obstacles for the climatotherapy tourism development can be found also in the lack of qualified employees, the insufficient specialized for climatotherapy infrastructure and in the relatively poor regulatory framework towards climatotherapy tourism development in Bulgaria. Therefore, it is advisable for national and local governments to support: specialized educational courses for employee qualification in the field of climatotherapy; needed infrastructure for

climatotherapy development such as climatotherapy routes, eco-trails etc.; development of legal framework for climatotherapy within the Tourism law in Bulgaria.

- Importantly, the perception of the respondent in terms of climatotherapy tourism development in rural regions is highly positive (nearly 94%) with also no survey participant to disagree with this statement. This result emphasizes the promising perspectives for climatotherapy tourism development in rural regions from the stakeholder's point of view and forms a solid basis for further integration in the existing local initiatives in the Bulgarian rural regions.
- Not surprisingly, most of the respondents demonstrate willingness for active participation in the climatotherapy development in their local rural area. A significant part stated that they would initiate a startup in the field of climatotherapy tourism, which demonstrates a good foundation in terms of specific local tourist products and services supply. The willingness of the local community to support climatotherapy development is also significant. Both statements guarantee a favourable business environment for climatotherapy tourism development in rural regions.
- It is notable that more than three quarters of the respondents see multiple benefits from climatotherapy tourism development – both social and economic. This states the ability of climatotherapy tourism to generate various benefits for the participants in the process and suggests wealth and social improvement for rural regions living. This also adds more value into the positive climatotherapy tourism development perspectives.
- More precisely, most of the respondents believe that climatotherapy tourism would improve mostly their economic well-being, social and cultural life and the rural local community well-being in general. This certifies the multiple positive influence of climatotherapy tourism activities in rural regions, which leads us to the conclusion that there are definitive positive prospects for climatotherapy tourism development in Bulgarian rural regions.
- In terms of development perspectives, the climatotherapy tourism in rural regions has distinct positive prospects in Bulgaria. It is remarkable that despite the economic and social benefits from the stakeholder's point of view, the main focus of this specialized type of tourism can be seen in health and prevention. This highlights the public importance of climatotherapy tourism as part of health tourism and public health.
- On the other hand, a high share of positive statements among respondents are reported also in terms of positive development prospects with a focus on local community well-being and as an effective alternative of mass tourism. It is a widely accepted statement, that the alternative tourism forms are more economic and social effective than the mass form of tourism. This leads us to the conclusion that climatotherapy development perspectives in the Bulgarian rural regions are not only positive but the perceived benefits from the stakeholder's point of view exceed the conventional development directions focusing on more society, health and economic based ones.

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IMPACT OF CLIMATE CHANGE ON RURAL DEVELOPMENT IN BULGARIA

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Abstract

This study aims to examine the impact of climate change on rural development in Bulgaria. This goal raised a series of questions related to identifying the main problems for increasing agricultural productivity, opportunities for resource allocation, and the socio-economic stability of rural areas and the country. The quantitative data collected from climate models has been analysed in relation to changes in agricultural yields. As a result, recommendations have been made for policy development and measures to address climate change. This study focuses on assessing the impact of climate change on the development of rural areas in Bulgaria. The results indicate that a significant decline in agricultural productivity is likely. The primary reasons for this decline are connected to the observed trend of rising temperatures and variable precipitation patterns. The increased vulnerability of rural areas in the country leads to changes in resource distribution, exacerbating socio-economic inequalities. The conclusion is that the country needs to develop adaptive strategies to mitigate the adverse effects of climate change, particularly with regard to creating conditions to ensure the livelihoods of the population in rural areas. In this regard, the development of sustainable practices requires cross-sectoral cooperation. Its use can create opportunities to increase sustainability in rural development. On the other hand, it will create opportunities to improve the overall well-being of the population.

Key words**:** *rural development, climate change, adaptive strategies, social and economic inequalities*

INTRODUCTION

Climate change is one of the most significant challenges facing modern society, as its impact is felt in all areas of economic and social life in every region of the world [11]. It is worth noting that rural areas are highly dependent on natural conditions and resources, and are therefore particularly vulnerable to these changes. Bulgaria is located in a region that is considered highly sensitive to climate change. The country faces the need not only to comprehend and understand, but also to adapt to new realities. Climate change poses a serious challenge to the development of rural areas in the country. Rising temperatures and changes in the intensity and timing of rainfall are threatening agricultural practices, which in turn will increase the risks of reduced productivity and food security for the rural population in the long term [7]. Furthermore, it is essential to note that climate phenomena impact all sectors of the country's economy. The current adaptation strategy involves the use of integrated approaches and resources to address vulnerabilities and promote sustainable development in the country [25, 17]. Climate change represents comprehensive changes in climatic conditions and is mainly the result of human activity and industrialization, directly affecting ecosystems and economic activities in rural areas. The results of climate change also include social, economic and environmental factors, which in turn affect the behavioral and adaptation mechanisms of the population and infrastructure. The Bulgarian economy is expected to grow 1.3 times by 2050, or an average annual growth of about 1.7 per cent, while with a temperature change of 2°C (optimistic) and 4°C (pessimistic) for Bulgaria by 2050. The loss in real GDP growth in 2050 is estimated at around 1 per cent in the optimistic scenario and 3.5 per cent in the pessimistic climate scenario. In other words, the projected annual GDP growth rate of

around 1.7 per cent by 2050 will be completely wiped out if Bulgaria faces the full impact of a 2°C temperature increase by 2050. [17]. These data clearly confirm the need to plan and take measures to adapt to climate change and its expected consequences. In agriculture, climate change is reflected in rising temperatures, leading to a decline in water resources, an increase in pests and diseases, and changes in precipitation patterns, which primarily put agricultural productivity at risk. These variables create complex challenges for the sustainable development of rural areas in Bulgaria, further emphasising the need for planning and implementing innovative approaches and policies.

Climate change exerts both economic and social impacts on the development of rural communities, not only within Bulgaria but also across all affected regions. The primary challenges to rural development encompass, on one hand, the decline in agricultural productivity and the increased risks to existing ecosystems. According to the World Bank, climate change has adversely affected the agricultural sector in Europe, rendering rural areas highly vulnerable, given that their economic development is directly linked to agriculture and the state of natural resources[22]. Addressing these challenges necessitates increased investment in sustainable agricultural development. Furthermore, given the reduction in water resources, the implementation of appropriate water management practices is imperative. A significant issue faced by farmers is limited access to financial resources and the difficulties associated with adopting modern technologies. The paramount goal for agricultural development in the country should be the strategic formulation of adaptation plans targeting vulnerable agricultural communities. The impacts of climate change are exerting considerable pressure on farmers and the agricultural sector. In recent years, the country has experienced an increase in the frequency of prolonged droughts and floods. The occurrence of these events affects agricultural productivity across various regions and simultaneously jeopardises the food security of rural populations, for whom agriculture constitutes the primary livelihood. An issue of concern for Bulgaria is that a substantial proportion of the inhabitants of rural municipalities depend on the agricultural products they produce themselves to supplement their dietary needs, as many live close to the poverty line, which for 2025 is set at BGN 638.

The observed image in rural areas of the country indicates the necessity of developing and implementing appropriate adaptation strategies. Such strategies should consider local conditions and specificities while also fostering the creation of conditions conducive to the implementation of effective management practices aimed at reducing vulnerability to climate change and enhancing economic sustainability across various regions. Climate change significantly influences employment opportunities in Bulgarian villages, particularly within the agricultural sector, which remains the primary income source for numerous households. The escalating adverse effects of climate change, including frequent droughts and floods, will not only constrain employment prospects in agriculture but also precipitate deeper social and economic issues, notably an increase in poverty levels. Furthermore, climate change is expected to continue exerting a substantial impact on the development of local markets and trade within Bulgaria. Variations in temperature and precipitation induce instability in crop production, ultimately affecting price dynamics in local agricultural markets. The ongoing transition toward sustainable practices is motivated by the anticipated effects of climate change on agriculture. Consequently, numerous innovations must be implemented in agricultural production, and the current infrastructure must be enhanced to preserve existing commercial opportunities. This requires that the adaptation process to climate change fully integrates the development of local economies with the aim of establishing sustainability within the framework of climate change mitigation. Therefore, coordinated actions involving both government entities and the private sector should be planned and executed to achieve sustainable development

and effectively respond to the socio-economic challenges posed by climate change.

MATERIALS AND METHODS

The research methodology is dictated by the subject matter of this study, namely rural areas and the manner in which they are influenced by climate change. A total of 215 municipalities in Bulgaria are classified as rural, specifically those lacking settlements with populations exceeding 15,000. Furthermore, rural municipalities contend with numerous challenges, including depopulation and aging populations. Demographic issues considerably impede the economic and social development of these areas. Rural development processes exert both positive and negative impacts on regions affected by climate change. This underscores the importance of establishing that rural areas possess unique frameworks that define their characteristics and developmental potentials, which must be identified and understood. Many studies on rural development [12, 1, 3, 5, 17, 16, 8, 26, 25, 10, 14, 23] tend to focus on isolated processes or phenomena, but a comprehensive analysis-including the impact of climate change-can offer a more complete perspective. Such an approach mandates institutional regulation and the development of relevant indicators to assess the current condition of rural areas, including metrics reflecting climate change effects. Only through this comprehensive evaluation can a realistic understanding of the agricultural sector's state be achieved, by analyzing multiple indicators influencing sectoral and rural development. Accordingly, the authors propose to investigate the vulnerabilities and opportunities related to disaster and catastrophe prevention in rural areas affected by climate change. Based on this, they will assess the administrative potential and capacity for risk management within these regions. Analyzing administrative capacity can reveal the current state and developmental trajectory of rural areas in Bulgaria, and this framework can be applied to assess rural regions across other parts of the European Union and globally. The adopted approach involves examining key regulatory documents and integrating statistical data concerning the economy, demographics, and the labor market. The data must be interpreted within the context of climate models that substantiate various scenarios and anticipated climate changes. This methodology incorporates the analysis of crises that have emerged in rural regions due to unforeseen and rapidly evolving events, particularly in highly vulnerable and inadequately protected settlements. Historically, gathering data from diverse users posed significant challenges for centralized systems; however, advancements in information and communication technologies now enable rapid data integration from multiple sources, which can be organized and transformed into valuable information for researchers, policymakers, and stakeholders. Given that it has been established that "the average values of the SPEI drought index with a 48-month step are negative for each of the last four decades for the territory of Bulgaria," and these are changes that lead to alterations in ecosystems and their distribution areas, these changes undoubtedly have "serious consequences for biodiversity, agriculture, and forestry"[20]. The primary objective of the authors of this study is to analyze and evaluate the condition of rural areas within the context of climate change. Simultaneously, they investigate existing and potential opportunities for the prevention and mitigation of crisis phenomena. Furthermore, emphasis is placed on the prospects for establishing conditions conducive to the adaptation of agriculture to climate change. This objective will be accomplished through the application of various approaches and methods. The study employs territorial, regulatory, and systemic approaches, including the analysis of cause-and-effect relationships, along with statistical, descriptive, and analytical techniques, as well as inductive and deductive reasoning, and the examination of regulatory documents. Data utilized in the research are sourced from public databases such as the National Statistical Institute, the Ministry of Agriculture and Food, the Institute of Agricultural Economics, and electronic platforms of municipalities, among

others. At the regional level, economic development assumes a significant role in mitigating the impacts of natural disasters and in the formulation of policies and measures to address climate change. Factors such as access to and the development level of the education system, the pursuit of opportunities to attract investment, and the strengthening of economic development within rural municipalities are critical, as they will substantially support processes aimed at reducing the impact of natural disasters induced by climate change. The research hypothesis proposed by the authors posits that rural areas are at an elevated risk of natural disasters and accidents stemming from climate change, particularly given the field-based nature of working conditions and the need for information and technological advancements to enhance the efficacy of disaster prevention and management systems. When identifying issues within rural regions, the implementation of appropriate public policies focused on developing quality prevention strategies for both local communities and all economic stakeholders is essential. Consequently, the primary aim should be to effectively address emerging crisis events and to establish conditions that prevent the deterioration of living conditions within rural communities.

RESULTS AND DISCUSSIONS

Undoubtedly, the social consequences of climate change for rural areas in Bulgaria are complex and multifaceted, as they affect not only economic sustainability but also the social structure of communities. On the one hand, the processes of depopulation and migration should be noted, which significantly reduce the capacity of local communities to manage their resources, including natural resources that are vital for agriculture. Demographic changes in small settlements in the country further highlight the need to seek opportunities for the application of innovations in agriculture, which should be adapted to the specific conditions of the region. To effectively enhance the resilience of rural regions in Bulgaria, it is essential to initially identify vulnerable communities, and subsequently undertake the planning of targeted activities aimed at mitigating the risks associated with climate change. It should also be noted that climate change means that migration patterns in Bulgaria will increasingly be shaped not only by economic but also by environmental factors. Climate change has a significant impact on agricultural practices, leading to a reduction in the income of the population whose livelihood depends on agriculture and, at the same time, will lead to increased migration pressure, as families living in rural areas will be forced to move to urban centres in search of work and better living conditions. Addressing this issue necessitates the enhancement of intensive interregional cooperation across diverse sectors. The primary objective must be to mitigate the risks associated with increasing migration flows from rural to urban areas, which are primarily driven by the ongoing deterioration of socio-economic conditions in rural regions. This requires local authorities, in collaboration with local communities, to adapt their economic strategies by implementing policies and measures to combat climate change. Furthermore, this process is interconnected with the increased implementation of inter-institutional partnerships at various hierarchical levels within the state. Such partnerships will establish conditions conducive to managing potential social conflicts that may emerge due to climate change, such as a significant reduction in water resources for irrigation, resulting from prolonged drought periods and the national water resource management practices. To effectively address many of these challenges, it is essential to plan and foster new social relationships among different communities, which entails improving inter-institutional relations and actively involving national institutions in addressing climate-related issues.

This process requires that, once the necessary analysis has been carried out, the necessary structural changes be planned with the involvement of all stakeholders. Overall, it should be noted that "the real rural area and its way of life have shrunk," because, on the one

hand, "cities have expanded their hinterlands into areas that were previously considered rural," while on the other hand, "the population of these areas increasingly travels to the city for work and for regular access to commercial, cultural, and other services" [9]. There is no doubt that rural residents are increasingly linked to urban economies and urban development. Climate change also has a significant impact on the health of rural populations, causing an increase in chronic diseases and potentially worsening the overall quality of life, as temperature changes, together with changes in precipitation, create conditions conducive for the spread of new diseases previously uncharacteristic of certain regions, transmitted by insects, such as malaria and dengue fever, which is particularly important for vulnerable population groups. Investments are required in the healthcare sector and rural development initiatives to enhance access to medical services, particularly considering the deficiency of healthcare professionals in rural regions. Furthermore, considerable efforts must be directed toward expanding educational programs aimed at elevating awareness among local communities regarding the escalating risks associated with climate change and the potential natural disasters that could impact specific rural areas. It is essential to justify the necessity of developing and regularly updating climate change adaptation plans in order to effectively implement planned and ongoing efforts at this stage, facilitate the reorganisation of agriculture, and enhance preparedness in combating climate change.

Requirement for strategies to adapt to climate change.

Adaptation plans should include both financial mobilization and risk management, targeting agriculture, water resources, and tourism as priorities, through the need to apply flexible policies and use modern technologies and innovations to address the challenges. On the other hand, the main problems that can be identified in relation to rural development in the country are primarily related to the economy in rural areas, which is heavily dependent on agricultural production. In rural regions of the country, there exists a discernible decline in the quality of life, attributable to the low standard of living among small-scale agricultural producers. It is an indisputable fact that farmers are attempting to adapt to climate change by employing a variety of individual strategies. For instance, they are modifying the timing of crop planting, adopting novel crop varieties, and striving to diversify their income sources. Considerable efforts are required to enhance existing adaptation capacities and to support producers in their individual endeavours to address climate change. As climate change alters the hydrological cycle, observable changes include shifts in precipitation patterns and a reduction in snow cover, leading to a decline in surface water volumes (such as rivers and lakes) and restricting groundwater recharge, which is essential for irrigated agriculture. Regions dependent on seasonal snowmelt are particularly susceptible, as rising temperatures induce premature and intensified melting, concurrently causing water shortages during critical stages of vegetation growth. In the agricultural sector, an integrated water management approach should be implemented nationally, incorporating practices such as water harvesting, micro-irrigation, and resource-conserving agricultural techniques. Furthermore, rural communities are predominantly inhabited by an aging population characterized by low educational attainment, with some individuals having not completed secondary education. This demographic profile of rural areas will undoubtedly impede the implementation and utilisation of modern technologies in agricultural production, which are essential in addressing climate change. Furthermore, the population living in rural areas has very limited opportunities to find work, which is a result of the limited production capacity of the agricultural business in rural municipalities in the country. There are undoubtedly significant differences in the lifestyle in rural and urban areas in terms of economic development, educational attainment, access to basic services, and use of information technologies, which in turn limits the development of social

capital in rural areas in the country. In connection with the fight against climate change, a Climate Change Mitigation Act was adopted in 2014. Since its adoption, the Climate Change Mitigation Act has been amended several times, including three times in 2023, four times in 2024, and twice so far in 2025.

In Bulgaria, the legislative adjustments pertain to the transposition of new European Union directives concerning climate change. To facilitate this, the country is devising and implementing requisite national policies and measures to ensure effective compliance with adopted and enforceable regulations. The activities undertaken by the executive and legislative authorities predominantly involve amending national legislation to align with current European legal standards, primarily aiming to avert the initiation of punitive procedures against Bulgaria. It is noteworthy that these amendments are predominantly reactive, driven by modifications in European legislation and their subsequent incorporation at the national level. Consequently, there is insufficient evidence to suggest that proactive initiatives are being planned or executed by the governmental branches in the context of combating climate change. It is, however, apparent that climate response policies possess a horizontal dimension, necessitating the concurrent integration of measures across various sectors of the economy to facilitate adaptation. The objective of climate legislation ought to be the establishment of conditions conducive to the effective regulation of both sector-specific and cross-sectoral relations, thereby creating opportunities to mitigate the escalating risks associated with climate change. It is imperative to underscore the necessity for coordinated action to manage climate risks effectively. In this regard, a practical and appropriate measure could involve establishing a "National Expert Council on Climate Change" under the auspices of the Council of Ministers, aimed at enhancing and streamlining coordination in the implementation of national climate policies. Currently, however, the existing "National Expert Council on Climate Change," serving as an advisory body to the Minister of Environment and Water, does not appear to be sufficiently effective in coordinating the implementation of national climate policies.

The establishment of such a change would facilitate more effective implementation of both long-term and proactive measures, aligning with the dynamic natural and political processes within the country. There exists a clear necessity to regulate the development and execution of a Long-Term National Strategy for Climate Change Mitigation, as an additional requirement stipulated under Article 15 of Regulation (EU) 2018/1999, which mandates the preparation and submission of a long-term strategy with a thirty-year horizon to the European Commission. The initial Long-Term Climate Change Mitigation Strategy, extending to the year 2050, was developed through a technical assistance project funded by the European Union under the Structural Reform Support Program for the period 2017-2020 and was adopted via Decision No. 809 of the Council of Ministers on October 21, 2022.

In the context of climate change mitigation, it would be judicious to reinforce the role of the National Expert Council on Climate Change by amending existing legislation to explicitly enumerate its functions, specify the number of members, define the frequency of meetings, and establish requirements for independence and transparency of its activities. Additional requirements concerning the scientific qualifications and experience of council members may also be considered, and a balanced representation of stakeholders-comprising business sectors, the scientific community, and civil society-could be sought. Consideration might also be given to establishing a fixed term of office for members, which would further safeguard the independence of the council's activities. Furthermore, provisions should be included to ensure that council members have no conflicts of interest in relation to their duties. Regarding the accountability of the council, a requirement for periodic reporting and assessment of the implementation and effectiveness of policies and measures aimed at reducing greenhouse gas emissions and adapting to climate change

could be introduced. Presently, the National Expert Council on Climate Change functions primarily as a coordinating body rather than an advisory entity, with its composition predominantly consisting of representatives from government agencies and limited participation from stakeholders such as qualified experts with relevant experience and scientific knowledge in the field of climate change. The proposal to establish a National Expert Council on Climate Change, which would serve as an advisory body to the Council of Ministers, necessitates the creation of an appropriate administrative framework. This includes the formation of a dedicated special secretariat responsible for supporting the activities of the National Expert Council on Climate Change and reporting to the administration of the Council of Ministers. One rationale for this initiative is that government actions related to climate adaptation and mitigation directly influence the development of various sectors, including agriculture and industry, particularly in rural regions. Additionally, the integration of adaptation measures into existing governmental policies and agricultural practices will be reinforced. Therefore, it is essential to consider the importance of planning and enhancing infrastructure, which must also encompass the implementation of sustainable agricultural practices to establish conditions for addressing climate change in vulnerable regions.

The necessity of planning, the enhancement of infrastructure, and the adoption of sustainable agricultural practices.

Planning and improving infrastructure will be supported to minimize vulnerability to climate risks, while simultaneously raising community awareness to enhance local capacities to effectively respond to climate change. The planning and implementation of sustainable agricultural practices constitute a vital component capable of establishing conditions to enhance the sustainability of rural regions. Concurrently, such practices must be incorporated into Bulgaria's strategic framework for climate change adaptation. The adoption of sustainable agricultural methods necessitates the inclusion and expansion of innovative initiatives in the realm of renewable energy sources. This approach will facilitate not only the reduction of carbon emissions and the generation of new employment opportunities but also promote economic growth and diversification. Diversification can further be achieved through investments and projects centred on biogas production from agricultural waste. In this context, opportunities should be explored to strengthen international cooperation and attract funding for various projects and initiatives aimed at combating climate change, with particular emphasis on vulnerable rural areas. The integration of international funding into the implementation of national strategies should be regarded as an effective mechanism for managing climate-related risks and fostering long-term food security. Additionally, international cooperation should prioritise the exchange of knowledge and technological advancements. According to data from the National Statistical Institute, as of December 31, 2024, Bulgaria's territory, based on digital models of the cadastral map, spans an area of 110,996.76 square kilometers. Agricultural land accounts for 54.5% of this area, followed by forested regions, which constitute 33.3%. Urbanised zones comprise 4.8%, approximately 5,279.4 square kilometers. The average population density as of December 31, 2024, is calculated at 58.0 persons per square kilometre, with urban regions experiencing a density of 1,214.7 persons per square kilometre- a decrease of 6.2 persons per square kilometre compared to the previous year. The highest population density within urban areas is observed in the districts of Sofia (capital) at 5,022 persons per square kilometre, Blagoevgrad at 1,999.2, and Plovdiv at 1,830.9. Conversely, the districts with the lowest density are Vidin at 534.9, Dobrich at 565.5, and Targovishte at 613.6. The association between climate change and the likelihood of extreme hydroclimatic events is unequivocal, thereby supporting the conclusion that all climatic phenomena are affected by climate change. Even minor variations in average values can lead to substantial percentage changes in extremes,

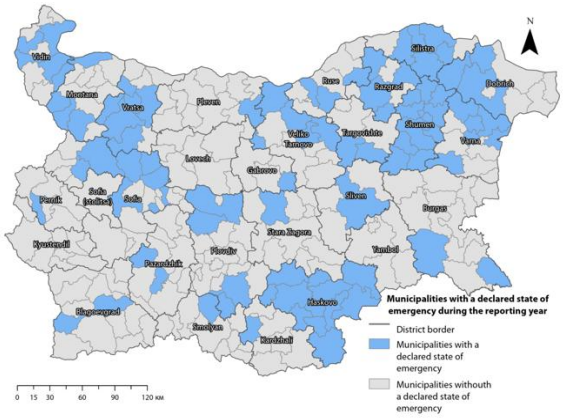
which will undoubtedly impact agriculture and forestry. Furthermore, the continuous increase of greenhouse gases and aerosols in the atmosphere is a persistent factor contributing to the rise in global temperatures, resulting in a 4% increase in evaporation from the world's oceans [24]. This is reflected in the observed trend of increasing precipitation and linked extreme events such as floods. In other words, as a consequence of rising global temperatures and the escalating risk of climate extremes associated with moisture, the agricultural sector, particularly rural areas, is anticipated to be significantly impacted. Undoubtedly, when formulating strategies for adaptation to climate change, it is essential to consider the increase in global temperatures. An analysis of events resulting from extreme climate phenomena should be conducted to establish the conditions necessary for the sustainable development of the country's agricultural sector.

Rising global temperatures and the escalating risk of extreme weather events.

The process of planning the necessary effective adaptation measures necessitates a comparative analysis of projected climate change scenarios. For the development of the agricultural sector within the country, it is of utmost importance to evaluate the potential impacts of climate change as well as the risks associated with adverse events and natural disasters. As a result of climate change, the following alterations related to agriculture have been observed:

- An increase in extreme temperatures.
- A significant reduction in the risk of crop frost, as well as decreased occurrences of late spring and early autumn frosts and frosts generally, correlated with a decrease in cold periods exhibiting significant negative anomalies.
- A reduction in the thickness and water content of snow cover, along with its duration and retention, attributable to lower winter precipitation and warmer winter conditions.
- An elevated risk of fires, insufficient moisture, and drought, resulting from increased frequency, intensity, and duration of heat waves during the summer months.
- Marked variability in precipitation levels.
- An increase in prolonged dry spells, which contribute to river drying and drought conditions.
- A heightened risk of extreme rainfall events, hail, and thunderstorms.
- An increased probability of floods, soil erosion, and landslides.

These developments exert a considerable influence on the advancement of agriculture and rural regions, where agriculture sustains the livelihood of the populace.

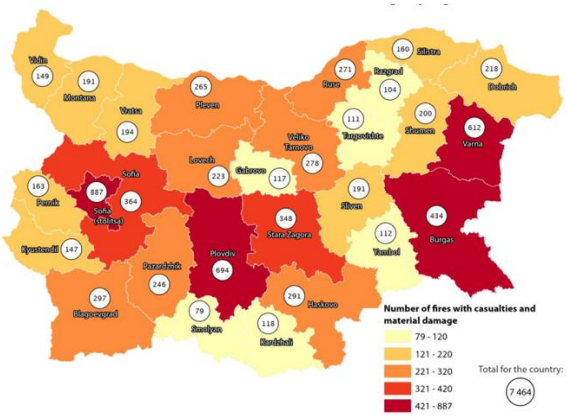


Map 1. Municipalities with a declared full or partial state of emergency in 2023
Source: NSI, [18].

When implementing the process of planning strategies for adaptation to climate change, these strategies must also be integrated into sectoral policies in order to create appropriate systems for reducing the risks of natural disasters. When creating appropriate systems, smart, innovative, and nature-based solutions can be used to support the process of creating long-term sustainable progress in the development of the country's agricultural sector. The application of such an approach is of significant importance, as 14,850 crisis events were recorded in 2023. Fires accounted for 50.4% of material damage, while the number of victims was highest in road traffic accidents, at 47.2%. A state of emergency was declared for 104 crisis events in 2023, which is an increase of 55 incidents compared to the previous year, 2022. It is noteworthy that the main disasters were related to events such as floods, storms, severe winter conditions, and forest fires. In addition, 2023 saw a 62.5% increase in the number of states of emergency

declared as a result of floods and an 85.7% increase in those declared as a result of forest fires compared to the previous year, 2022. Map 1 shows the municipalities that declared a state of emergency in 2023. Considering that 215 of the 265 municipalities in the Republic of Bulgaria are rural municipalities, we can unequivocally state that rural municipalities are the most vulnerable to natural disasters resulting from climate change.

Map 2 illustrates the fires documented by region in Bulgaria in 2023. The total number of fires reached 7,464, resulting in 113 fatalities and 289 injuries, constituting 50.4% of all recorded hazardous events. It is important to highlight that the regions with the highest fatalities due to fires are Sofia (the capital) with 57 individuals and Plovdiv with 50 individuals, primarily attributable to the high population density in these areas. Forests and woodland in the Republic of Bulgaria encompass approximately 4.270 million hectares, which accounts for 38.5% of the national territory. The forest fires in 2023 led to significant loss of tree cover in the regions of Haskovo, Stara Zagora, Blagoevgrad, and Burgas. This loss not only reflects the immediate impact of the fires but also poses long-term risks to biodiversity and potentially accelerates climate change processes. These environmental impacts have the potential to influence socio-economic development, particularly in rural municipalities, which constitute the majority of the country's territory.

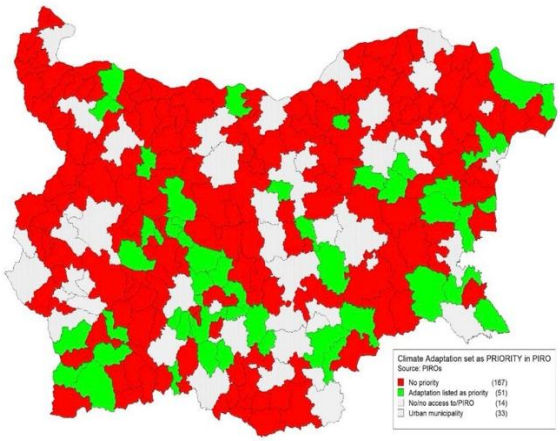


Map 2. Number of fires with casualties or material damage by regions in 2023
Source: NSI, [18].

The causes of the fires that we can point out are related to changes in climatic conditions, such as the observed trend of increasingly high temperatures and low humidity, as well as human activity related to improper handling of fire, burning grass or waste.

The impact on the environment is undeniable, as forest fires result not only in the loss of tree cover and biodiversity in the affected areas, but also in reduced soil stability and erosion, as well as disruption of ecosystem services. In order to solve some of the problems in the field of forestry development in the country, it is necessary to seek opportunities to increase investment for the consistent implementation of appropriate forms of forest management. Considering the evolving climatic conditions, the initiatives of the relevant parties should focus on establishing optimal circumstances to enhance the sustainability and vitality of forests. This necessitates systematic research on the effects of climate change to identify appropriate forestry practices for forest adaptation. In this regard, we can point out some basic practices that can be applied to varying degrees in different rural areas, depending on the available funding and administrative capacity. For example, the selection of suitable tree species, which involves exploring the possibilities of using more drought-resistant and heat-loving species. The research process should be based on strengthening and implementing close cooperation with the scientific community by involving academia in the analysis of suitable tree species for each individual region, including the use of local genetic material from seeds and seedlings from local populations that are adapted to the specific conditions of the area. A suitable practice would also be to create forests with mixed species composition, as this is expected to increase the resilience of forests to diseases, pests, and climate stress. In addition, conditions will be created for the maintenance and conservation of diversity at different levels. On the other hand, based on the mapping and investigation of potential vulnerable areas, the planning and construction of protective belts should be carried out, which involves creating the necessary firebreaks to

control potential fires in certain areas, the construction of water reservoirs, as well as belts of less flammable species. In addition, existing forest fire monitoring and warning systems could be improved and new ones could be built. There is an undeniable need to expand the coverage of automated monitoring systems, which would, on the one hand, improve the integration of the various systems in place in order to increase the speed and efficiency of information transmission to operational centers and the population. However, the necessary funding must be provided for ongoing training and maintenance of equipment in good working order and readiness, the purchase of new equipment, and the implementation of preventive measures. In other words, capacity must be built up for rapid firefighting and fuel management, including planning activities to remove dry branches, shrubs, and other combustible material to reduce the risk of intense fires in potential high-risk areas. Numerous of the best practices can be incorporated into the implementation of the integrated planning process when developing both national and regional plans and strategies. Map 3 indicates that only 51 rural municipalities are highlighted in green; these are the municipalities that have recognised climate change adaptation as a priority within their existing and developed strategic documents. Conversely, the remaining 167 municipalities, marked in red, do not identify climate change adaptation as a priority in their strategic documents. This disparity highlights, on one hand, a lack of awareness among a significant number of rural municipalities regarding the risks associated with climate change, and on the other hand, a failure to acknowledge the necessity of planning appropriate policies and implementing measures to address these challenges. Undoubtedly, climate change has a markedly different impact on agricultural yields, which necessitates a tailored approach to policies for adapting to climate change in the agricultural sector. It also involves identifying risks associated with climate change and planning and implementing suitable policies and measures that consider the specific characteristics and differences in agricultural yields.



Map 3. Rural municipalities with climate adaptation priority (in green)
Source: [12].

Peculiarities in agricultural yield differences.

Climate change exerts a markedly differentiated influence on both cereal crops (such as wheat, corn, and barley) and other agricultural products including vegetables and fruits. The variation in yields arises, firstly, from the direct effects of climate change and, secondly, from alterations in cultivated areas. A tailored approach to climate change adaptation policies for Bulgaria's agricultural sector is therefore necessary. Traditionally, Bulgaria has produced substantially more grain and oilseed crops than are required to satisfy domestic demand, thus facilitating considerable annual exports. For instance, in 2024, the grain corn harvest reached 1,386.6 thousand tons, representing a 38.3% decrease compared to the previous year, primarily due to lower yields per hectare attributable to adverse weather conditions. Additionally, the sunflower oilseed harvest in 2024 decreased by 11.5% annually, mainly owing to dry and hot summer conditions. Moreover, reports from the National Institute of Meteorology and Hydrology indicate that the summer of 2025 ranks among the hottest and driest since 1950, suggesting the likelihood of further reductions in agricultural yields. Consequently, climate change is anticipated to precipitate a decline in the overall gross agricultural output of

Bulgaria, predominantly impacting the crop production sub-sector, which is directly susceptible to climate-related effects. Table 1 delineates the principal economic indicators for agriculture over the period 2021–2023.

Table 1. Main economic indicators for agriculture for the period 2021 - 2023, BGN million

	Indicators	2021	Change 2022/2021 %	2022	Change 2023/2022 %	2023
1	Value of crop and livestock production (at producer prices*), including:	10,072.3	20.3%	12,113.7	-20.3%	9,649.2
1.1	Crop production	8,133.8	20.4%	9,796.1	-27.1%	7,137.9
1.2	Livestock production	1,938.5	19.6%	2,317.6	8.4%	2,511.3
2	Agricultural services	546.3	9.0%	595.3	0.1%	595.7
3	Non-agricultural inseparable secondary activities	202.3	35.0%	273.2	9.4%	299.0
4	Value of gross production from the Agriculture sector (at producer prices *) (line 4 = line 1.1 + line 1.2 + line 2 + line 3)	10,820.9	20.0%	12,982.2	-18.8%	10,543.9
5	Value of final production from the Agriculture sector (at basic prices**)	10,821.4	19.2%	12,901.9	-18.2%	10,554.4
6	Intermediate consumption (excluding internal turnover)	5,612.8	24.5%	6,988.7	-9.3%	6,337.4
7	Gross value added at basic prices	5,208.6	13.5%	5,913.2	-28.7%	4,217.0

Source: NSI, [19]

As evidenced in Table 1, the gross agricultural output value for the year 2023 at current producer prices amounts to BGN 10,543.9 million. This represents a decline by 18.8% relative to the year 2022, when it was valued at BGN 12,982.2 million. The gross output of the agricultural sector comprises the output from the following segments:

- Crop production, BGN 7,137.9 million (constituting 67.7% of the total);
- Livestock farming, BGN 2,511.3 million (constituting 23.8%);
- Agricultural services, BGN 595.7 million (constituting 5.7%);
- Production from inseparable secondary activities, BGN 299.0 million (constituting 2.8%).

The subsequent figure illustrates the distribution of the gross production value within the agricultural sector for the period spanning 2021 to 2023.

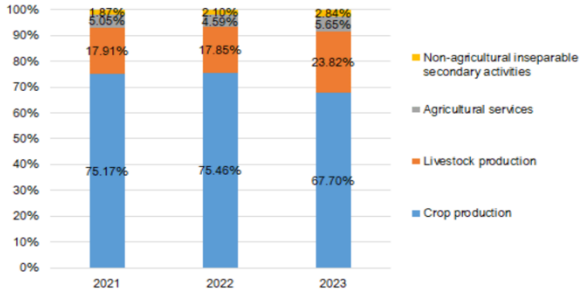


Fig. 1. Structure of the value of gross production from the Agriculture sector for the period 2021 - 2023,%
Source: [15].

As demonstrated by Figure 1, the decline in overall gross agricultural output is primarily attributable to a reduction in the crop production sub-sector, which decreased by BGN 2,658.2 million, or 27.1%, relative to the preceding year. Conversely, the value of production within the livestock sub-sector experienced an increase of BGN 193.7 million, or 8.4%, while non-agricultural inseparable secondary activities grew by BGN 25.8 million, or 9.4%. The primary decline is concentrated within the leading areas of crop production, specifically grain production, which diminished by BGN 1,441.7 million, or 25.5%, and oilseed production, which declined by BGN 1,190.3 million, or 42.7%. Fruit production decreased by BGN 31.7 million, or 9.1%; potato production decreased by BGN 11.9 million, or 13.3%. The only positive growth in gross production value was observed in vegetables (excluding potatoes), which increased by BGN 13.6 million, or 2.8%, and tobacco, which grew by BGN 8.7 million, or 33.2%. On the livestock front, the majority of key production sectors reported year-on-year increases, notably pigs, which rose by 36.4% (BGN 127.9 million); poultry, which increased by 18.2% (BGN 67.2 million); and ewes and goats, which grew by 19.4% (BGN 29.9 million). It is anticipated that climate change will lead to progressively frequent damage to agricultural crops due to adverse weather phenomena—such as frosts, storms with heavy or torrential rain accompanied by strong winds, flooding, hail, and drought—posing a threat to all farms with regard to low yields. Consequently, it would be prudent to institute additional measures aimed at restoring the agricultural production capacity of affected areas and to develop and implement suitable preventive strategies designed to mitigate the impact of natural disasters, adverse climatic conditions, and catastrophic events.

Certainly, the economic repercussions of climate change are expected to be most profound for rural communities within the nation, as these populations are extensively reliant on agriculture for their livelihoods. Addressing climate change requires a process of diversifying socio-economic activities and

redefining new multifunctional roles to balance agricultural production with opportunities such as tourism development, among other initiatives, while simultaneously addressing local needs. The challenges associated with the development and adaptation of rural populations to climate change are intensified by the fact that most of these populations are impoverished and predominantly dependent on agriculture, yet they possess a relatively limited capacity to adapt to climate change. This limited capacity is partially attributable to the fact that they allocate a significant portion of their income to food and nutritional needs, which consequently constrains their resources available for adaptation measures.

CONCLUSIONS

Climate change is certainly exerting significant pressure on rural areas within the country, as it presents not only economic challenges but also social and environmental ones. These challenges must be addressed with utmost seriousness, and suitable sustainable strategies should be meticulously planned and executed. The costs associated with inaction amid the climate risks and threats confronting modern society will substantially surpass the expenses of adaptation efforts. Proactive measures, including the integration of adaptation strategies into existing policies and, specifically for the agricultural sector, the planning and execution of hydro and agro-investments, will be essential in enhancing resilience and ensuring food security. Upgrading existing infrastructure, developing new infrastructure, and increasing financial flows directed towards the country's climate change adaptation initiatives will secure a sustainable future for both rural regions and the nation overall. Undeniably, nature connectedness as a key metric for a sustainable future [21]. The impact of climate change on agricultural development in Bulgaria is complex and necessitates a thorough analysis of the primary challenges faced by the country [2, 13, 4]. Strengthening links between various sectors requires bolstering institutional capacity and elevating public awareness. Proactive measures to combat climate change are crucial, as they must not only facilitate local economic adaptation to climate effects but also reduce potential losses across agriculture and other sectors. It is vital to develop integrated approaches that involve local communities and foster cooperation among different institutions, including educational initiatives and technological innovations aimed at promoting sustainable farming practices. The sector's future vision must incorporate innovation and adaptive strategies to cope with the ever-changing climatic conditions and sustain the viability of rural areas [6]. In this context, the roles of government, local communities, and non-governmental organisations are fundamental in formulating innovative adaptation strategies that minimise climate-induced damages. A practical approach would involve integrating public initiatives with circular economy principles, especially concerning pollution reduction and waste management. The importance of implementing educational programs targeting local populations is undeniable. The current state of agriculture highlights the urgent need for innovations to adapt farming practices to meet climate challenges.

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MODELING OF A BONUS SCHEME IN MICROSOFT VISUAL BASIC FOR AGENTS EMPLOYED IN AGRICULTURAL COMPANIES: CASE STUDY OF NEW LAND PURCHASE OR LEASE

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Abstract

Any agricultural company during the period of business expansion faces the dilemma, whether to purchase or lease agricultural land. Such problem entails many questions and related dilemmas that involve different fields of business and permeate the very business core of the agricultural company. Usually, after the agricultural production planning department develops a strategic expansion plan with incorporated range and defined types of land, the board of directors must decide on adoption, while the main part of the work is left to the agents employed by the agricultural company. They must get down to business and find the right location through careful fieldwork and communication with stakeholders. However, commonly there will be more than one suitable location that meets the predetermined conditions for a given planning range. This will put the agent in a dilemma about what is the proper location to be chosen. Thus, agents face several more dilemmas, where the most significant is whether to purchase certain land or to lease it, how to negotiate a lease price lower than the defined Key Performance Indicator (KPI), etc. The subject of this paper is the modeling of a bonus scheme in Microsoft Visual Basic for acquisitions employees in agricultural companies based on a business case linked to purchase or lease of new agricultural land. As the main conclusion derives the stance that the modeled bonus scheme can be of significant benefit to agricultural companies when deciding on the purchase or lease of new land. Using presented bonus scheme, they can simply and easily calculate the amount of the bonus realized at the individual level (for each agent), but also at the company level, after defining and adopting the internal bonus policy, as well as individual and collective KPIs.

Key words**:** *agricultural land, purchase or lease, bonus scheme, Microsoft Visual Basic.*

INTRODUCTION

In today's business environment, strategic decision-making in the agricultural sector requires a comprehensive approach that considers several economic, legal, technological and social factors. One of the key decisions with long-term financial and operational implications is the choice between purchasing and leasing farmland [15; 19; 39]. The decision mentioned has a direct impact on the cost structure [12], financial stability, business flexibility and growth opportunities of farms and businesses [1; 8]. Before all, it must be underlined that land represents one of the key factors in agriculture [42]. Establishing a business model that underpins the decision-making process in previous context becomes essential, especially in the circumstances of changing market, limited resources, and growing competition [28]. The application of analytical tools and contemporary decision-making methods enables informed and comprehensive decision-making that maximizes economic benefits, while minimizing business risks [4]. The aim of paper is to develop and present a potential framework for business model modeling that will support decision-making in purchasing or leasing agricultural land. Previously considers certain relevant factors such as cost efficiency, availability of capital, long-term sustainability, legislation and local market

specifics, etc. [31; 35]. In addition to theoretical analysis, research will also rely on practical examples and simulations that demonstrate the applicability of proposed model in real conditions.
Every agricultural company, or any legal entity, in the period of business expansion faces the dilemma, whether to purchase or lease agricultural land [7; 44]. Such issues entail numerous questions and related dilemmas that involve different areas of business and permeate the very business core of agricultural companies [13]. Once the agricultural production planning department has established strategic plan for business expansion, that also incorporates range and predefined types of land, management must decide on its adoption [41], while the main part of the mentioned activity remains with the agents employed by agricultural companies. They must be able to find the right locations through careful fieldwork and communication with involved stakeholders [23]. Basically, selection of proper parcels in agriculture, no matter to type of ownership, is linked to several criteria, as are its size, type of land, mechanical and biological characteristics of soil and its quality status, closeness of water intakes, urban centers, or primary elements of infrastructure, etc.
In addition to the current land purchase price or lease costs, the choice of right land parcel is among crucial factors, as transportation costs (linking the production locality with sale or further processing) can significantly affect the overall financial performance of agricultural enterprises. However, in many cases, there will be more than one suitable land parcel that meets the predetermined conditions for a given planning range. That will put the agent in a dilemma about which land parcel to choose [4]. Thus, agent faces several dilemmas, while the most important are whether to purchase a certain land parcel or to lease it, how to negotiate a lease price lower than the defined Key Performance Indicator KPI, etc. [32]. Subject of this research is the modeling of a bonus scheme in Microsoft Visual Basic for acquirers employed in agricultural companies based on a business case in purchasing and lease of new land.
The purpose of the paper is to develop a business model with a bonus scheme for new acquirers and agricultural companies, which can use the proposed model in their daily operations and in planning new acquisitions.

Literature review

Many authors [21; 11] believe that agricultural land is extremely important segment of business in any economy, especially related to making a proper business decision to purchase or lease agricultural land. Other have been presented the research results derived from experiment due to reconsideration of the modeling process apropos discrete choice within differential analysis, or method of choice, when making a business decision of individual farmers in Germany towards the purchase or lease the agricultural land [42; 5]. They believe that farmers, as individual producers of agri-food products, have a more pronounced tendency to purchase than to lease agricultural land [17]. Certain dependent variables incorporated into the structured research model, such as farmers' attitude towards their risk aversion, influence the final decision due to options of purchasingor leasing agricultural land [38; 45; 18]. However, dependent variable that emphasizes farmers' individual expectations about the trend of agricultural land prices over the next ten years did not have any significant impact on decision-making process at any respondent [3]. Simultaneously, existence of certain levels of absolute or relative price discount for full payment within the option to land purchasing has important fact in individual decision-making, while expressing the willingness to purchase or lease agricultural land [23; 2]. Some research shows that farmers' decisions significantly deviate from the normative predictions in currently used value models [43].
Meanwhile, in western part of Canada, that is historically important region with strong heritage, or currently major agricultural region, farmland has been inherited through generations over the centuries [47]. However, with rapid technological progress, many heirs have given up agricultural production, what initiates development of agricultural land market, including its leas too [24; 9]. Thus, many agricultural producers have come to the situation of considering a serious dilemma about whether to purchase or lease a certain parcel of agricultural land that has appeared on the local market [4; 10]. Meanwhile, some agricultural producers believe that increased ownership in

agricultural land by external investors has potential to expose negative impacts on farms' structure [34; 30]. Still, there are many good financial reasons why institutional investors want farmland as object of investment, including the benefits of diversifying investment portfolios.
[29; 22]. Due to complexity and heterogeneity of individual decisions in farmland market, there are summarized and analyzed various models, further upgraded to develop a simulation framework based on the dilemma of agent-based decision-making, designed to highlight the interplay between potentially opposing factors that elaborate the dilemma of purchasing or leasing farmland [46]. There is certain conclusion that institutional investors will affect future structure of agriculture within the micro region, but their presence can manifest itself in very subtle way. The relevant argument is that success of agriculture with institutional investors operating in mentioned land markets depends on whether future farmers are willing to rely on land leases rather than ownership during the process of maintaining or expanding the farm properties [6].
Some research underscores strategic importance of designing adaptive bonus schemes for agricultural agents engaged in land acquisition or leasing decisions. By aligning individual incentives with broader organizational and economic goals, proposed model fosters informed decision-making rooted in profitability, sustainability, and yield optimization [47; 40; 49]. The incorporation of scenario-based bonuses, performance multipliers, and flex components encourage agents to evaluate both short-term transactional outcomes and long-term land productivity. Paired with robust modeling tools and transparent performance metrics, such frameworks not only motivate agents effectively but also enhance overall institutional agility in responding to market fluctuations and policy incentives [33; 16]. As the agricultural sector will continue to be navigated by dynamic global challenges, well-calibrated bonus schemes will remain a vital mechanism for driving efficiency, accountability, and strategic land management [36].
Designing a bonus scheme for agricultural agents who advise towards purchasing or leasing agricultural land involves balancing motivation [14], performance metrics, and long-term strategic goals. Here's a breakdown in how such model can be structured to encourage agents to make data-driven recommendations (purchase vs. lease) according to profitability and sustainability, while rewarding agents for successful transaction and long-term land productivity, that aligns agent incentives with organizational goals (e.g. land acquisition strategy, ROI targets, etc.).
Agricultural companies face a complex challenge when deciding whether to purchase or lease land [26], while decision can significantly impact their financial health, operational flexibility, and long-term strategy [48]. There is a breakdown of key problems they encounter high upfront costs for purchasing land can tie up capital that might otherwise be used for equipment, labor, or crop inputs, rising land prices and interest rates make ownership increasingly expensive, especially for smaller or newer operations, leasing offers lower initial costs, but doesn't build equity, which can limit long-term financial leverage [43; 27].
Market volatility and Risk analysis include commodity price fluctuations that affect profitability, making long-term investments in land riskier, while land value instability can lead to losses if purchased land depreciates due to environmental or economic shifts, leasing exposes companies to lease uncertainty, including potential non-renewal or lease hikes.
Strategic planning challenges including ownership allow long-term planning, but reduce flexibility if market conditions change, leasing offers adaptability, but limits control over land improvements and infrastructure investments. Companies must weigh opportunity costs, whether the capital is better spent on land or operational growth [37; 25].
Operational and succession issues include young farmers and beginners that often lack capital to purchase land, relying on leases that may not be secure. Succession planning becomes more complex when land is leased, especially in family-run operations, landlord relationships can affect operational decisions, especially if landlords lack agricultural experience [22; 20].
Legal and Policy Complications include lease agreements may not clearly define rights to government subsidies or program payments, crop-share arrangements can lead to disputes over

revenue and risk-sharing and environmental regulations, and zoning laws may differ for owned vs. leased land, affecting compliance costs.

MATERIALS AND METHODS

When considering a business case, it is defined that the farm agent needs to enter the available data in two defined fields. In the first, agent needs to choose type of land parcel, and in the second, it must enter the amount of the expected fee for the purchase of the land area. In Table 1, according to the rough estimate, the formula will include all the costs that arise to acquire the land parcel, and are directly related to the acquisition process, including the agreed fee, costs of contract certification, tax, and related costs, which are shown below.

Table 1. Purchase descriptions

Crt. No.	Description of the purchase	Costs (EUR)
1	Purchase price of the land	17,000
2	Notary fees	850
3	Tax	425
4	Registration fee	510
Total		18,785

Source: Authors' own calculations.

In the first row, the assumed purchase price from the assumed contract with the buyer is shown. In the second line, the assumed notary fee is shown, which is calculated as the fifth percent increase to the assumed purchase price. In Serbia, the notary fee is an integral part of the process of ownership and is defined by law as a mandatory element. In the third row, the tax is shown, which is calculated as a two-and-a-half percent increase to the assumed purchase price. It is a tax on the transfer of ownership that is paid to the corresponding payment account of public revenues of the competent local self-government unit on whose territory the land in question is located. In the fourth row, the assumed fee for registering the change of ownership in the Republic Real Estate register is shown, which is calculated as a three percent increase to the assumed purchase price. It is also an integral part of the initial costs when purchasing a certain land parcel, bearing in mind that the buyer is obliged to hire an authorized surveyor who would go out into the field with the accompanying equipment and record the land parcel, after which the change in the republic real estate register is recorded on the basis of relevant and available data, after the payment of obligatory fee.

Table 2. Lease descriptions

Crt. no.	Lease description	Costs (EUR)
1	Agreed monthly lease (from contract)	350
2	Tax	35
Total		385

Source: Authors' own calculations.

If we look at the lease option, only the monthly lease according to the KPI, selected based on the type of contracted land parcel, and the tax as a one percent increase of the assumed monthly lease, are assumed. A discount rate of 9.8% and a 10-year period are assumed. If we look at the tables above, we can look at the structure of the initial costs when selecting both options. If the agent decides to purchase agricultural land, in addition to the purchase price from the contract, he also has the costs of certifying the contract, the associated taxes, registration on the portal of the Geodetic Authority and recording the ownership of agricultural land in the real estate register. If he decides on the option of leasing agricultural land, the agent will, in addition to the agreed monthly lease, preferably have a relevant legally defined cost of taxes and contributions in accordance to the relevant matters. On the other hand, when considering a bonus scheme, the starting point is the present net value.

Table 3. Weighted Average Cost of Capital -WACC and inflation

	%	
WACC	9.8	Discount rate should be like actual WAAC in the country
Inflation	2.1	Should be close to long term local Central Bank target
Savings	10.0	

Source: Authors' own calculations.

Namely, the assumption is that the bonus that the agent can reach is generated based on a percentage in addition to the difference in the present value of both variants, i.e. the purchase or lease option. A discount rate of 9.8% and a 10-year period are assumed.

Two more rates of five percentage points each were assumed for contracting land parcel of highly targeted interest and for land parcel that exceeded planned expectations in terms of planned characteristics.

Land of highly targeted interest	%
Yes	1.05
No	1
Land that exceeded planning expectations	%
Yes	1.05
No	1
Bonus for reached KPI	50

Source: Authors' calculations

It is assumed that there is no negative bonus, that is, an agent who fails to reach the KPI will not be punished with penalties, but at the same time will not receive a bonus. KPIs should be defined initially, before the release of the business case and bonus scheme into production, in a package with accompanying internal acts and procedures, imbued with presentations and training so that agents sufficiently understand the technique of filling in data and how to evaluate their office and field work, primarily in the field of communication with partners. The assumed structure of the KPIs on which the business case and bonus calculator are based is shown in Table 4.

Table 4. Business case

Land coefficient	
Urban land	200
Suburban land	150

Source: Authors' calculations.

Based on the selection of the site type, the table will import the data according to the defined KPIs. All formulas and accompanying contents are defined in Microsoft Excel using the classic approach as well as the Visual Basic approach.

RESULTS AND DISCUSSIONS

The business case model is defined at the level of net present value. Cash outflows based on the assumed lease based on the defined KPI are discounted based on the assumed discount rate, added together and compared with cash outflows based on the assumed purchase of the site in question. If the primary oriented difference between the two previously calculated present values is positive, then purchasing is a better option. On the other hand, if the difference between the two calculated present values is negative, then lease is the better option. [33] For example, in this case, the formula in Excel would look like this:

=IF (NPV (discount rate; sum (cash flow year 1, cash flow year 2, cash flow year 3, cash flow year 4, cash flow year 5, cash flow year 6, cash flow year 7, cash flow year 8, cash flow year 9, cash flow year 10) > purchased price; purchase is better (Source: Authors' determination).
If we wanted to model the case in Visual Basic, the formula would look like this:

VBA
function compare purchase lease (discount rate as double, cash flows as range, purchase price Asdouble) as string
dim NPV value as double
smoke and integer
dim CF() as double
redimCF(1 to cash flows. count)
for i = 1 to cash flows count
CF (i) = cash flows. cells(i). value
next i NPV value = application.worksheet function.NPV(discountrate,CF) – purchase price
if NPV value > 0 Then
comparepurchaselease = "purchase is better option"
else
comparepurchaselease = "lease is better option"
end if
end function
(Source: Authors' determinations).

If the difference between the two calculated present values is positive, the agricultural company benefits more if purchases the site in question than if it were to lease it for a period of ten years.
On the other hand, if the difference between the two calculated present values is negative, the

agricultural company benefits more if it leases the site for a period of ten years than if purchases it [33].

In the case of modeling a bonus scheme, cash outflows based on a presumed lease based on a defined KPI are discounted based on an assumed discount rate, added up and compared with cash outflows based on an assumed purchase of the site in question. If the difference between the two calculated present values is positive, the agent receives a 50 bonus plus an additional 5% on the difference in the calculated net present value, as a reward for the transferred KPI. If the difference between the two calculated present values is zero, the agent receives only a €50 bonus as a direct result of reaching the predetermined KPI. If the difference between the two present values calculated is negative, the agent will not receive the bonus. To the bonus thus achieved, another five percentage points are added if it is a land of highly targeted interest, these can be mainly land parcels with highly fertile agricultural land or land with developed infrastructure, close to highways, sources of drinking water, etc., and another five percentage points for land that are highly rated by the planning department as land that have exceeded planning expectations in terms of planned characteristics. In this case, the formula in Excel would look like this:

=IF(land that exceeded planning expectations="Yes",IF(land of highly targeted interest="Yes",IFS(difference in NPV>0,difference in NPV*5%, difference in NPV =0,'bonus for reached KPI,difference in NPV<0,0)*1,05,IFS(difference in NPV>0,difference in NPV*5%, difference in NPV =0,'bonus for reached KPI, difference in NPV<0,0)*1,05)*1,05,IF(land of highly targeted interest="Yes",IFS(difference in NPV>0,difference in NPV*5%, difference in NPV =0,'bonus for reached KPI,difference in NPV<0,0)*1,05,IFS(difference in NPV>0,difference in NPV*5%, difference in NPV =0,'bonus for reached KPI, difference in NPV<0.0)*1.05)

(Source: Authors' determination).

If we wanted to model the case in Visual Basic, the formula would look like this:

VBA

```
function calculate bonus (exceeded planning as string, highly targeted as string, differenceNPV as double, bonusKPI as double) as double
dim base bonus as double
dim multiplier as double
multiplier = 1.05
if differenceNPV > 0 then
base bonus = differenceNPV * 0.05
elseif differenceNPV = 0 then
base bonus = bonusKPI
else
base bonus = 0
end if
if exceeded planning = "yes" then
if highly targeted = "yes" then
calculate bonus = base bonus * multiplier * multiplier * multiplier
else
calculate bonus = base bonus * multiplier * multiplier
end if
else
if highly targeted = "yes" then
calculate bonus = base bonus * multiplier
else
calculate bonus = base bonus
end if
end if
end function
```

(Source: Authors' determination).

It is essential that the agent points out the bonus only in situations where a positive difference in present net value based on the discounted lease KPI is reached.

In situations where the difference in net present value is zero, the agent will not be left without a bonus because he has reached the KPI and thus would receive a €50 fiscal fee.

At the same time, when the difference in present net value is negative, the agent will not lose any amount as shown in the figure below. There is no negative bonus. The agent will not be penalized for unfulfilled KPIs.

CONCLUSIONS

In essence, this calculation serves to achieve a general understanding of concrete practical cases from everyday operative action on the contracting

of existing and new land, and in the context of looking at profitability to make a business decision on whether to lease a certain land parcel for a period of 10 years or to purchase it permanently. By entering the data in the costs sheet in the part where the assumptions are made, the calculator, based on the calculation of the present value of both options for a period of 10 years, generates an output in field h33 that is not binding, but exclusively advisory in nature for the needs of management. The calculator is based only on numerical inputs and does not consider a number of other factors, such as the strategic importance of the land, the potential for leasing to other farmers, the availability of access, the availability for generating income on another basis, such as the installation of solar panels, windmills, or leasing to other companies for placing advertisements, building pipelines or others. The main conclusion is that a modeled bonus scheme can be of significant benefit to agricultural companies when deciding on the purchase or lease of new land sites, while by using the exposed bonus scheme, they can simply and easily calculate the amount of the bonus at the level of each agent individually, but also at the level of the agricultural company after defining and adopting an internal bonus policy and individual and collective KPIs. Agricultural companies need to define internal procedures and adapt internal acts so that the entire process is completed in such a way that the targeted goals are met. If agricultural companies decide to apply business cases and bonus schemes defined in this way, they must first carefully consider defining KPIs that will be properly measured, realistic and neither easy nor too difficult to achieve. This is most realistically possible to achieve through experiential practice and accumulated knowledge. They must further define a base bonus for achieving KPIs and rates for land parcels of highly targeted interest and land parcels that exceeded planning expectations. The proposed bonus scheme for acquirers in the agribusiness sector, based on the business case of purchasing or leasing new land parcels, is proving to be an effective tool for encouraging proactivity and achieving key business indicators (KPIs). Through this model, acquirers are not only directly motivated to identify and secure strategic land parcels but also contribute to the company's long-term growth and valuation. By linking individual performance to measurable effects on the firm's asset and market position, the bonus scheme positions itself as a sustainable and scalable business strategy instrument. This approach opens space for a deeper integration of incentive mechanisms with development goals, and thus for strengthening the competitive advantage of agricultural companies in a dynamic market environment.

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ECONOMIC ANALYSIS OF PADDY RICE PRODUCTION: THE CASE OF EDİRNE, TÜRKİYE

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Abstract

The purpose of this study is to calculate paddy production costs, gross production value, and profitability indicators for paddy rice farms in the Edirne province of Türkiye. Primary data were collected via face-to-face surveys from 65 paddy rice farms using a proportional sampling method. The data used in this study are from the 2023 production season. A single budget analysis was employed to calculate the production costs. According to the results, the average paddy cultivation area was 23.99 hectares, the average yield was 8,057.69 kg/ha, and the average price per kg was $0.84. The average production cost for paddy farms was $4,439.17 per hectare, with variable costs constituting 59.26% and fixed costs 40.74% of the total. The major cost components were identified as land rent (32.00%), water and electricity (14.62%), harvesting (11.05%), and fertilizer (7.63%). The gross production value, gross profit, and net profit per hectare of paddy production were calculated as $6,853.52, $4,223.06, and $2,414.35, respectively. The relative profitability was determined to be 1.54. The high cost of land rent and irrigation, as identified in this study, represents a major burden on producers. Therefore, implementing policies that lower these costs and offering targeted incentives would be a key strategy to substantially reduce overall production costs for paddy farmers.

Key words**:** *Paddy rice, cost analysis, profitability analysis, revenue*

INTRODUCTION

Rice is a fundamental global food source, providing sustenance for nearly half of the world's population. It is a vital crop, accounting for over 21% of total human caloric intake [22]. According to data from the Food and Agriculture Organization of the United Nations (FAO), as of 2023, global paddy rice production reached approximately 800 million tons, with the majority of production taking place in India and China. These two countries together account for more than half (51.67%) of total paddy rice production. Bangladesh, Indonesia, and Vietnam are among the other leading producers [6].

Paddy cultivation is a major agricultural activity in the Edirne province of Türkiye. When examining the province's share of national paddy production area and volume from 2004 to 2024, a notable trend is observed (Fig 1). Although its share has, at times, peaked at around 50%, it has more recently levelled off to approximately 40%. This indicates that while Edirne continues to be a dominant player, its share of national production has become more consistent in recent years (Fig 1).

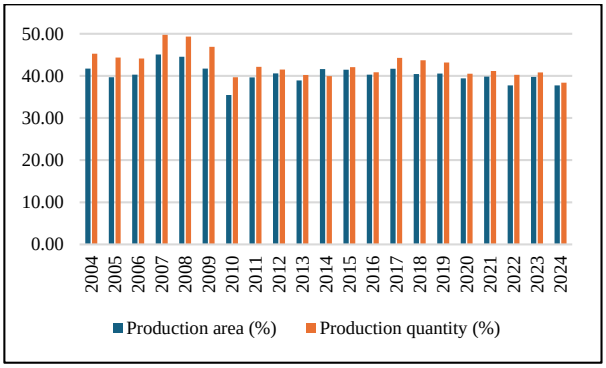


Fig. 1. Edirne province's share in Türkiye's paddy production area and production
Source: [16].

Figure 2 illustrates the fluctuation of Türkiye's self-sufficiency rate for paddy between 2000 and 2023. The data shows a notable increase in the rate over this period, indicating a growing capacity to meet domestic demand.

Initially, from 2000 to 2002, the self-sufficiency rate was relatively low, hovering between 35% and 40%. A significant and rapid increase began in 2003, with the rate rising

sharply to 68.21% in 2003 before falling back to around 50% in 2004. The period from 2005 to 2010 saw a general upward trend, culminating in a peak of nearly 90% in 2010. Following this peak, the rate experienced considerable volatility until 2019, when it reached another high of over 80%. In the last five years of the period (2019-2023), the self-sufficiency rate has remained relatively stable, averaging around 75%.

This sustained level suggests that Türkiye has achieved a more consistent and robust domestic supply of paddy in recent years, despite earlier fluctuations.

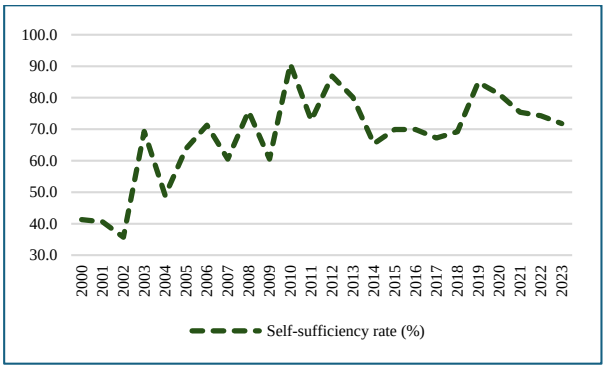


Fig. 2. Türkiye's self-sufficiency rate in paddy
Source: [17].

Thanks to its geographical location, climatic conditions, fertile soils, and the irrigation opportunities provided by the Meriç River, Edirne province alone accounts for more than 40% of Türkiye's total rice production. Production in the region contributes directly not only to the local economy but also to national food security. However, factors such as rising input costs (fertilizers, seeds, pesticides, and fuel), challenges in water resource management, market price fluctuations, and the potential impacts of climate change have recently threatened the profitability and sustainability of rice production in the region.

Therefore, it is of great importance to examine in detail the current economic structure of rice production activities in Edirne.

A review of the existing literature reveals that studies focusing on the economic aspects of rice production are quite limited and have been conducted in different regions. Among the studies carried out in various provinces, some have specifically focused on economic analyses. These include studies conducted in Kastamonu [21], Çanakkale [8] [14], Sinop [20], and Samsun [8]. In contrast, research conducted in Edirne has primarily focused on policies related to paddy production, sustainability, environmental pollution, and marketing [2, 3, 7, 13, 15, 18].

The main objective of this study is to conduct an economic analysis of rice farming enterprises in Edirne province—Türkiye's most important rice production center—and to reveal their production costs, income levels, and profitability. This study aims to contribute significantly to the existing literature by presenting the current cost and profitability structure of rice production in Edirne province. The findings of the research are expected to support rice producers in their decision-making processes toward achieving more profitable and sustainable production.

MATERIALS AND METHODS

The original data for this study were collected through structured surveys conducted via face-to-face interviews with farmers in the İpsala district of Edirne province, a region where rice cultivation is particularly intensive.

The research area was given in Map 1.

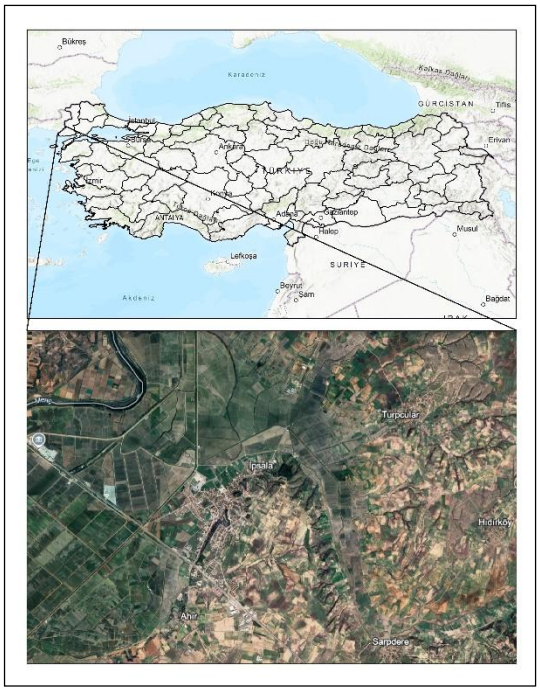
The survey data cover the 2023 production period. In addition to these primary data, the secondary data employed in the study were obtained from the Turkish Statistical Institute (TURKSTAT) and the Edirne Provincial Directorate of Agriculture and Forestry under the Ministry of Agriculture and Forestry.

The total number of rice-producing farms, the size of the cultivation area, and the addresses were obtained from the İpsala District Directorate of Agriculture and Forestry. The sample size for the study was determined using proportional sampling.

The sample size was calculated using the following formula [11].

$$n = \frac{Np(1-p)}{(N-1)\sigma^2_{px}+p(1-p)^2} \quad \text{.....(1)}$$

where:
n: Sample size,
N: Total number of units in the population,
p: Prediction rate
σ^2: Population variance.



Map 1. Location map of the study areas
Source: Own calculation.

A total of 65 farms were surveyed, with the sample size calculated to ensure a 90% confidence level and a 10% margin of error.
The production costs for paddy farms were analyzed using a single-product budget analysis method. Total costs were categorized into variable costs (VC) and fixed costs (FC), with all calculations based on prices from the 2023 production season. Specific assumptions were made for certain cost items: family labor wages were based on the prevailing foreign labor wages in the region, and the revolving fund interest was calculated at half of the 2023 crop production loan interest rate from the Turkish Ziraat Bank. Additionally, general administrative expenses were assumed to be 3.00% of the total variable costs.
To evaluate profitability, key metrics were calculated using established methodologies from the literature [1, 4, 5, 9, 12]. The gross production value was determined by multiplying the paddy yield (kg/ha) by its market price ($/kg). Gross profit was calculated by subtracting variable costs from the gross production value, and net profit was obtained by subtracting total production costs. Relative profit was derived by dividing the gross production value by the total costs, providing a key indicator of profitability.

RESULTS AND DISCUSSIONS

An analysis of the demographic and socioeconomic characteristics of the surveyed farmers reveals a profile of experienced and mature producers highly specialized in paddy cultivation. The average age of the farmers is 51.75 years, with a wide range from 22 to 79 years, as indicated by a standard deviation of 16.41. This suggests a mix of generations within the farming community. The average farmer has 9.40 years of education, which is notable. With an average of 26.06 years of general agricultural experience and 24.32 years specifically in paddy production, the farmers are highly seasoned and knowledgeable in their field. The small difference between these two figures highlights that a majority of the farmers have focused on paddy production throughout most of their careers.
The data on income sources shows a strong reliance on farming. While 72.31% of farmers do not have non-agricultural income, a significant 72.31% also reported having agricultural income from sources outside their own farm, indicating diversification within the agricultural sector. The majority of farmers (81.54%) are covered by social security, and an even higher percentage (78.46%) have agricultural insurance, which points to a certain level of stability and risk awareness. The data also reveals a high rate of indebtedness among the farmers, with 76.92% reporting debt.
Finally, a substantial majority of the farmers (86.15%) are members of agricultural organizations (Table 1).
An analysis of the land ownership and usage of the surveyed farms reveals a strong emphasis on paddy cultivation. The average farm size is 30.57 hectares, with a substantial portion (23.99 ha) dedicated to paddy, underscoring its central role in agricultural operations. While the majority of the total land (62.35%) is

owned by the farmers (19.06 ha), a significant portion of the paddy cultivation area consists of rented land (39.45%), suggesting that farmers often rent land to expand their production beyond their own property. Common land accounts for a smaller share, at 9.20% of the total and 7.15% of the paddy area.

Table 1. General characteristics of farms and farmers

Characteristics	Average	Minimum	Maximum	Standard deviation
Age (year)	51.75	22.00	79.00	16.41
Education (year)	9.40	0.00	16.00	2.21
Population (person / family)	4.14	1.00	6.00	1.42
Experience in agriculture production (year)	26.06	4.00	50.00	13.54
Experience in paddy production (year)	24.32	4.00	45.00	12.24
	N		%	
	Yes	No	Yes	No
Non-agricultural income	18	47	27.69	72.31
Agricultural income (from outside own farm)	47	18	72.31	27.69
Social security status of farmers	53	12	81.54	18.46
Farmers' agricultural insurance status	51	14	78.46	21.54
Farmers' situation in livestock	21	44	32.31	67.69
Indebtedness of farmers	50	15	76.92	23.08
Membership status of farmers in agricultural organizations	56	9	86.15	13.85

Source: Own calculation.

The data also highlights the critical importance of irrigation for paddy production. A high percentage of the total land (75.60%) is irrigated, but this figure is even more pronounced for paddy cultivation, where 91.58% of the land is irrigated. This finding reinforces the crop's high dependency on water and proper irrigation infrastructure, while dry land accounts for a minimal share of both total (24.40%) and paddy land (8.42%) (Table 2).

Table 2. Land presence of farms

Indicators	Total land		Paddy land	
	ha	%	ha	%
Land size	30.57	100.00	23.99	100.00
Property land	19.06	62.35	12.81	53.40
Rent land	8.70	28.45	9.46	39.45
Common land	2.81	9.20	1.72	7.15
Irrigated land	23.11	75.60	21.97	91.58
Dry land	7.46	24.40	2.02	8.42

Source: Own calculation.

The cropping pattern analysis showed that paddy cultivation was the primary crop, covering an average of 23.99 hectares per farm. The farms also diversified their production with other crops, such as sunflower seeds, wheat, rapeseed, and walnuts (Table 3).

Table 3. Plants grown in farms

Plants	ha	%
Paddy	23.99	78.48
Sunflower seeds	3.24	10.60
Wheat	2.44	7.97
Rapeseed	0.54	1.77
Walnut	0.23	0.75
Other products	0.13	0.43
Total	30.57	100.00

Source: Own calculation.

Sunflower seeds were the second most common crop, with an average area of 3.24 hectares, followed by wheat at 2.44 hectares. Proportionally, paddy accounted for 78.48% of the total cultivated area, followed by sunflower seeds at 10.60%, and wheat at 7.97% (Table 3).

The production costs in paddy cultivation were analysed on both a per-hectare and per-farm basis, categorized into variable and fixed costs. The variable cost components included water and electricity, harvesting, fertilizer, temporary labour, machine rental, seeds, pesticides, and interest on revolving capital. The fixed costs comprised land rent, general administrative expenses, and wages for permanent family labour. The analysis revealed that the average total variable costs were $63,031.33 per farm ($2,630.46 per hectare), while average total fixed costs were $43,336.51 per farm ($1,808.71 per hectare). This resulted in an average total production cost of $106,367.84 per farm, or $4,439.17 per hectare.

A proportional analysis of production costs reveals the key expenditure categories for the surveyed farms. Variable costs constituted 59.26% of the total costs, with water and electricity (14.62%), harvesting (11.05%), and fertilizer (7.63%) representing the largest components within this category. Other notable variable expenses included machine rent (5.94%), seed cost (5.68%), pesticide cost (4.78%), foreign labor (2.91%), and revolving fund interest (5.39%), along with other variable costs (1.26%).

Fixed costs, which accounted for the remaining 40.74% of total costs, were dominated by land rent at a significant 32.00%. Other fixed cost components were relatively minor, including family labor wages (5.19%), general administrative expenses (1.78%), and other fixed costs (1.77%) (Table 4). This distribution underscores the considerable financial burden of land rent on paddy farmers in the region.

In a study conducted in the province of Çanakkale [14], the total cost of paddy production was calculated as $2,906.17 per hectare. The share of variable costs in total costs was determined to be 71.87%, while fixed costs accounted for 28.13%. Among total production costs, the highest proportion was land rent (25.98%), followed by land preparation (15.22%), harvesting (13.87%, including drying, bagging, and transportation), irrigation water and energy costs (9.83%), fertilization (8.59%), and pesticide costs (5.72%). Similarly, in a study carried out in the Biga district of Çanakkale province [8], the share of variable costs in total costs was 71.60%, and fixed costs accounted for 28.40%. Within the total production costs, the largest cost item was pest control (23.34%), followed by soil preparation, sowing, and maintenance (21.17%), land rent (15.50%), irrigation (10.18%), and harvesting and transportation (7.01%). In another study conducted in Sinop province [20], variable costs accounted for 83.74% of total costs, while fixed costs represented 16.26%. In Samsun province, a study focusing on the paddy variety Osmancık found that variable costs accounted for 51.22% of total costs, while fixed costs accounted for 48.78%. Among total costs, land rent (24.40%) represented the largest share, followed by fertilization (7.60%) and seed cost (7.09%). In the same study, for the Baldo variety, the share of variable costs was 52.48%, and fixed costs accounted for 47.52%. The largest cost component was land rent (23.34%), followed by fertilization (7.66%) [10]. The results of this study reveal that the average production cost of paddy farms in Edirne ($4,439.17/ha) is considerably higher than those reported in other provinces such as Çanakkale ($2,906.17/ha). The share of variable costs in Edirne (59.26%) is lower than in Sinop (83.74%) and Çanakkale (71.87%), but similar to the levels observed in Samsun (around 51–52%). This indicates that paddy production in Edirne is characterized by a higher proportion of fixed costs, likely due to elevated land rent and energy-related expenses.

Across all regions, land rent remains the dominant cost component. However, its share in Edirne (32.00%) is substantially higher compared to other provinces (15–26%), suggesting intense competition for agricultural land. In addition, water and electricity (14.62%) and harvesting (11.05%) constitute significant shares of total costs, reflecting the high irrigation requirements and mechanization levels in the region. Overall, these findings demonstrate that paddy production in Edirne is more cost-intensive than in other rice-producing provinces of Türkiye, primarily due to higher land and energy costs.

Table 4. Production costs and rates in paddy farms

Cost items	Cost (US ($) per hectare)	Cost (US ($)/farms)	%
Water and electricity	649.00	15,715.90	14.62
Harvesting (mowing, drying, marketing)	490.01	11,730.64	11.05
Fertiliser	338.85	8,095.67	7.63
Machinery rental	263.85	6,316.50	5.94
Seed	252.07	6,020.51	5.68
Pesticide	212.20	5,062.63	4.78
Temporary labour	129.28	3,024.71	2.91
Revolving fund interest	239.13	5,730.12	5.39
Other variable costs	56.07	1,334.65	1.26
Total variable costs (1)	2,630.46	63,031.33	59.26
Land rent	1,420.72	34,213.99	32.00
Permanent labour	230.35	5,423.10	5.19
Administrative costs	78.91	1,890.94	1.78
Other fixed costs (insurance, taxes, licenses)	78.73	1,808.48	1.77
Total fixed costs (2)	1,808.71	43,336.51	40.74
Total costs (1+2)	4,439.17	106,367.84	100.00

Source: Own calculation.

The total gross production value of rice refers to the sum of the income earned from the sale of rice and the agricultural support given for rice production. In the calculated gross production value for rice, income derived from rice sales accounted for 98.20%. The remaining 1.80% was obtained from government support (Table 5).

The total gross production value of paddy production in the farms was calculated as $6,853.52 per hectare. Gross profit, which was calculated by subtracting the variable costs from GPV, was calculated as $4,223.06 per hectare. Net profit, which is calculated by subtracting total production costs from GPV, was calculated as $2,414.35 per hectare. The relative profit calculated by dividing GPV by total production costs was found to be 1.54 on average. It shows that rice-producing farms obtain 1.54 units of production value for one unit cost, 0.54 units of which are profit (Table 5).

In a study conducted in Çanakkale province [14], the paddy yield was reported as 7,852 kg/ha, with a gross production value of $4,161.03 per hectare, a gross profit of $2,072.47 per hectare, a net profit of $1,254.85 per hectare, and a profitability ratio of 1.43.

In Sinop province, a study determined that the paddy yield was 6,530 kg/ha, with a relative profit ratio of 1.17 [20].

In another study conducted in Samsun province [10], the yield of the Baldo rice variety was 6,944 kg/ha with a relative profit ratio of 1.18, while for the Osmancık variety, the yield was 7,445 kg/ha with a relative profit ratio of 1.15.

In Edirne province, paddy yield was found to be 8,483 kg/ha [2], whereas a study covering various provinces across Türkiye reported an average paddy yield of 7,617 kg/ha [19].

The results of the current study demonstrate that paddy production in Edirne exhibits higher yield and profitability indicators compared to previous studies conducted in other provinces. The average paddy yield in Edirne (8,057.69 kg/ha) surpasses those reported for Çanakkale (7,852 kg/ha), Sinop (6,530 kg/ha), and Samsun (ranging from 6,944 to 7,445 kg/ha), as well as the national average of 7,617 kg/ha. In addition, the gross production value ($6,853.52/ha), gross profit ($4,223.06/ha), and net profit ($2,414.35/ha) in Edirne are substantially higher than those found in Çanakkale ($4,161.03, $2,072.47, and $1,254.85/ha, respectively). The relative profitability ratio of 1.54 in Edirne also exceeds the levels observed in other provinces (ranging from 1.15 to 1.43).

These findings suggest that paddy production in Edirne is more efficient and economically advantageous, likely due to higher yields and more favourable production conditions compared to other major rice-producing regions of Türkiye.

Table 5. Profitability indicators in rice farms

Profitability indicators	Farms average
1. Rice GPV (US ($)/ha) (9x11)	6,730.45
2. Agricultural support (US ($)/ha)	123.07
3. Total GPV (US ($)/ha) (1+2)	6,853.52
4. Variable costs (US ($)/ha)	2,630.46
5. Gross profit (US ($)/ha) (3-4)	4,223.06
6. Total production costs (US ($)/ha)	4,439.17
7. Net profit (US ($)/ha) (3-6)	2,414.35
8. Yield (kg/ha)	8,057.69
9. Kg cost (US ($)) (6/8)	0.55
10. Selling price per kg (US ($))	0.84
11. Net profit per kg (US ($)) (10-9)	0.28
12. Relative profit (3/6)	1.54

Source: Own calculation.

CONCLUSIONS

This study provides significant data by conducting an economic analysis of paddy rice farms in the Edirne province, which accounts for approximately 40% of Türkiye's total paddy production. The findings indicate that paddy farming is a profitable activity in the region. The average net profit per hectare was calculated as $2,414.35 and the relative profitability was determined to be 1.54, confirming that production is economically sustainable. This result validates that paddy rice cultivation continues to be a crucial source of income for farmers in Edirne. Land rent, which constitutes 32% of the total costs in the research, stands out as the single largest expense for producers. This situation significantly impacts the profit margin of farmers, particularly those who operate on rented land. Similarly, costs such as water and electricity (14.62%) and harvesting (11.05%) also represent high proportions of the total expenditure. These findings suggest that the cost structure needs to be examined more closely to enhance the profitability of producers.

In light of the study's findings, several policy recommendations can be made to improve profitability and ensure the sustainability of paddy cultivation. The largest cost item, land rent, can be mitigated through state land policies and rental regulations. Since water and electricity are also significant expenses, promoting the use of renewable energy sources, such as solar power for irrigation pumps, could effectively reduce these costs. Providing financial support to producers—through low-interest loans or grant programs—for the acquisition of new and fuel-efficient machinery would further lower operational costs and increase profitability. Additionally, farmers can achieve more favourable prices for inputs (e.g., fertilizers, seeds) by acting collectively. Strengthening the role and function of producer organizations in this regard would increase the bargaining power of individual farmers. These measures would not only boost farmer profitability but also help Edirne maintain its leading position in Türkiye’s rice production and contribute to the long-term sustainability of paddy rice cultivation. Future research could provide more in-depth analyses on optimizing these specific cost items, thereby enriching these recommendations.

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MELIPONICULTURE AS A CATALYST FOR RURAL AGRICULTURAL LIVELIHOODS: INSIGHTS FROM KOTA TINGGI DISTRICT, MALAYSIA

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Abstract

This study examines the role of stingless beekeeping, or meliponiculture, as a catalyst for enhancing rural enterprise and agricultural livelihoods in Sedeli Kecil Village, located in the Kota Tinggi District of Johor, Malaysia. This study evaluates the meliponiculture initiative through the lens of the One Village One Product approach, in alignment with the objectives of Malaysia's National Rural Development Policy 2030, which envisions rural transformation toward inclusivity, prosperity, and sustainability. The project's performance is measured using 24 systematically developed indicators, each mapped to the three fundamental OVOP pillars namely, Think Globally, Act Locally; Self-Reliance and Creativity, and; Human Resource Development. A quantitative approach was employed through questionnaire-guided interviews with 15 participants comprising project managers and local community members. Data were analysed using descriptive statistics and mean score analysis. Findings reveal a strong alignment between the stingless beekeeping initiative and the OVOP framework. Indicators such as cultural identity, digital market access, product innovation, and community support were rated as highly influential, underscoring the project's success in promoting local enterprise and environmental sustainability. However, relatively lower scores for income gains, product certification, and capacity-building efforts suggest areas for improvement. Overall, this study provides empirical evidence on the role of niche rural enterprises in diversifying agricultural livelihoods and advancing community-based development. The stingless beekeeping model presents a promising and replicable approach for revitalizing rural economies in Malaysia and comparable contexts globally.

Key words**:** *stingless beekeeping, rural enterprise development, agricultural livelihoods, OVOP, sustainable rural development*

INTRODUCTION

The National Rural Development Policy 2030 (NRDP 2030), launched by Malaysia's Ministry of Rural and Regional Development in 2019, envisions transforming rural areas into modern, inclusive, prosperous, and sustainable communities by 2030 [12, 17]. Anchored on nine strategic pillars, including economic prosperity, entrepreneurship, infrastructure development, environmental sustainability, and human capital empowerment; the NRDP 2030 seeks to bridge the rural-urban development gap by fostering entrepreneurship, modernising the agricultural sector, promoting income diversification through non-farming activities, advancing green technologies, and enhancing the overall quality of rural livelihoods [17].

The launch of NRDP 2030 complements existing frameworks, particularly the National Rural Physical Planning Policy 2030 and the National Agrofood Policy 2.0 (NAP 2.0) [3]. These integrated strategies are aimed at diversifying rural income sources and strengthening rural development initiatives beyond the traditional agricultural economy. This emphasis stems from the diminishing role of agriculture in Malaysia's GDP, implying that reliance on agriculture alone may no longer be sufficient to sustain long-term rural development [13].

Against this backdrop, the One Village One Product (OVOP) initiative has re-emerged as a

viable, community-led strategy for driving rural transformation [13]. Inspired by Japan's OVOP movement, Malaysia's adaptation emphasizes locally grounded product development rooted in the natural, cultural, and traditional strengths of each rural area [10, 6]. The OVOP agenda aligns with the NRDP's pillars by fostering localized economic growth, supporting value-added activities, and building resilient community enterprises [7, 8]. It also directly supports grassroots implementation of the Sustainable Development Goals (SDGs), especially those related to poverty reduction (SDG 1), decent work (SDG 8), and sustainable communities (SDG 11) [17].

The OVOP model has been shown to contribute positively to rural entrepreneurship and social capital by encouraging participation, innovation, and local pride [14, 15]. However, its success depends significantly on local capacity, effective institutional support, market connectivity, and access to training and resources [10, 19, 24]. In this regard, community-based stingless beekeeping projects have emerged as innovative and sustainable models of OVOP, particularly in rural regions like Kota Tinggi, Johor. These projects not only promote rural entrepreneurship but also complement agricultural livelihoods by integrating ecological conservation and non-timber income generation.

Against this backdrop, this study addresses the need for comprehensive empirical research to assess the effectiveness of OVOP-inspired rural enterprise models such as stingless beekeeping projects, in enhancing rural livelihoods and agricultural resilience. In this article, the authors have assessed the effectiveness of stingless beekeeping project carried out by the rural participants. The findings could offer critical insights for rural planners and local stakeholders working towards sustainable agricultural livelihoods and rural transformation.

Literature review

Rural Economic Transformation and Livelihood Diversification in Malaysia

Malaysia's rural development trajectory has experienced significant transformation since the early 2000s, largely driven by national efforts to reduce the rural–urban development gap and to create more inclusive, resilient, and sustainable rural economies [11]. Traditionally, rural communities have relied heavily on agriculture as their primary economic activity. However, the long-term viability of this sector has come under pressure due to several structural and socio-economic challenges, including declining productivity, land fragmentation, an ageing farming population, youth outmigration, and heightened vulnerability to climatic and market fluctuations [3, 12].

These challenges have highlighted the limitations of agriculture as a sole engine of rural growth, prompting the need for more diversified and enterprise-driven development strategies. In response, the Malaysian government has launched several integrated policy frameworks aimed at revitalizing the rural economy through entrepreneurship, innovation, and agricultural diversification [9]. The NRDP 2030 serves as a comprehensive roadmap for transforming rural areas into modern, inclusive, and sustainable communities. It emphasizes economic empowerment, infrastructure development, environmental stewardship, and human capital enhancement [17].

Complementing this, the National Agrofood Policy 2.0 (NAP 2.0) aims to reposition the agrifood sector by promoting smart agriculture, value-added agro-based products, and stronger agropreneur ecosystems. Collectively, these policies signify a paradigmatic shift away from subsistence-based livelihoods toward a more entrepreneurial and diversified rural economy [11, 14]. A key strategy within this transformation agenda is agricultural diversification, which has been widely acknowledged as essential for reducing rural poverty, enhancing household resilience, and mitigating the risks associated with monoculture farming and commodity price volatility. Diversification involves expanding rural income-generating activities beyond conventional farming to include agri-tourism, aquaculture, agro-processing, and the

sustainable utilization of non-timber forest products (NTFPs) [22]. One of the most promising and innovative diversification approaches in Malaysia is stingless beekeeping, which effectively integrates ecological conservation with enterprise-based rural development [10].

According to the Food and Agriculture Organization [4], livelihood strategies that focus on high-value niche products, especially those grounded in local knowledge and environmentally sustainable practices, can be transformative for rural communities. Stingless bee honey, harvested from indigenous *Trigona* species, has gained traction due to its medicinal qualities, market potential, and organic appeal. These enterprises are particularly well-suited for smallholder systems, requiring relatively low capital investment and relying on locally available natural resources. Moreover, stingless beekeeping can be implemented alongside other agricultural activities, making it ideal for integrated rural livelihood systems [1, 2].

The benefits of this diversification model are multi-dimensional [9]. Economically, it opens additional income streams and market opportunities, particularly when integrated with branding, certification, and tourism-related ventures [5, 16]. Socially, it fosters local participation, particularly among youth and women, revitalizing interest in agriculture and strengthening community cohesion. Environmentally, it contributes to pollination services, biodiversity conservation, and sustainable land use, thereby enhancing ecosystem resilience [18].

OVOP, Community-Based Enterprises and Stingless Beekeeping Project

The One Village One Product (OVOP) movement, first introduced in Oita Prefecture, Japan, in the late 1970s, was envisioned as a strategy to revitalize rural areas through community-led entrepreneurship [6, 8]. Led by Governor Hiramatsu, the initiative emphasized empowering rural residents to develop and commercialize unique, locally based products by leveraging indigenous knowledge, natural resources, and cultural heritage [15, 23]. The OVOP philosophy is anchored in three core principles as stated in Figure 1 below.

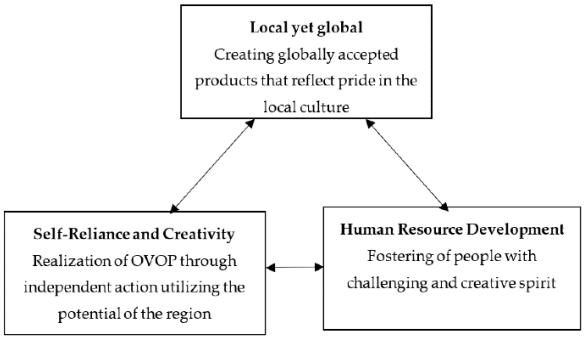


Fig. 1. The three core principles of OVOP concept. Source: [6, 10, 8].

The success of the OVOP model in Japan spurred its adaptation in several Southeast Asian countries, including Thailand, Indonesia, the Philippines, and Malaysia [8, 21]. In the Malaysian context, OVOP was integrated into the rural development agenda in the early 2000s and has since been recognized as a key instrument in advancing inclusive rural economic growth. Central to the OVOP strategy is the role of community-based enterprises (CBEs), which function as vehicles for collective ownership, participatory governance, and local innovation [10].

The application of OVOP model in rural Malaysia's context however not without its challenges which in turn have limited the success and scalability of CBEs. According to Kamarudin [10], common barriers include limited market access, weak branding and packaging strategies, poor digital marketing competencies, and difficulties in navigating certification systems such as halal or food safety compliance. Moreover, supply chain fragmentation and inadequate institutional coordination often hinder the ability of rural producers to integrate with regional or global markets. These issues highlight the need for more targeted interventions in areas such as capacity building, product innovation, digital upskilling, and infrastructure support.

Despite these hindrances, there are cases of successful CBEs which shown strong resilience that enable rural communities to pool resources, apply indigenous knowledge, and build entrepreneurial capacities in a way that enhances local agency and social capital.

Studies by [6, 10, 20] have shown that well-functioning CBEs lead to improved livelihoods, equitable economic participation, and enhanced community cohesion, particularly when supported by effective leadership, institutional support, and access to markets. In this sense, CBEs are not only income-generating mechanisms but also tools for strengthening resilience, especially in the face of external shocks such as economic downturns or pandemics.

Within this framework, stingless beekeeping stands out as a compelling example of an OVOP-aligned community-based enterprise. Stingless beekeeping, or *meliponiculture*, has emerged as a viable rural enterprise in Malaysia, particularly in areas seeking sustainable income diversification (Photo 1). This practice involves the cultivation of native *Trigona* species, which offer multiple ecological and economic benefits. Beyond producing high-value products such as honey, propolis, and beeswax, stingless bees play a vital role in enhancing biodiversity and supporting natural pollination processes, making the activity well-aligned with environmental sustainability goals [1].



Photo 1. Among stingless keeping products by rural community in Kota Tinggi, Malaysia
Source: [20].

Due to its low capital requirements and compatibility with existing agricultural practices, stingless beekeeping has gained traction among smallholders, particularly in rural areas like Kota Tinggi, Johor. As a form of non-timber forest product (NTFP) enterprise, it complements traditional farming while contributing to income generation, food security, and ecological conservation [10, 19]. In this sense, stingless beekeeping exemplifies the core principles of the OVOP (Figure 1), positioning it as a CBE with high potential for rural resilience.

Table 1. Indicators for stingless beekeeping project formulated based on the OVOP key principles

OVOP Core Principle	**Potential Indicators**
Think globally, act locally (OVOP Market and Product Identity)	1. Local products reflect local cultural identity and taste. 2. Products have access to broader/digital markets. 3. Increased value and recognition of local products. 4. New economic opportunities opened through OVOP product branding. 5. Support from government (marketing, branding, export assistance). 6. Use of local materials and workforce in production. 7. Compliance with quality standards and certification.
Self-reliance and creativity (Entrepreneurial Resilience & Local Initiative)	1. Ability of entrepreneurs to run business independently. 2. Innovation in product design, packaging, or flavour. 3. Use of inherited or traditional skills in product development. 4. Willingness to adopt new production technology. 5. Existence of community support and participation in the project. 6. Increase in income from stingless bee products. 7. Creation of new job opportunities in the village. 8. Existence of SME incentives or support schemes. 9. Utilization of local natural resources (e.g., plants, herbs, forests).
Human Resource Development (Capacity Building & Local Leadership)	1. Improvement in technical/marketing/management skills after training. 2. Knowledge gained in business management (e.g., cost, pricing, promotion). 3. Continuous innovation and experimentation with new ideas. 4. Leadership qualities among project members (trustworthy, committed). 5. Access to mentoring, peer support, or expert advice. 6. Government support in SME education and skills development. 7. Strengthening of links with rural–urban supply chains. 8. Awareness in the community about the importance of business development.

Source: [6, 8, 10, 11, 14, 15, 19].

However, the expansion of stingless beekeeping faces notable constraints. Challenges such as limited access to training, inadequate product certification, fragmented supply chains, and poor digital marketing skills continue to inhibit scalability and market penetration [10, 14, 15]. Nevertheless, successful cases have shown that when supported by strong leadership, institutional backing, and strategic capacity building, stingless beekeeping can serve as a replicable

model for OVOP-based rural development across Malaysia and Southeast Asia [1, 19].

Despite its challenges, the project has shown its ability to combine environmental sustainability, low capital requirements, cultural significance, and high market value, all while being rooted in local ecosystems. Projects like those in Kota Tinggi, Johor, showcase how stingless bee honey production can foster rural innovation, environmental stewardship, and income diversification. Therefore, this study explores how OVOP principles can be operationalized in such niche sectors to enhance the resilience and economic viability of CBEs related to stingless beekeeping projects in rural Malaysian communities, using a set of indicators as presented in Table 1.

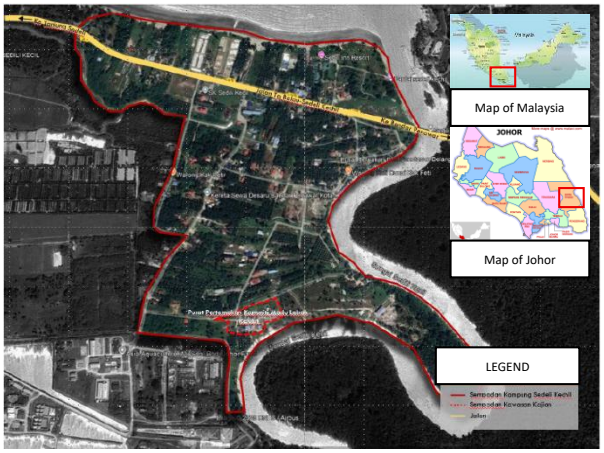
The list of indicators as shown in Table 1 is organized around the three core principles of the OVOP framework namely; Think Globally, Act Locally (7 indicators), Self-Reliance and Creativity (9 indicators), and Human Resource Development (8 indicators). These indicators were carefully selected after consultation with researchers from local university to assess key dimensions of the stingless beekeeping project's performance, including market access, innovation, community participation, capacity building, and income generation.

The streamlined set ensures clarity, relevance, and measurability for effective data collection and analysis in the field.

MATERIALS AND METHODS

Study Area of Kota Tinggi, Malaysia

This study conducts an in-depth investigation of Sedili Kecil, a traditional Malay village located in the Kota Tinggi District of Johor. The village was deliberately selected as the case study site due to its active involvement in stingless beekeeping and its relevance to rural development within the One Village One Product (OVOP) framework [13] (Map 1). With a total area of 347 ha, the village community has effectively utilized surrounding forest resources and rich local flora, making it highly suitable for stingless beekeeping farming [20]. This ecological advantage has enabled the production of high-quality stingless bee honey, positioning it as a potential OVOP signature product. What sets Sedili Kecil apart is the strong community participation and entrepreneurial spirit demonstrated by its residents. Villagers are directly involved across the entire honey production value chain, from farming and processing to packaging and marketing, exemplifying the core OVOP principles of self-reliance and community empowerment through local enterprise.



Map 1. Location of Sedili Kecil Village in Kota Tinggi District of Johor, Malaysia.
Source: Research fieldwork [20].

Moreover, the village's location within a tourism zone, as outlined in the Kota Tinggi Local Plan 2035, enhances the potential of stingless bee honey not only as a health product but also as a culturally significant tourism commodity. It offers visitors an authentic rural experience, aligning with community-based tourism strategies. Sedili Kecil has received support from multiple agencies including Malaysian Agricultural Research and Development Institute (MARDI), The Federal Agricultural Marketing Authority (FAMA), the Ministry of Rural Development (KPLB), and Universiti Malaysia Terengganu (UMT) [20].

Methodology

As shown in Map 1, the village's small and well-defined sample size i.e. active participants of 15 people including project leaders, beekeepers, and community members directly engaged in stingless beekeeping-related activities such as production, processing, and

marketing, which allows for a complete census, ensuring rich, accurate data collection from all involved participants. This study adopts a quantitative case study approach to assess the performance and impact of a community-based stingless beekeeping project within the framework of the OVOP initiative.

The methodological design was informed by the main objective of this research that is to assess the effectiveness of the project in supporting rural agricultural livelihoods. Given the small and identifiable population involved in the project (based on the preliminary study in February 2025), a full census approach was employed to ensure comprehensive data coverage. A structured questionnaire was developed based on 24 refined indicators derived from the three OVOP principles as previously presented in Table 1). Each principle was represented by 4 Likert scale (1 = Not influential to 4 = Highly influential), designed to measure participants' perceptions of performance, challenges, and benefits across multiple dimensions of the project. Prior to full deployment, the questionnaire was piloted with a small subset of respondents to ensure clarity, validity and for adjustment of mean score categorization. Data were analyzed using descriptive statistics and mean score analysis (Table 2). To interpret the mean scores from the survey responses, this study employed a modified categorization scale tailored to the distribution pattern observed in the data. Initial analysis revealed a clustering of responses in the upper range of the Likert scale (particularly between 3.0 and 3.5), suggesting a tendency among respondents to rate most factors as important or influential. This pattern, while common in perception-based surveys, posed a challenge for drawing meaningful distinctions between moderately and highly rated factors. To address this issue and enhance interpretive clarity, the following customized mean score ranges were used.

Table 2. Category of mean score result and interpretation

Mean Score Range	Level/Interpretation
0.0 – 1.3	Not influential
1.4 – 3.0	Moderately influential
3.1 – 3.5	Influential
3.6 – 4.0	Highly influential

Source: Research Fieldwork [20].

This adjusted categorization enables finer differentiation among the factors, particularly at the upper end of the scale, and supports a more nuanced discussion of the findings.

It also allows the study to better identify which elements are merely accepted as important versus those that stand out as critical in shaping outcomes.

This methodological framework also provides a robust empirical foundation for understanding the operational dynamics of rural OVOP initiatives and contributes valuable insights into improving the scalability of stingless beekeeping as a sustainable rural enterprise model in Malaysia.

RESULTS AND DISCUSSIONS

Profile of Respondents and Beekeeping Activities

As shown in Table 3, the respondents comprised a total of 15 individuals, with a majority being male (60%) and the remaining 40% female.

Table 3. Profile of respondents (n=15)

Question	Answer	Frequency	%
Gender	Male	9	60.0
	Female	6	40.0
Age category	17-40 years	1	7.0
	41-55 years	6	40.0
	Above 55 years	8	53.0
Race	Malay	15	100.0
Origin	Born and raised here	9	60.0
	Migrated to this village	6	40.0
Status of involvement	Full-time participant	15	100.0
Income from beekeeping project	As a main income source	10	67.0
	As a side income	5	33.0
Number of hive/respondents	< 10 hives	7	46.0
	11-20 hives	4	27.0
	>20 hives	4	27.0

Source: Research Fieldwork [20].

Most respondents (53%) were aged above 55 years, followed by 40% in the 41–55 age group, and only one respondent (7%) aged between 17 and 40 years.

All participants were Malay.

In terms of origin, 60% were born and raised in the village, while 40% had migrated to the area.

All respondents were fully involved in the stingless beekeeping project on a full-time basis.

Regarding income, two-thirds (67%) relied on the beekeeping project as their main source of income, while the remaining 33% considered it a supplementary income source.

Hive Ownership and Honey Production (Kg/Month)

Table 4 presents a cross-tabulation of hive ownership and monthly honey production. The majority of respondents (46%) owned 6-10 hive units, typically producing only 1-2 kg of honey per month. This suggests that 6-10 hives may represent the optimal number manageable by most participants, potentially due to constraints in time, knowledge, logistics, or manpower. In contrast, respondents with more than 10 hives (11-20 units and above), though fewer in number (27% each), demonstrated higher productivity, with several producing more than 2 kg of honey monthly. This implies that those with greater hive ownership are better equipped, both in resources and management capacity.

Table 4. Cross-tabulation of hive ownership and monthly honey production among respondents (n=15)

Hive ownership (unit)	Honey production (kg/month)		
	<1 kg	1-2 kg	>2 kg
<10	0(0.0)	7(46%)	0(0.0)
11-20	0(0.0)	0(0.0)	4(27%)
>20	0(0.0)	0(0.0)	4(27%)

Source: Research Fieldwork [20].

The association is statistically significant (Chi-square = 30.000, $p < 0.001$), confirming a strong relationship between hive ownership and honey output. Overall, higher honey yields are consistently linked to ownership of more than 10 hives, reinforcing the notion that expanding hive capacity can substantially enhance production potential.

Evaluating the Effectiveness of *Meliponiculture* Aligned with OVOP Principles

This section analyses the survey findings to evaluate the perceived effectiveness of the stingless beekeeping community initiative in Sedili Kecil Village, based on respondents' perspectives [13].

The evaluation focuses on the list of indicators which have been identified earlier in Table 1, comprising a total of 24 indicators aligned with the principles of the OVOP principles (Table 5).

Table 5 presents the effectiveness of the stingless beekeeping project as evaluated against the key principles and indicators of the OVOP.

The analysis, based on the responses from 15 project participants, reveals overall positive perceptions, with the majority of indicators receiving mean scores within the “influential” (3.1–3.5) and “highly influential” (3.6–4.0) categories. This trend suggests a strong alignment between the stingless beekeeping initiative and the foundational principles of OVOP.

Under the first principle “Think Globally, Act Locally”, indicators such as “local products reflect local cultural identity and taste” and “access to broader or digital markets” received the highest mean score of 3.93, categorised as highly influential. These results underscore the project’s effectiveness in integrating local identity with global marketing strategies.

Similarly, branding and government support (mean scores of 3.60 and 3.47 respectively) were also seen as critical enablers. However, some indicators such as “increased value and recognition of local products” (3.40) and “compliance with quality standards” (3.53) were slightly lower, though still regarded as influential. Meanwhile, under the second principle “Self-Reliance and Creativity”, several indicators emerged as particularly impactful. For instance, “innovation in product design, packaging, or flavour”, “creation of new job opportunities”, “existence of community support”, and “utilization of local natural resources” all scored 3.80, highlighting the project’s role in fostering innovation, employment, and sustainable resource use. Interestingly, the indicator “increase in income” recorded a relatively lower mean score of 3.07, suggesting that while the project

contributes to economic improvement, income gains may not yet be fully optimised.

Table 5. Effectiveness of *meliponiculture* initiative aligned with OVOP principles (n=15)

Indicators	Likert Scale				Mean Value	Level of Effectiveness	Rank
	1	2	3	4			
OVOP Principle 1: Think globally, act locally							
1. Local products reflect local cultural identity and taste.	0	0	1	14	3.93	Highly influential	1
2. Products have access to broader/digital markets.	0	0	1	14	3.93	Highly influential	1
3. Increased value and recognition of local products.	0	1	7	7	3.40	Influential	5
4. New economic opportunities opened through OVOP product branding.	0	0	6	9	3.60	Highly influential	2
5. Support from government (marketing, branding, export assistance).	0	1	2	12	3.47	Influential	4
6. Use of local materials and workforce in production.	0	0	7	8	3.53	Influential	3
7. Compliance with quality standards and certification.	0	0	7	8	3.53	Influential	3
OVOP Principle 2: Self-reliance and creativity							
1. Ability of entrepreneurs to run business independently.	0	1	5	9	3.53	Influential	3
2. Innovation in product design, packaging, or flavour.	0	1	5	9	3.80	Highly influential	1
3. Use of inherited or traditional skills in product development.	0	1	2	12	3.73	Highly influential	2
4. Willingness to adopt new production technology.	0	1	8	6	3.33	Influential	4
5. Existence of community support and participation in the project.	1	0	0	14	3.80	Highly influential	1
6. Increase in income from stingless bee products.	0	3	8	4	3.07	Influential	6
7. Creation of new job opportunities in the village.	1	0	0	14	3.80	Highly influential	1
8. Existence of SME incentives or support schemes.	0	0	13	2	3.13	Influential	5
9. Utilization of local natural resources (e.g., plants, herbs, forests).	0	0	3	12	3.80	Highly influential	1
OVOP Principle 3: Human Resource Development							
1. Improvement in technical/marketing/management skills after training.	0	1	9	5	3.27	Influential	5
2. Knowledge gained in business management (e.g., cost, pricing, promotion).	0	1	4	10	3.60	Highly influential	1
3. Continuous innovation and experimentation with new ideas.	0	0	10	5	3.33	Influential	
4. Leadership qualities among project members (trustworthy, committed).	0	1	4	10	3.60	Highly influential	1
5. Access to mentoring, peer support, or expert advice.	0	1	6	8	3.47	Influential	2
6. Government support in SME education and skills development.	1	1	7	6	3.20	Influential	6
7. Strengthening of links with rural–urban supply chains.	0	1	7	7	3.40	Influential	3
8. Awareness in the community about the importance of business development.	0	0	10	5	3.33	Influential	4

Note: Mean score value of 0.0-1.3 denoted not influential; 1.4-3.0 denoted moderately influential; 3.1-3.5 (influential); 3.6-4.0 (highly influential)
Source: adopted from [13].

Lastly, under the third principle "Human Resource Development", indicators related to knowledge acquisition, leadership development, and business management skills performed well, with scores ranging from 3.27 to 3.60. Notably, "leadership qualities among project members" and "knowledge gained in business management" were rated as highly influential (3.60). However, areas such as "government support in SME education and skills development" and "technical/marketing skills after training" received relatively lower scores (3.20 and 3.27, respectively), indicating potential gaps in capacity-building support that warrant further attention.

Overall, the findings affirm the potential of stingless beekeeping as a catalyst for enhancing rural agricultural livelihoods, consistent with the objectives of the OVOP framework and the aspirations of the NRDP 2030. The project in Sedeli Kecil village demonstrates strong alignment with the core OVOP principles, particularly in leveraging local identity, fostering innovation, and building community-driven enterprise. While some limitations remain, especially in areas such as income optimization, product certification, and skills development, the initiative has also clearly contributed to diversifying economic opportunities, strengthening social capital, and promoting sustainable resource use.

CONCLUSIONS

In summary, this study has shown that the stingless beekeeping initiative in Sedili Kecil village, Johor, holds strong potential as a CBE model aligned with the OVOP approach. The project demonstrates positive impacts on rural livelihoods through enhanced community participation, product innovation, use of local

resources, and promotion of local identity. High effectiveness scores across key indicators such as access to broader markets, community support, and utilization of natural resources, reaffirm the project's alignment with the OVOP principles of Think Globally, Act Locally, Self-Reliance and Creativity, and Human Resource Development. Despite its relatively small scale, the initiative has provided employment, strengthened social capital, and diversified income sources among participants. These findings underscore the viability of stingless beekeeping as a scalable and replicable model for community-based rural transformation in Malaysia and other comparable rural contexts.

The study also provides a strong foundation for designing inclusive, locally rooted rural enterprise models under the OVOP agenda. Some valuable insights for policymakers and rural development practitioners, particularly on the need for targeted interventions in skills training, technology adoption, and institutional coordination can be highlighted for longitudinal studies regarding this topic in the future.

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STUDY ON THE TURKIYE ONION MARKET FROM 2013 TO 2024

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Abstract

Türkiye is one of the important onion producing countries. It is a country that has a surplus in its onion foreign trade. The study presents the main tendencies on the Türkiye onion market from 2013 to 2024. The indicators which were analyzed were sourced from both domestic and international databases and are as follows: cultivated area, total onion production, average output per hectare, base price, average growth rate for indicators and trade balance also (export and import). From these data, average for the duration, the standard deviation and the coefficient of variation were calculated. The study found that onion cultivated area in Türkiye remained constant between 2013 and 2024, while production increased by 32.2%. Onion yield was 28.9 tons/ha in 2013, reaching 37.9 tons/ha in 2024. Looking at the onion foreign trade balance, we may see that Türkiye is an exporting country. Onion yields fluctuate significantly over the years. Improving storage facilities in onion farming will ensure price stability in the domestic market.

Key words**:** *onion, Türkiye, cultivated area, production, growth rate, trade*

INTRODUCTION

Originating in Central Asia, the onion was domesticated in lands now known as Afghanistan, Iran, and Pakistan. The onion is a widespread and ancient agricultural crop, with a history dating back to 600 BC. Introduced to Northern Europe in the early Middle Ages around 500 AD, onions were a highly popular vegetable and food source cultivated and consumed by the Greeks and Romans between 400 and 300 BC [26]. Today, onion is cultivated worldwide due to their high nutritional value and health benefits, but the most widespread production is in the Northern Hemisphere due to favourable climatic conditions [27]. The historical and geographical importance of the onion also highlights its central role in global vegetable production statistics.

Indeed, the main species in global vegetable production are tomatoes, onions, cucumbers, cabbages, eggplants, mushrooms, carrots and turnips, peppers, and spinach, which account for approximately 50% of total production. Considering that global vegetable production has exceeded 1,500 million tons over the last 10 years, it can be said that these species have dominated vegetable production. When evaluating vegetable-producing countries, onions, with a total production of over 100 million tons, are the second most produced vegetable after tomatoes [3, 19]. In addition, global onion consumption has increased steadily by 30.3% from 2013 to 2022, reaching 109.9 million tons in 2022. Tajikistan and Niger are the world leaders in onion consumption, with 56.3 kg/person for each year. These countries are followed by Albania (38.9 kg/person), Algeria (38.8 kg/person), Sudan (32.1 kg/person), Senegal (31.9 kg/person), Uzbekistan (29.6 kg/person), and Libya (27.4 kg/person) [9]. However, an examination of onion consumption in Türkiye between 2013 and 2020 reveals that the increase did not parallel the global increase. Onion consumption (kg/person), which was 22.9 kg in 2013, increased by 8.7% to 24.9 kg by 2022 in Türkiye. Also, India leads the world in onion production with 31.7 million tons, followed by China, Egypt, the United States, Bangladesh, and Türkiye. Production in global

onion producers like India, China, Egypt, and the United States increased from 45.9 million tons in 2013 to 62.9 million tons in 2022. Türkiye ranks first not only in onion production but also in total vegetable production in the European Union (EU), and is also the EU's most important vegetable producer [21]. According to 2022 data, production was 2.3 million tons, ranking 6th in global onion production. Furthermore, the national onion area planted in 2024 increased by 0.8% compared to 2013, while onion production increased by 32.2% [23]. Türkiye is a major exporter to the United Arab Emirates, Iraq, Azerbaijan, and Saudi Arabia. In summary, it can be said that these production and consumption patterns around the world also reveal Türkiye's strategic position in onion and general vegetable production.

Türkiye is a competitive and important producer country not only in vegetable production but also in many horticultural crops, both in the EU and the world [1, 2]. However, although Türkiye does not experience major problems in terms of production in the fruit and vegetable market, producers sometimes have difficulty determining the vegetable species they will produce due to price volatility and problems related to environmental effects [13, 16, 20].While price fluctuations are affected by the scarcity or abundance of products offered to the market, environmental stress factors such as salinity, drought and high temperatures, which negatively affect vegetable production, can also be effective [14, 15, 25]. In addition, since the export status of the product in Türkiye also affects the prices, it affects which vegetable type will be preferred, especially in the production planning for the next year. Despite this strong production capacity, the Turkish onion sector is not immune to challenges shaped by market dynamics and environmental stress factors.

Among the species most affected by these factors in Türkiye is the onion. Onion production, and particularly its prices, are among the top priorities for producers in Türkiye almost every year. Considering these interrelated factors, understanding the dynamics of onion production and trade is of great importance to both producers and policy-makers.

For these reasons, the overall objective of this research is to analyse onion market trends in terms of area, production, and trade balance at the national and regional levels during the 2013-2024 period.

MATERIALS AND METHODS

The primary data for the study comprised onion planted area, production quantity, yield, producer price, import export, and foreign trade figures obtained from the Turkish Statistical Institute and Trade Map for the years 2013-2024.

The study aimed to reveal the foreign trade balance for the period under study. The data were processed using Excel, and descriptive statistics (mean, standard deviation, coefficient of variation) and annual growth rate were calculated.

The analysis results are presented in tables and figures. Standard deviation determines the level of dispersion of the data set. In short, it is used to understand how far the data in the data set deviates from the mean [4]. The codified indicators used in the presentation of the descriptive statistics are:

$$\partial = \sqrt{\frac{(xi - \bar{X})^2}{n}}$$

∂ = standard deviation;
xi = values of the data series over a number of years;
$\bar{X}$ = arithmetic mean
n = number of years considered.

Coefficient of variation:
$C = (\partial / \bar{X}) * 100$.

Its values can be between 0 and 100%. Between 0-10% indicates a higher degree of homogeneity of the series, between 10-20% is medium variation; over 20% - high variation [18].

Annual growth rate indicates the annual increase of the analysed indicator:

R (%) = [(Ending Value - Beginning Value) / (Beginning Value)]*100

RESULTS AND DISCUSSIONS

In line with Türkiye's harmonization with the European Union, it has also classified its regions according to the classification method developed by the European Union Statistical Office (Eurostat) since the 1970s. This classification is divided into 12 subregions according to the Nomenclature of Territorial Units for Statistics (NUTS1) [8, 22]. While onion cultivation areas in Türkiye during the period under review have fluctuated over the years, the cultivated area has remained constant. In 2013, onions were cultivated on 71,295 hectares, and in 2024, onions were cultivated on 71,882 hectares (Table 1). The Western Black Sea region ranks first with 22,032 hectares of cultivation area, followed by the Western Anatolia region with 20,983 hectares. An examination of the NUTS1 regions reveals significant decreases in the Istanbul, Western Marmara, and North-eastern Anatolia regions. In the Western Anatolia region, 79.8% increase was observed between 2013 and 2024 (Table 2). This finding points to the spatial differentiation of agricultural production areas in Türkiye [5, 6].

Table 1. Area cultivated with onion by development regions in the period 2013-2024 (hectares)

Regions	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Istanbul	111	89	88	67	68	61	61	58	57	53	47	43
Western Marmara	4,533	4,381	3,730	3,534	2,765	2,814	2,721	2,361	2,152	2,218	2,033	1,923
Aegean	4,578	4,357	4,199	3,972	4,417	4,278	4,693	3,587	3,544	3,450	3,005	2,886
Eastern Marmara	9,728	9,441	8,874	8,694	8,506	6,806	6,783	7,025	7,040	5,559	6,002	6,841
Western Anatolia	11,671	11,694	11,628	13,734	15,743	14,492	18,980	20,708	21,781	18,041	19,815	20,983
Mediterranean	14,962	15,100	14,622	14,601	11,995	10,681	10,589	13,909	12,113	9,712	9,146	8,885
Central Anatolia	3,338	3,116	3,008	2,707	2,406	2,313	2,014	2,114	2,560	2,549	2,460	2,698
Western Black Sea	17,023	15,670	15,032	16,311	15,597	14,950	18,621	21,450	23,000	18,455	19,828	22,032
Eastern Black Sea	181	184	164	144	124	135	133	115	117	114	105	104
North-eastern Anatolia	294	278	268	213	142	116	128	131	126	120	121	121
Central Anatolia	1,387	1,360	1,293	1,280	1,248	1,264	1,307	1,070	1,052	1,047	1,063	1,083
South-eastern Anatolia	3,489	3761	3,876	3,942	3,420	3,435	3,779	3,495	3,425	3,088	3,093	4,283
Total	71,295	69,430	66,783	69,200	66,431	61,344	69,806	76,022	76,967	64,406	66,717	71,882

Source: Turkstat Online, Accessed on 08.09.2025, [23].

Table 2. Descriptive statistics regarding area cultivated with onion in the period 2013-2024

Regions	2024/2013 (%)	MIN.	MAX.	Average	Standard deviation	Coefficient of variation (%)	Annual growth rate (%)
Istanbul	-61.7	43	111	67	19.88	29.77	-5.61
Western Marmara	-57.6	1,923	4,533	2,930	905.57	30.90	-5.23
Aegean	-37.0	2,886	4,693	3,914	607.17	15.51	-3.36
Eastern Marmara	-29.7	5,559	9,728	7,608	1,375.06	18.07	-2.70
Western Anatolia	79.8	11,628	21,781	16,606	3,901.88	23.50	7.25
Mediterranean	-40.6	8,885	15,100	12,193	2,374.93	19.48	-3.69
Central Anatolia	-19.2	2,014	3,338	2,607	395.59	15.17	-1.74
Western Black Sea	29.4	14,950	23,000	18,164	2,858.69	15.74	2.67
Eastern Black Sea	-42.8	104	184	135	28.04	20.81	-3.90
North-eastern Anatolia	-58.7	116	294	171	70.48	41.11	-5.34
Central Anatolia	-21.9	1,047	1,387	1,205	130.60	10.84	-1.99
South-eastern Anatolia	22.8	3,088	4,283	3,590	350.26	9.76	2.07
Total	0.8	61,344	76,967	69,190	4,505.03	6.51	0.07

Source: Own calculation.

An examination of the NUTS1 subregions reveals a concentration of cultivated areas in certain regions. A significant increase in cultivated area is observed in the Western Anatolia region, where the climate is suitable for onion production, and specialization is increasing. Onion acreage has decreased in regions where the service sector and industry are developing. A coefficient of variation analysis reveals a low variability (9.76%) in the South-eastern Anatolia region and a high variability (41.11%) in the North-eastern Anatolia region (Table 2).

A look at Türkiye's total onion production reveals an upward trend over the years. Total onion production in 2013 was 2,058,000 tons, rising to 2,722,000 tons by 2024 (Table 3).

Türkiye's average onion production between 2013 and 2024 was 2,329,000 tons. Western

Anatolia holds the largest share of production, as does its cultivation area.

Table 3. Total onion production by development region in the period 2013-2024 (thousand tons)

Regions	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Istanbul	2.1	1.6	1.7	1.3	1.3	1.1	1.1	1.0	1.2	1.1	0.9	0.8
Western Marmara	75.8	46.7	51.9	47.2	45.5	48.7	41.8	31.8	34.1	40.7	34.8	16.4
Aegean	85.6	83.0	79.8	78.4	106.9	88.0	98.4	86.0	84.9	93.1	83.3	87.5
Eastern Marmara	296.2	274.7	264.0	272.4	312.8	245.7	254.3	244.3	251.3	224.9	257.7	312.1
Western Anatolia	500.3	493.3	399.4	550.0	650.6	636.1	811.6	726.4	1,001.3	869.4	1,121.2	991.8
Mediterranean	408.3	442.7	525.1	525.9	440.2	334.5	340.7	434.4	392.7	351.2	316.0	322.2
Central Anatolia	60.2	56.9	57.1	56.4	58.0	56.2	62.8	67.7	74.3	78.5	61.8	73.9
Western Black Sea	530.5	440.7	534.8	616.2	585.4	539.8	616.0	707.2	679.0	708.5	731.8	762.2
Eastern Black Sea	1.2	1.3	1.1	1.2	1.1	1.2	1.2	1.1	1.1	1.2	1.0	1.0
Northeastern Anatolia	4.3	3.6	3.5	2.8	2.0	1.9	2.0	2.0	1.9	1.9	1.8	1.9
Central Anatolia	28.0	26.9	24.6	23.2	36.5	36.7	21.6	16.0	16.2	17.5	16.8	18.9
Southeastern Anatolia	65.8	66.7	78.0	80.1	74.7	83.6	90.8	91.3	88.1	86.7	88.5	133.1
Total	2,058.3	1,938.3	2,020.9	2,255.1	2314.9	2,073.5	2,342.3	2,409.0	2,626.2	2,474.6	2,715.7	2,721.8

Source: Turkstat Online, Accessed on 08.09.2025 [23].

When looking at production changes between 2013 and 2024, the largest increase in production occurred in the South-eastern Anatolia region, with a 102.3% share, followed by Western Anatolia, with a 98.2% share (Table 4). Türkiye's onion production increased by 32.2% during the period under review. It is noteworthy that the decline continued in the Istanbul and Western Marmara regions, which account for a relatively small share of total production. An examination of coefficients of variation revealed that variation was low across Türkiye (11.66%). The coefficient of variation in the North-eastern Anatolia region was 35.06%, indicating significant variation. The lowest variation occurred in the Eastern Black Sea region, with a 7.89% share. These findings are consistent with studies that highlight regional disparities in vegetable production and the role of spatial specialization in Turkish agriculture [5, 6]. Furthermore, the coefficient of variation has been widely used as a statistical measure to assess stability and fluctuation in agricultural production [10, 17].

Table 4. Statistical indicators calculated for total onion production in the period 2013-2024

Regions	2024/2013 (%)	MIN.	MAX.	Average	Standard deviation	Coefficient of variation (%)	Annual growth rate (%)
Istanbul	-63.3	1	2	1	0.37	29.13	-5.76
Western Marmara	-78.3	16	76	43	14.17	33.00	-7.12
Aegean	2.2	78	107	88	8.06	9.17	0.20
Eastern Marmara	5.3	225	313	268	27.49	10.28	0.49
Western Anatolia	98.2	399	1,121	729	230.98	31.67	8.93
Mediterranean	-21.1	316	526	403	73.50	18.25	-1.92
Central Anatolia	22.6	56	79	64	7.97	12.53	2.06
Western Black Sea	43.7	441	762	621	98.50	15.86	3.97
Eastern Black Sea	-12.0	1	1	1	0.09	7.89	-1.09
North-eastern Anatolia	-54.7	2	4	2	0.86	35.06	-4.97
Central Anatolia	-32.6	16	37	24	7.33	31.11	-2.96
South-eastern Anatolia	102.3	66	133	86	17.30	20.21	9.30
Total	32.2	1,938	2,722	2,329	271.65	11.66	2.93

Source: Own calculation.

A significant increase in onion yields was observed in 2024 compared to 2013. While it was 28.9 tons/ha in 2013, it increased to 37.9 tons/ha in 2024 (Table 5). The Western Anatolia region had the highest onion yield in Türkiye in 2024, at 47.3 tons/ha. The Western Marmara region had the lowest yield, at 8.5 tons/ha.

Table 5. Average production/ha of onion by development region during 2013-2024 (tons/ha)

Regions	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Istanbul	18.5	18.5	18.8	19.1	19.0	18.8	18.4	16.6	21.0	20.5	19.8	17.7
Western Marmara	16.7	10.7	13.9	13.3	16.4	17.3	15.4	13.5	15.8	18.3	17.1	8.5
Aegean	18.7	19.1	19.0	19.7	24.2	20.6	21.0	24.0	24.0	27.0	27.7	30.3
Eastern Marmara	30.5	29.1	29.7	31.3	36.8	36.1	37.5	34.8	35.7	40.5	42.9	45.6
Western Anatolia	42.9	42.2	34.3	40.0	41.3	43.9	42.8	35.1	46.0	48.2	56.6	47.3
Mediterranean	27.3	29.3	35.9	36.0	36.7	31.3	32.2	31.2	32.4	36.2	34.5	36.3
Central Anatolia	18.0	18.3	19.0	20.8	24.1	24.3	31.2	32.0	29.0	30.8	25.1	27.4
Western Black Sea	31.2	28.1	35.6	37.8	37.5	36.1	33.1	33.0	29.5	38.4	36.9	34.6
Eastern Black Sea	6.4	7.1	6.5	8.6	8.8	8.8	8.7	9.4	9.7	10.5	9.6	9.9
North-eastern Anatolia	14.7	13.1	12.9	13.3	13.8	16.0	15.6	15.6	15.0	15.5	15.2	16.1
Central Anatolia	20.2	19.8	19.1	18.2	29.2	29.0	16.5	15.0	15.4	16.7	15.8	17.4
South-eastern Anatolia	18.9	17.7	20.1	20.3	21.8	24.3	24.0	26.1	25.7	28.1	28.6	31.1
Total	28.9	27.9	30.3	32.6	34.8	33.8	33.6	31.7	34.1	38.4	40.7	37.9

Source: Turkstat, Online, Accessed on 08.09.2025 [23].

Compared to 2024, nine regions, excluding Western Marmara, Istanbul, and Central Anatolia, experienced significant increases in onion yield. The average onion yield across Türkiye was 34 tons/ha. An examination of the coefficient of variation for onion yield revealed that it ranged from 6.19% to 25.13% (Table 6). The increase in onion yield across Türkiye is noteworthy. Table 2 shows a 0.8% increase in onion planting area for Türkiye between 2013 and 2024, while the increase in yield was 31.2%. While production area remained constant, yields increased significantly due to both the use of technology and more modern agricultural practices.

Table 6. Descriptive statistics for onion production /hectare in 2013-2024

Regions	2024/2013 (%)	MIN.	MAX.	Average	Standard deviation	Coefficient of variation (%)	Annual growth rate (%)
Istanbul	-4.2	16.6	21.0	19	1.17	6.19	-0.39
Western Marmara	-48.9	8.5	18.3	15	2.90	19.68	-4.44
Aegean	62.1	18.7	30.3	23	3.88	16.93	5.65
Eastern Marmara	49.8	29.1	45.6	36	5.26	14.65	4.53
Western Anatolia	10.3	34.3	56.6	43	5.94	13.68	0.93
Mediterranean	32.9	27.3	36.7	33	3.11	9.35	2.99
Central Anatolia	51.7	18.0	32.0	25	5.15	20.60	4.70
Western Black Sea	11.0	28.1	38.4	34	3.37	9.83	1.00
Eastern Black Sea	54.0	6.4	10.5	9	1.32	15.25	4.91
Northeastern Anatolia	9.6	12.9	16.1	15	1.17	7.94	0.88
Central Anatolia	-13.7	15.0	29.2	19	4.86	25.13	-1.25
Southeastern Anatolia	64.8	17.7	31.1	24	4.20	17.58	5.89
Total	31.2	27.9	40.7	34	3.86	11.45	2.83

Source: Own calculation.

Onion is one of the most widely produced crops in Türkiye and is one of the crops that experiences intense annual price fluctuations. Producers make production decisions based on prices from the previous production period [7]. If production was high the previous year, prices are low. Producers incur losses and therefore do not produce the following year. In this case, supply is less than demand and prices increase excessively. The reason for price fluctuations in the dry onion market is explained by the Cobweb theory [11]. When Figure 1 is examined, it is striking that onion prices increased in one year and decreased in the following year between 2013 and 2021. While the onion price was 0.53 ₺/kg in 2013, it

decreased to 0.52-0.53 ₺/kg in 2014 and increased to 0.67-0.53 ₺/kg in 2015. The COVID-19 pandemic, particularly after 2020, and the subsequent instability in southern Türkiye have negatively impacted the country's economy. This situation, as with other agricultural products, has led to abnormal increases in onion prices. In 2021, the price of onions rose from 3.21 ₺0.53/kg to 7.53 ₺0.53/kg in 2012.

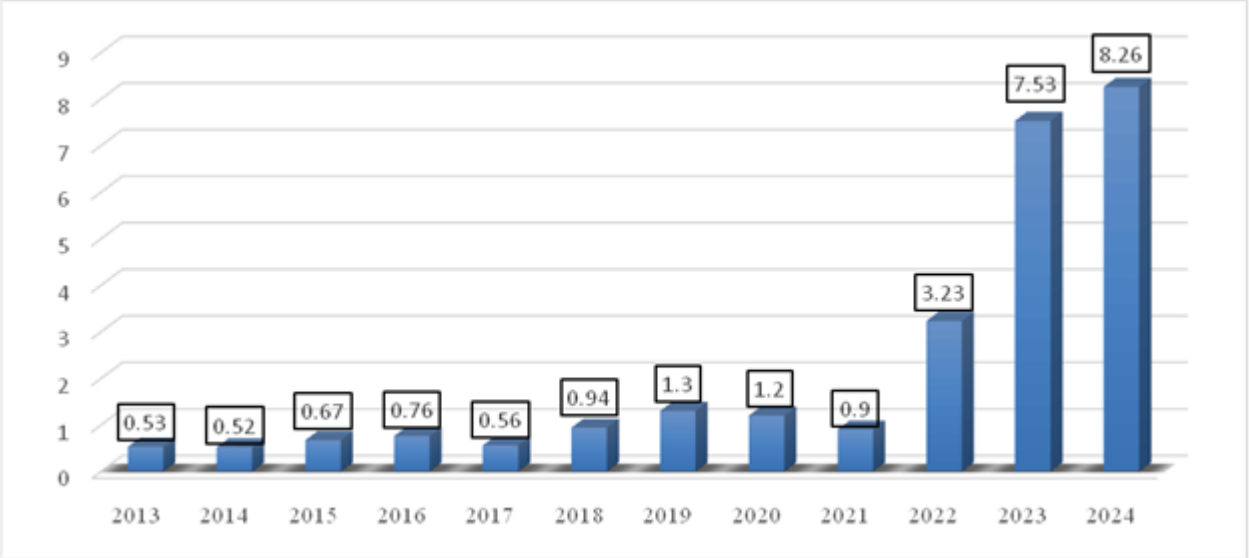


Fig. 1. Evolution of average annual prices for onion production in Türkiye, 2013-2024 (₺/kg).
Source: Turkstat Online, Accessed on 08.09.2025 [24].

Türkiye is not a major onion importer. In 2013, it imported 1,287 tons, 95.1% of which came from Iran. By 2024, total imports would reach 1,367 tons, 95.2% of which came from Uzbekistan (Table 7). Azerbaijan accounted for 4.8%.

Table 7. Onion imports in Türkiye

	Trade Value (US$ thousand)	Quantity (tons)
Country	2013	
World	180	1,287
Iran	171	1,224
Ukraine	9	64
	2024	
World	273	1,363
Uzbekistan	259	1,297
Azerbaijan	14	66

Source: Trademap Online, Accessed on 01.09.2025 [21]

Türkiye can be said to be a leading onion exporter in the 2013-2024 period. While 158,059 tons were exported in 2013, exports decreased to 95,440 tons in 2024 (Table 8). Iraq holds the leading position among the countries with the highest exports during the period under review.

A look at Türkiye's onion exports reveals that the variability in production has been reflected in exports over the years.

Table 8. Onion export in Türkiye

	Trade Value (US$ thousand)	Quantity (tons)
Country	2013	
World	27,233	158,059
Iraq	7,624	82,740
Russian Federation	8,278	22,260
	2024	
World	34,112	95,440
United Arab Emirates	8,479	21,027
Iraq	8,389	19,824

Source: Trademap Online, Accessed on 01.09.2025, [21].

Figure 2 reveals that Türkiye is a leading onion exporter. It can be argued that price increases within the country since 2021 have also negatively impacted exports.
An examination of the onion foreign trade balance between 2013 and 2024 reveals that exports exceed imports, demonstrating a

continuous increase in foreign trade. Despite the decline in exports in recent years, it is noteworthy that the foreign trade balance increased in 2023 and 2024 due to price increases. A study has also indicated that Türkiye's competitiveness in onion foreign trade is quite high [12].

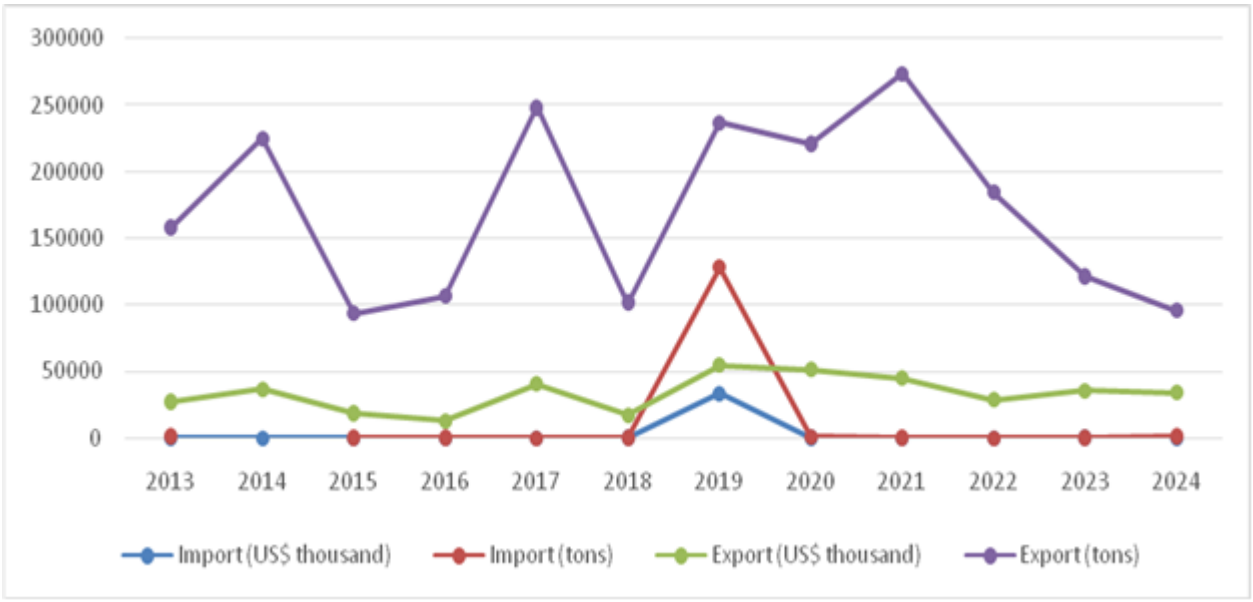


Fig. 2. Türkiye import and export during, 2013-2024
Source: Trademap Online, Accessed on 01.09.2025, [21].

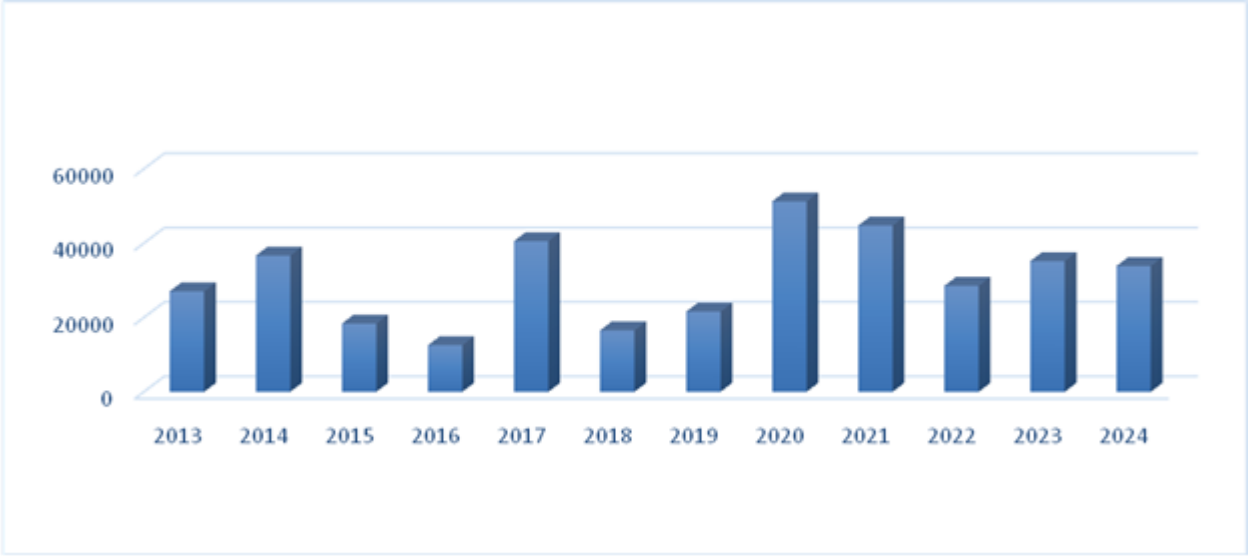


Fig. 3. Evolution of the trade balance in value with onion in Türkiye, between 2013-2024 (US$ thousand)
Source: Trademap Online, Accessed on 01.09.2025, [21].

CONCLUSIONS

Onions are an important vegetable whose production is increasing globally, widely grown in many regions of Türkiye, and frequently used as a staple food for human nutrition. When the years evaluated in this study were examined, it was determined that there were significant increases in onion cultivation area, production volume, and especially yield in Türkiye.

It is noteworthy that onion production in Türkiye is concentrated in the Western Anatolia, and Western Black Sea regions. During the period studied, Türkiye achieved a surplus in onion foreign trade, both in quantity and in monetary terms.

However, despite the overall increase in production, significant fluctuations in production and exports were also observed. These fluctuations are largely due to the mismatch between supply and demand. From a farmer's income perspective, the resulting price volatility poses a serious challenge to the stability of onion production.

Therefore, it is vital to take the necessary measures in both production and marketing processes. Furthermore, priority should be given to production planning, support for producer organizations, development of storage technologies, and increased warehouse capacity. Implementing these measures or improvements will not only contribute to price stability in the domestic market, but will also support the sustainable growth of the Türkiye's foreign trade and enhance its competitiveness in international markets.

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THE ROLE OF NON-GOVERNMENTAL ORGANIZATIONS ON THE DEVELOPMENT OF THE AGRARIAN SECTOR OF AZERBAIJAN IN THE CONTEXT OF CLIMATE CHANGE

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Abstract

The areas of activity of NGOs are diverse. The social dimension, particularly related to ecology, remains highly relevant. The most active NGOs are those implementing projects aimed at the development of the agricultural sector. In the context of climate change, farming enterprises require appropriate equipment, innovative technologies, and training in modern resource management methods to reduce environmental impact. A positive growth in environmental protection projects is also evident from quantitative indicators. Thousands of projects have been implemented through the third sector, with grants from the state budget allocated to NGOs on a competitive basis. Grant funding is provided according to criteria that define the maximum amount, duration, and thematic relevance in alignment with the NGOs' goals. This article analyzes the valuable experience accumulated in Azerbaijan, using statistical data and observational evidence to assess NGO programs, their coverage and outcomes, as well as their impact on the environment. Conclusions and recommendations are offered to foster cooperation between NGOs and business structures in the agricultural sector across all regions.

Key words**:** *non-governmental organizations, agrarian sector, ecology, climate risks, grants, Azerbaijan*

INTRODUCTION

Climate change has significantly affected the structure and productivity of agriculture worldwide [12]. Many agricultural organizations have already begun to assess how climate change may impact their operations in the future, [16; 14] and to determine whether this issue should be addressed in conjunction with other pressing challenges [1] currently facing the agricultural sector [7]. As a result, climate considerations are increasingly being integrated into organizational policies and objectives, becoming part of broader risk and opportunity management strategies [21]. In achieving these specific goals, non-governmental organizations (NGOs) often serve as key partners for business entities [15; 5; 10]. In the late 1990s, on the threshold of the 21st century, Azerbaijan began its collaboration with the United Nations Development Programme (UNDP) to establish and expand its non-governmental sector. This process was accelerated by the creation of the Azerbaijani National NGO Forum. The law "On Non-Governmental Organizations (public associations and foundations)," which became the first piece of legislation within the Commonwealth of Independent States (CIS) to regulate NGO activity, has since undergone continual revisions in response to changing times [11]. In 2007, the adoption of the Concept of State Support for NGOs marked a turning point, establishing favorable conditions for their development. Subsequently, the Council on State Support to NGOs under the President of the Republic of Azerbaijan was founded as the principal coordinating body for governmental support to NGOs. Today, nearly 3,000 officially registered NGOs operate in Azerbaijan across various domains, including education,

healthcare, human rights, and environmental protection, agri-business and agriculture. Many of these organizations participate in international projects and initiatives, representing Azerbaijan on the global stage. In recent years, Azerbaijani NGOs have been increasingly active in international forums. For example, in October 2024, the NGO sector presented a concept for addressing climate-related challenges at COP29, emphasizing the importance of combating global climate change [13]. Azerbaijan is home to several dozen officially registered NGOs specializing in agribusiness and agriculture [18]. These organizations implement projects aimed at improving agricultural practices, enhancing environmental sustainability, and fostering the development of rural areas.

The aim of this study is to examine the extent to which NGOs are contributing to the creation of favorable conditions for investors and to the introduction of innovative technologies in the agricultural sector of the Republic of Azerbaijan—seeking to balance dynamic production growth with environmental sustainability.

The role of NGOs in agriculture has been explored in previous studies that examined how members of rural communities perceive the impact of existing NGOs on community development, including their support for human resource development, educational programs, and employment services.

Some researchers have found that a significant portion of the rural population is not only unaware of organized community structures to which they belong but also unfamiliar with the terminology and functions of public NGOs [8].

Other researchers have investigated the role of NGOs in supporting social farming initiatives. Their objective was to establish partnerships for developing local strategies, adapting policies to specific contexts, and supporting sustainable development. According to the authors of that study, a necessary condition for facilitating and accelerating sustainable development processes is the mediation role played by one or more networked organizations in the field of social farming [17].

Researchers who advocate for agricultural cooperatives as a rational model of land use organization have argued that landowners who form cooperatives—often with the support of NGOs—can at least double their incomes, while local budget revenues rise by approximately 25%. This, in turn, promotes increased prosperity among landowners and stimulates the development of other local enterprises [3].

MATERIALS AND METHODS

In examining the experiences and findings presented in existing literature, [4; 20] the authors of this study investigate the influence of non-governmental organizations (NGOs) on the sustainable development of the agrarian sector amid efforts to overcome the negative consequences of climate change. By analyzing the role of NGOs in agriculture, the authors assess how these organizations design and implement projects aimed not only at the development of rural areas but also at encouraging rural residents to actively contribute to Azerbaijan's broader efforts—alongside other nations—to address climate change [23].

The research explores several climate-related challenges faced by the country, [22] where NGOs support the agrarian sector in the following key areas:

(i)Implementation of advanced technological solutions in agriculture that promote environmental sustainability, including renewable energy sources, eco-friendly transportation, and environmentally safe materials;

(ii)Adoption of ecotechnologies that help conserve electricity and water while reducing harmful emissions into the atmosphere and soil;

(iii)Advocacy for legislative reforms that protect soil, water, and air quality;

(iv)Assessment and monitoring of climate risks, recognizing that reliable and continuous climate surveillance is essential for any state [6];

(v)Support for local producers, acknowledging the link between climate change and food

security, and the fact that farming communities are among the most affected;
(vi)"Green" public investment in clean technological infrastructure, including alternative energy grids, electric vehicle charging stations, land reclamation projects, nature reserves, and afforestation initiatives;
(vii)Promotion of safety standards to reduce anthropogenic impacts on the climate by minimizing risks related to the use of agrochemicals;
(viii)Facilitation of population adaptation, especially in rural communities and farms, which are highly vulnerable to climate change;
(ix)Public education and dissemination of climate information, recognizing that awareness of the current state of the climate is a powerful tool for addressing the crisis.
This study seeks to identify how NGOs contribute to the sustainable development of the agricultural sector. The research methods employed include statistical data analysis, literature review, interviews with NGO representatives and agricultural workers, and comparative data analysis.
The scientific novelty of this work lies in identifying specific mechanisms and tools that NGOs can employ to enhance the effectiveness of agricultural production under climate change conditions. The study addresses a key gap in current national research—namely, the insufficient understanding and appreciation of the societal significance and impact of NGOs on agriculture.
The target audience for this research includes agricultural researchers, NGO representatives, agricultural enterprise managers, and governmental officials.

RESULTS AND DISCUSSIONS

Agricultural land area in Azerbaijan has remained largely unchanged over the past decade, as evidenced by the statistical data presented in Figure 1.
Based on this, it can be concluded that the serious challenges periodically faced by the agricultural sector are not related to changes in the area of land suitable for farming.

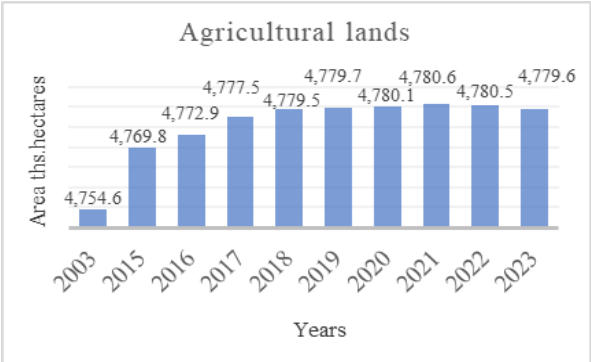


Fig. 1. Utilised agricultural area, end of the year, 2024
Source: Data of the State Service on Property Issues under the Ministry of Economy of the Republic of Azerbaijan [19].

The primary climatic risks to Azerbaijani agriculture are reflected in statistical information regarding natural and man-made events that have occurred in the country over the last seven years. In 2019, a total of 16,571 natural and technogenic incidents were recorded within the territory of the Republic of Azerbaijan, representing an increase of 1,107 events, or 7%, compared to 2018. In 2020, there were 14,780 such incidents, marking a decrease of 1,791 events, or 11%, compared to 2019, which is directly associated with the COVID-19 pandemic.
However, in the following period, there was a resurgence in the number of emergencies: in 2021, 15,247 natural and technogenic events occurred, which is 467 events, or 3%, more than in 2020.

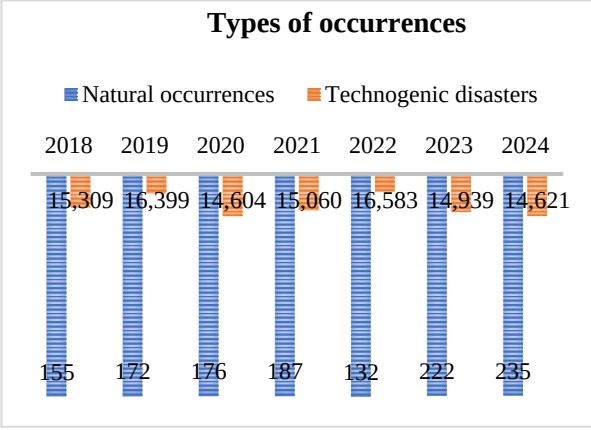


Fig. 2. Statistics on natural and man-made disasters
Source: Processed by the authors using the data from the Ministry of Emergency Situations of the Republic of Azerbaijan [19].

The year 2022 saw an increase to 16,714 incidents, up by 1,467 events, or 10%, compared to 2021. In 2023, the number of incidents decreased to 15,161, which is 1,553 fewer cases, or 9% less than in 2022. For 2024, 14,856 natural and technogenic incidents were reported, 305 fewer cases, or 2% less compared to 2023. This data is visually summarized in Figure 2.

A more detailed classification of natural phenomena occurring in Azerbaijan in the context of the global issue of climate change is presented by the authors in Table 1.

Table 1. Major Climate Risks to Agriculture in the Territory of the Republic of Azerbaijan

Natural Phenomena	Number of Events (units)						
	2018	2019	2020	2021	2022	2023	2024
Hazardous meteorological and agrometeorological phenomena:	**82**	**91**	**117**	**114**	**75**	**120**	**155**
- strong wind	41	69	74	79	36	43	34
-hurricanes, tornado	-	-	1	-	-	-	-
- precipitation	33	15	29	19	31	56	96
- dense fog	6	5	1	-	-	8	9
- heavy snowfall	-	-	10	13	6	7	10
- severe frost	-	1	1	-	-	-	-
- extreme heat	2	1	-	1	-	1	-
- large hail	-	-	1	2	2	5	6
Hazardous geological phenomena :	**8**	**2**	**2**	**6**	**1**	**14**	**3**
- landslides	3	2	2	3	-	12	-
- volcano eruptions	4	-	-	1	-	-	1
- avalanches	1	-	-	2	-	2	2
Hazardous hydrological phenomena (mudflows and floods)	**5**	**3**	**-**	**1**	**1**	**6**	**10**
Hazardous geophysical phenomena (earthquakes)	**60**	**76**	**57**	**66**	**55**	**82**	**64**
Poisoning of people due to toxic and similar substances (excluding accidental cases), high radiation levels							**3**
Total:	**155**	**172**	**176**	**187**	**132**	**222**	**235**

Source: Official data of the Ministry of Emergency Situations of the Republic of Azerbaijan [19].

As seen from Table 1, over the past seven years, there has been a sharp increase in the number of events related to hazardous meteorological and agrometeorological phenomena. Specifically: a) the amount of precipitation in 2024 increased 6.4 times compared to 2019 and 1.7 times compared to 2023; b) the frequency of large hail events has increased 2 to 3 times annually, resulting in significant losses in crop yields and damage to livestock farm property.

Assessing the vulnerability of the agricultural sector due to the impact of climate change and the necessity for adaptation under these conditions, regional and global climate change stakeholders have supported Azerbaijan's approach to the establishment of non-governmental organizations (NGOs) (Table 2). Non-governmental organizations (NGOs) may receive funding from various sources, including private donations; government grants and subsidies; international grants; corporate sponsorships; foundations and charitable organizations; private investments and venture capital; crowd funding; organizational revenues; and membership fees. Each of these sources can be utilized depending on the type of organization, its objectives, and activities.

In Azerbaijan, cooperation between NGOs and farming households is carried out through various collaboration models aimed at supporting the agricultural sector and improving conditions for farmers. The main models of such interaction are shown in Fig. 3.

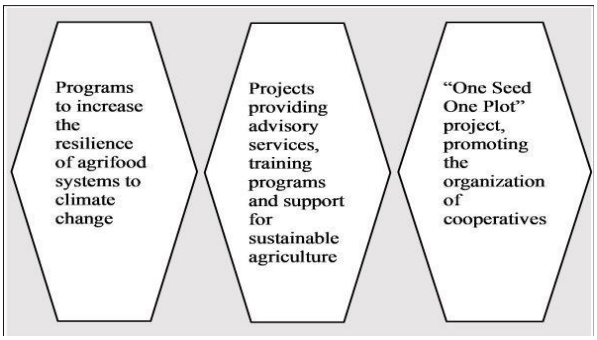


Fig. 3. Models of interaction between NGOs and farms
Source: Own synthesis based on the studied literature.

Table 2. Major NGOs Operating in the Agricultural Sector of Azerbaijan

NGO Name	Main Areas of Activity	Region of Operation	Source of Funding
Azerbaijan Agricultural Foundation	Support and development of agriculture through grants and consulting services for farmers and agribusinesses	Nationwide	Grants
	Attracting investments and developing agricultural enterprises in liberated territories	Liberated territories	Grants
	Microloans for rurar residents	Nationwide	Loan-funded financing
	Seed fund insurance: collection, storage, renewal, and use of agricultural plant seeds; price regulation to prevent price increases during natural disasters	Nationwide	Grants
Agroexpert	Training and professional development of specialists in agribusiness; promoting the introduction of innovative technologies in agriculture	Nationwide	Grants
Center for Sustainable Rural Development	Support for environmentally friendly agriculture and improving living conditions of rural communities	Liberated territories	Grants
	Implementation of innovative technologies, increasing resource use efficiency, and reducing environmental impact	Nationwide	Grants
	Transition of farmers to organic farming; providing consultations, training, and support for product certification	Nationwide	Grants
	Construction and modernization of irrigation systems; training farmers in rational water use methods and introducing water-saving technologies	Nationwide	Grants
	Development of rural tourism; training local residents in hospitality, organizing excursion routes, and promoting local products and traditions	Nationwide	Grants

Source: Own synthesis based on the studied literature.

Several projects have been implemented in Azerbaijan to adapt agriculture to climate change. The climate initiative project "Baku Harmony" was launched with the aim of providing farmers with tools to increase resilience to climate change. The project includes the preparation of accessible guidelines in cooperation with financial institutions to assist farmers in increasing their incomes. Presented at COP29, the "Baku Harmony" initiative represents an important step in expanding efforts to restore land and enhance drought resilience. It seeks to ensure agricultural sustainability in the face of climate change by fostering collaboration between multilateral and national development banks. The primary goal is to close financing gaps and support farmers in adapting to the changing climate by preventing soil erosion and promoting sustainable agricultural practices. To this end, a Loss and Damage Compensation Fund has been established, and international carbon markets have been created, providing new financial opportunities for land restoration and forestry, attracting both public and private investments. To fully unlock the potential of these financial mechanisms, key barriers must be removed. Creating more favorable conditions for private sector participation through regulations and financial incentives is crucial. Public funding, including grants, subsidies, and tax incentives, can assist in implementing long-term restoration projects that yield both environmental and social benefits. The Ministry of Agriculture of Azerbaijan is developing a national adaptation plan to address climate change and water scarcity issues in agriculture. These projects aim to increase the resilience of Azerbaijan's agriculture to climate change, improve food security, and support farmers in adapting to new conditions. Within Azerbaijan's agricultural sector, NGOs also implement a range of projects:

Biodiversity Projects

In 2007, BP-Azerbaijan, together with its partners, held the 6th annual competition for biodiversity protection. Within this

competition, the NGO "Ecostyle-Azerbaijan" received the main award for the project "Reproduction and Reintroduction of Unique and Endangered Plant Species of the Absheron Peninsula." Other organizations were also recognized for projects aimed at preserving rare species of birds and plants.

Agricultural Development Volunteers

Under the project "Agricultural Development Volunteers," young people provide support to the development of the agricultural sector. The project's goal is to foster public support for agriculture and to build a volunteer movement in this field. Volunteers operate within the State Centers for Agricultural Development under the Ministry of Agriculture in various regions, as well as in the Ministry's departments, research institutes, and specialized laboratories. The volunteers aim to promote sustainable agricultural development by forming a voluntary community dedicated to agricultural sector development, preparing specialized personnel for future work in this field, and advancing innovative technologies with effective use of available resources. The scope of the "Agricultural Development Volunteers" includes the implementation and promotion of e-agriculture, use of new market tools, support to farmers in land quality assessment, and participation in the adoption of innovative technologies, including the acquisition of digital skills [9]. It is planned that over 10,000 people, including students from Azerbaijan State Agricultural University, will join the project within three years. Additionally, projects such as "Specialized Agricultural Journalists," "From Audience to Field," and others aim to increase the potential of young specialists focused on agriculture. To improve soil fertility, training has been provided on the proper use of fertilizers and laboratory techniques.

Grant-based Programs and Projects

In 2024, the State Agency for Support to Non-Governmental Organizations of the Republic of Azerbaijan, the legal successor of the Council for Support to NGOs under the President of Azerbaijan [24] held a grant competition in cooperation with various state bodies. Among the topics related to the agricultural sector, particularly focusing on ecology and climate change threats, the winners included: the project "Support for the Development of Rural Tourism" by the Public Association "Center for Cultural Development," which received a small grant of 7,900 AZN; the project "Promoting Green Development in Agricultural and Tourism Enterprises in Azerbaijan" by the Public Association for Ecological Awareness and Monitoring, awarded a medium grant of 17,000 AZN; the project "Increasing Agroecosystem Resilience" by the Public Association for Partnerships in Economic and Social Initiatives, which received a small grant of 8,000 AZN; the project "Promotion of Agrotourism" by the Public Association for Ecotourism "Zarya," awarded a small grant of 10,000 AZN; and the project "Sustainable Agriculture and Environmental Protection" by the Public Association for Agricultural Development Support of Khachmaz, which received a small grant of 8,000 AZN. In 2025, winners included the Public Association for Socio-Economic Development of Agriculture and Ecology with the project "Support for Sustainable Ecotourism Development in the Regions," awarded a grant of 8,000 AZN, and the Public Association for Sustainable Community Development with the project "The Role of Tourism in Sustainable Development of Rural Areas," which received a grant of 7,500 AZN [25].

International Environmental Initiatives

In 2024, Azerbaijani NGOs participated in a tree-planting campaign in Kenya in memory of flood victims. This initiative highlighted global solidarity and Azerbaijan's contribution to combating climate change.

These examples demonstrate the active involvement of Azerbaijani NGOs in the development of the agricultural sector and environmental protection, both nationally and internationally. The assistance provided by NGOs in addressing environmental issues in rural Azerbaijan is summarized in Table 3.

Table 3. Comparison of the effectiveness of different NGO programs

Program	Scope	Results	Environmental impact
Project: Creation of a National System for Producing Healthy Seed Potatoes in Azerbaijan	Farmer groups in three different production regions in the Tovuz district; agronomists	Dissemination of technologies and knowledge among rural workers; creation of necessary infrastructure such as laboratories for testing viral, fungal, and bacterial diseases; production of mini-tubers from in vitro plants in greenhouse conditions; seed production and greenhouse facilities; construction of a 350-ton cold storage warehouse	Reduction of resource consumption: fuel, fertilizers, water
Project: Increasing Efficiency and Sustainability of Hazelnut Cultivation in Azerbaijan	Farmers from various regions of Azerbaijan	Improvement of cultivation methods and hazelnut yield quality, with particular attention to reducing the risk of aflatoxin contamination	Reduced use of chemical fertilizers
Project: Improving Food Security and Livelihoods in Rural Areas through the Expansion of Economic Rights and Opportunities for Women	Over 200 women farmers from 12 target districts	Providing rural women with knowledge and skills necessary to start their own businesses, as well as access to markets, financial resources, and services	Decreased environmental burden, including cleaning of riverbanks, improvement of springs, clearing areas adjacent to farms, and enhancement of agrotourism facilities
Project: Creation and Implementation of Value Chains for Sustainable Development of Sheep Breeding and Food Production	Three pilot districts (Zagatala, Aghjabadi, and Beylagan) with different value chains (mutton, milk, and wool)	Development of the sheep breeding sector by promoting the production of new dairy products and wool, introduction of improved hygiene practices, and enhancement of farmers' skills in product preparation and marketing	Production of feed and silage (from seed sowing to final product); animal vaccination program
Project: Improvement of Cattle Breeds	Small and medium farmers from all regions of Azerbaijan	Improvement in breeding and feeding, animal health management, and enhancement of farmers' business management skills	Establishment of small dairy, meat processing, and cutting stations
Project: Increasing Employment in Agriculture (AMAL)	32 young people (12 women and 20 men) representing 28 regions of Azerbaijan	Poverty reduction in rural areas through strengthening sustainable youth employment	Development of agri-food systems and a sustainable and diversified rural economy

Source: Own synthesis based on the studied literature.

The brain center of non-governmental organizations is the Agency for State Support of NGOs [2].

To objectively inform the public of the country, the Agency provided a financial report. The Agency strives to ensure alignment between the goals, objectives, development priorities, and strategic aims of the Republic of Azerbaijan as a specialized state institution implementing state policy in strengthening and sustainable development of the NGO sector. By 2024, the Agency for State Support of NGOs presented a financial report on cash flow results for 2022 and 2023 (Table 4).

Between 2022 and 2023, there was an improvement in operating and investing activities, especially in investing (an increase in net inflows). Net cash from financing activities decreased, but only slightly. Overall, a positive balance was maintained despite some reductions in inflows.

Table 4. Cash Flow Report as of 31.12.2022 and 31.12.2023 (in AZN)

Indicator	2023	2022
Allocated grants	4,647,316	4,916,718
Payments to suppliers (general and administrative)	653,016	867,244
Employee obligations payments	858,345	802,539
Net cash from operating activities	6,158,677	6,586,501
Net cash from investing activities	23,670	143,552
Net cash from financing activities	6,048,670	6,559,352
Net decrease in cash and cash equivalents	133,677	170,701
Cash at the beginning of the year	737,556	908,257
Cash at the end of year	603,879	737,556

Source: Own synthesis based on the studied literature.

The main economic indicators of individual entrepreneurship in agriculture were also analyzed. From year to year, the amount of damage caused to agriculture is growing, including in connection with climate change. Despite various approaches to improve the situation related to the world irreversible environmental problems, there is still an outstripping growth of damage experienced by individual entrepreneurs in the country. For this purpose, we analyzed the proportions between the individual elements of gross profit, namely: profit and the amount of damage (Figure 4).

As can be seen in Figure 4, and in parallel in Table 1, indicating the increase in the occurrence of natural disasters in 2023 to 222 cases the amount of damage amounted to 7.526 % of the profit earned by individual entrepreneurs in the agricultural sector. When observing the main economic indicators of individual entrepreneurial rural farms for the period 2005-2023, it was found that during the ten years from 2005 to 2015, the damage increased from 0.14% to 4.220 %. It was possible to reduce the growth of damage from 2016 to 0.575 % also due to the influence of non-governmental organizations on the development of the agricultural sector in various activities. However, this influence did not reach such a large scale, which affected the growth of the amount of damage in subsequent years, including damage associated with natural anomalies.

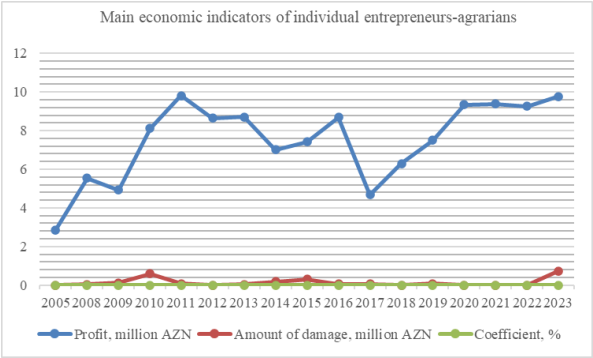


Fig. 4. Statistical indicators of profit of individual entrepreneurs in agriculture

Source: Processed by the authors using the data from the State Statistics Committee of the Republic of Azerbaijan [19].

CONCLUSIONS

The analysis and synthesis of results related to government support provided to non-governmental organizations (NGOs) highlight the necessity of building activities in this sphere on more advanced foundations, as well as improving regulatory mechanisms to ensure the active participation of NGOs in state and societal life with more effective use of their potential in the preservation and sustainable use of ecology. By actively participating in protecting the country's national interests, implementing state programs across various sectors, and addressing environmental issues arising in several areas of public life, the financial system supporting NGOs should be restructured to aid the restoration of liberated lands affected by environmental terrorism and to secure a sustainable future for the country. The development of cooperation between NGOs and business structures creates additional opportunities for expanding the activities of NGOs and their involvement in addressing socially relevant issues. It also promotes increased social responsibility of business entities towards society and further strengthens the spirit of solidarity within the community. NGOs must engage in activities aimed at fostering a positive attitude towards private businesses, businesspeople, the press, and journalists by conducting independent research and organizing public events.

In Azerbaijan, NGOs sometimes fail to adequately inform the public about their activities and specific projects. Openness and transparency are key criteria for maintaining public relations. Where these are lacking, harmful rumors begin to spread. Unlike business entities, NGOs cannot conceal their activities and financial status from society by citing "commercial secrecy." To eliminate unnecessary rumors, NGOs should inform the public about their financial activities.

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DEVELOPMENT AND PROSPECTS OF GRAIN CROPS PRODUCTION AND EXPORT IN UKRAINE: IMPLEMENTATION OF ALTERNATIVE TECHNOLOGIES IN THE CONDITIONS OF GLOBAL WARMING

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Abstract

The negative consequences of global warming and other stress factors on the environment have been established, which have become a global problem that carries the likelihood of a food crisis and limits the impossibilities of ensuring the sustainable development of grain production and export, which will affect the global food security of humanity in the future. An analysis of the dynamics of national and global grain production for 1990–2023 was carried out based on official statistical data from the State Statistics Service of Ukraine and the Food and Agriculture Organization of the United Nations, as a powerful information base for the study. The results of the analysis confirm that in 2023Ukraine maintained high competitive positions in the global grain market, in particular its entry into the top ten largest global grain producers and sixth place among exporting countries. At the same time, during 1990–2023, Ukrainian wheat grain production decreased by 29% and amounted to 21.6 million tons. Based on the calculations performed, it was proven that, along with the negative consequences of abiotic and biotic factors caused by global warming, as well as anthropogenic factors, which consisted in an unsystematic change in the structure of sown areas of various groups of crops: grain, technical and fodder crops, violation of the regulated periods of returning grain crops to their previous place of cultivation in crop rotations and the principles of rational selection of predecessors, the decrease in grain production was influenced by the reduction in sown areas, including irrigated ones, as well as the complication of mechanisms for planning, organizing and implementing logistics activities. Because of this, during 1990–2023, wheat yield in Ukraine was characterized by a significant deviation from the potentially achievable level, as it increased only 1.2 times and amounted to 4.64 t/ha. To ensure food security and sustainable development of grain production and export in the context of global warming, martial law, and in order to ensure further integration of Ukraine into the EU, it is proposed to introduce alternative technologies that will contribute to preserving the water and nutrient regime of the soil, improving the ecological state of the environment, which will ensure the formation of prerequisites for strengthening the health of the population and balanced socio-economic development of rural areas.

Key words**:** *grain crops, winter wheat, alternative technologies, irrigation, global warming, Ukraine*

INTRODUCTION

For Ukraine, which is currently in extremely difficult conditions of martial law, solving the problem of food security while simultaneously overcoming the negative consequences of global warming is of particular importance [5; 6]. In addition, ensuring the further integration of Ukraine into the European and world economic space requires a scientifically sound and systematic approach taking into account the needs of European integration transformations, the need for strategic measures to promote sustainable development of the grain industry by adapting grain production to the negative effects of global warming, which will affect the volume of its exports [12]. In the context of ensuring food security and creating sustainable conditions for grain production and export under climate change caused by global warming, as well as martial law, for Ukraine's further integration into the EU, it is important to substantiate and implement alternative technologies for growing competitive varieties and hybrids of grain crops [18; 41]. Such technologies should help minimize the anthropogenic load on the environment, preserve and restore soil fertility, and guarantee the production of competitive grain products that meet current quality

requirements and the needs of national and world markets [21].

In order to minimize the negative impact of global warming on the environment, Ukrainian and foreign scientists have proposed alternative approaches to reduce risks in the formation of grain crop productivity depending on soil-climatic growing conditions. In particular, the implementation of promising varieties and hybrids of grain crops with stable resistance to adverse environmental factors [9; 20; 25; 40]; effective selection of predecessors and permissible periods of repeated cultivation of grain crops in crop rotations [7; 14]; optimized combination of organic and mineral plant nutrition [30; 41]; systematization of soil protection tillage with the integration of biological factors [1; 3; 35; 36]; scientifically based irrigation systems at optimizing water supply to crops [22]; justification of the influence of weather conditions and market conditions on the formation of production and export volumes of grain crops [31; 32; 33]. At the same time, in the context of global warming, further substantiation of the effectiveness of their integrated application becomes particularly relevant.

The purpose of the article is to identify trends the long-term dynamics and determine the prospects for increasing grain production and export in Ukraine through the comprehensive implementation of elements of alternative technologies to minimize abiotic and biotic factors and adapt to the negative consequences of global warming.

MATERIALS AND METHODS

The research was carried out in compliance with the established ethical requirements and norms [10; 11], the basis of which is the use of general scientific principles. Analysis and synthesis, graphical and statistical methods were used to analyze the dynamics of changes in productivity indicators of national and world grain production and export during 1990–2023; world ranking of grain producing countries, exporting countries and importing countries in 2023. Using comparative analysis and the computational-constructive method, trends in the structure of sown areas, yields, and the introduction of irrigation systems in Ukraine during 1990–2023 were identified. Thanks to the abstract-logical method, conclusions were summarized and elements of alternative technologies were substantiated, which are aimed at overcoming the negative impact of global warming and other factors.

The information base includes a significant array: statistical data from the State Statistics Service of Ukraine and the Food and Agriculture Organization of the United Nations (FAO). In addition, scientific developments of scientists dedicated to the development and implementation of a set of components of alternative technologies for growing grain crops in conditions of global warming were used.

RESULTS AND DISCUSSIONS

I. Features of the impact of global warming on the environment. At the beginning of the 21st century, the world community recognized global warming as one of the most significant long-term challenges, overcoming which requires coordinated actions by all countries of the world [21]. According to the results of many years of observations, it has been established that since 1880 the average annual air temperature on the planet has increased by 0.8°C [39]. In Ukraine, the warming process is occurring more intensively: during 1901–2020, the indicated indicator increased by 2.0°C [34]. Due to global warming, the agroclimatic zones of Ukraine have undergone significant changes. There are three traditional agroclimatic zones in Ukraine – Steppe, Forest-Steppe and Polissya [29]. This classification was introduced based on the ratio of the amount of precipitation to the amount of accumulated heat. However, with the change in these indicators, their boundaries have actually shifted 200 km to the North in recent decades. Thus, with climate change, the Polissya zone is gradually shrinking and the Forest-Steppe and especially the Steppe zone are expanding. In particular, the vegetation conditions in the Dnipropetrovsk and Kropyvnytskyi regions of the traditional subzone of the Northern Steppe are optimally consistent with the soil and

climatic conditions of the Southern Steppe [37]. There is also a trend towards spatial expansion of the borders of the Northern Steppe by involving territories that previously belonged to the Forest-Steppe, in particular Poltava and Cherkasy regions [24]. Agroclimatic transformations are causing the optimal conditions for growing traditional agricultural crops for the Steppe – corn, rapeseed, soybeans, and sunflowers – to shift to the Forest-Steppe [6].

The greatest warming in recent decades has been observed in Kyiv, Chernihiv, Sumy and Zhytomyr regions, which causes the spread of negative phenomena in these territories. Dry winds are spreading to the Northern and Eastern parts of Ukraine, which was previously an atypical phenomenon for these regions. Hail is observed in the spring and autumn months, which are not typical for this phenomenon, which provokes the freezing of crops [37]. In addition, there is an uneven distribution of air temperature throughout the year. In particular, over the past 30 years, the number of summer days with air temperatures above 30–35°C has increased several times in the Steppe zone [2]. The impact of these abiotic factors has led to irreversible consequences in the technologies of growing wheat and barley, which are traditional grain crops for this zone, which has caused a rapid decrease in their yield. In addition, in the summer period there is a periodic decrease in air temperature, which leads to an extension of the duration of ripening of heat-loving grain crops, as a result of which the harvest is annually shifted to later dates [15]. The duration of winter periods has significantly decreased, and winters have become less cold. Over the past 30 years, average temperatures in Ukraine in the first winter months of the year have increased by 1.5–2.0°C [17], which has led to a change in the system of seasonal phenomena – snowfall, spring floods and the beginning of grain flowering. Climate threats have intensified, including reduced and uneven precipitation, shorter duration of rains. In particular, early spring leads to stress in the preparation of agricultural machinery and field work, which requires clarification of the optimal timing of sowing early spring grain crops. There is an increase in the number, duration and intensity of extreme climatic phenomena that affect grain production – droughts, dry winds, storms, dust storms, downpours, hail, frosts and frostbite, snowfall, freezing and icing, floods, flooding and submersion, which are associated with climate change [26; 37]. For example, in 2020, a record drought in the last forty years, spring frosts and strong winds led to the fact that agrarian production in the Steppe zone suffered significant losses, when even drought- and heat-resistant corn and sunflower were affected [6]. Thus, Ukraine is one of the regions of the planet where climate change is becoming quite noticeable, especially in the direction of increasing aridity, which reduces the productive potential of grain crops.

The reduction in the duration of the winter period, the decrease in the depth of soil freezing and the number of frosty days cause the negative impact of biotic factors: early activation, more intensive reproduction and spread of pests and pathogens [16]. It can cause problems in the spring, when vegetation begins and winter grain crops grow rapidly. The formation of numerous burrows in the soil by pests can cause conditions of artificial drought, since the supply of moisture to the plant root system is disrupted through the system of tunnels. Therefore, with the preservation of the current rates of warming, the likelihood of phytosanitary destabilization of grain production increases, which is accompanied by the comprehensive spread of pests and pathogens, which reduces grain productivity and quality. In addition, the implementation of an effective irrigation system is decreasing as one of the effective measures to provide soil moisture, especially in drought conditions. In particular, during 1990–2023, the area of irrigated land in Ukraine with the appropriate land reclamation infrastructure decreased by 18% and amounted to 2.17 million hectares or only 5% of the agricultural land area (Fig. 1) [28]. The area of actually water land during this period decreased by 94% to 0.14 million hectares, which is equivalent to only 7% of the total area of irrigated land in the country, which indicates a significant limitation of the

potential for stable water supply for agricultural production. During 2010–2023, the area of land requiring irrigation increased to 1.67–2.03 million hectares. To expand the implementation of effective irrigation systems, it is necessary to apply innovative technological solutions to adapt agricultural production to the new conditions of climate change, which, with significant investment, will ensure a 2–3-fold increase in the yield and quality of grain crops, compared to their cultivation under rainfed conditions [41].

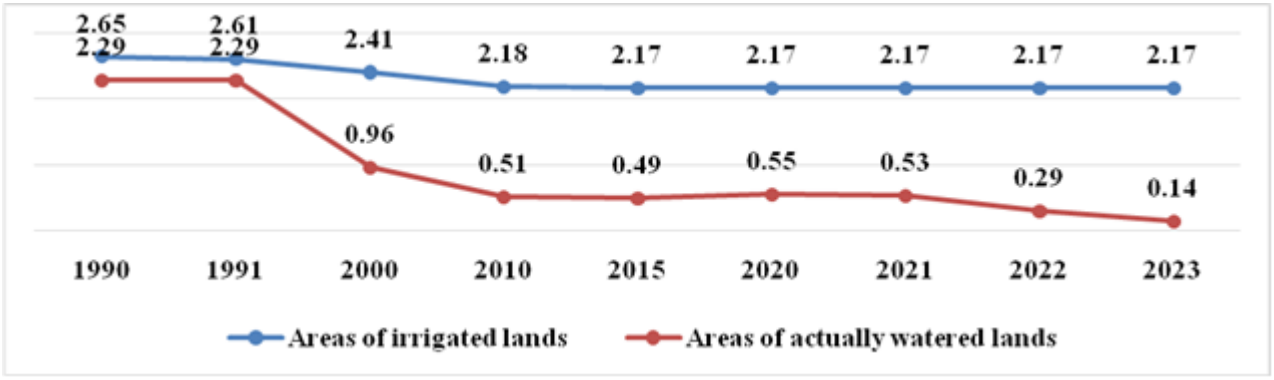


Fig. 1. Dynamics of the areas of irrigated and actually watered lands in Ukraine, million hectares, 1990–2023.
Source: Compiled by the authors based on data [28].

Therefore, due to the consequences of global warming, problems caused by abiotic and biotic factors are increasing in agro-eco systems, in particular phytosanitary and ecological crises, a decrease in their fertility and processes of soil degradation, which negatively affects the productivity and quality of grain crops. This necessitates the development and implementation of alternative technologies that will counteract the negative effects of global warming and contribute to the accumulation, preservation and rational use of soil moisture, especially in drought conditions.

II. Prospects for national and global grain production and export. Due to the growth of the world's population, global grain consumption is increasing, which necessitates the need to increase its production and export volumes [4; 8]. The analysis of trends in global grain production and export is based on the results of research conducted by the FAO, which, in order to implement the concept of "building a world without hunger", generates relevant statistical data to guarantee global food security. Let us analyze the dynamics of the main indicators of the grain market, which show that during 2010–2023, global grain production increased by 24%, and global grain exports – by 74% (Fig. 2) [27].

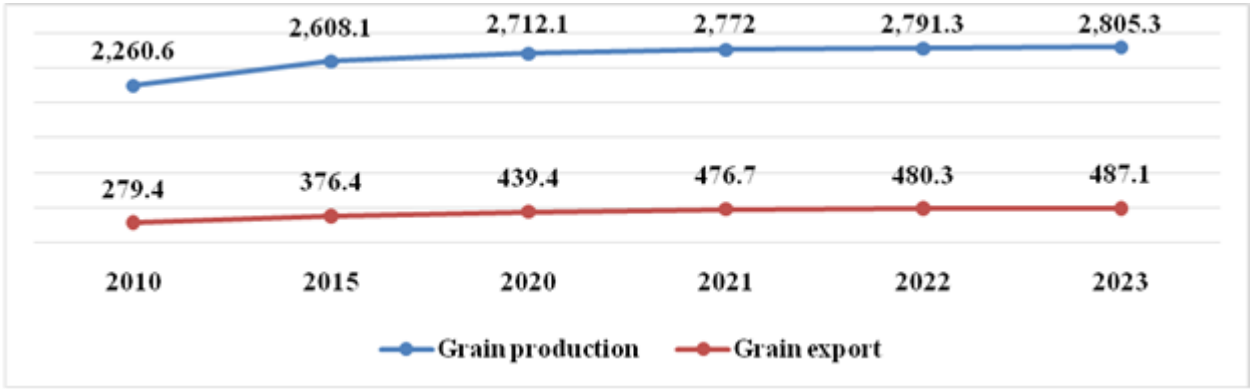


Fig. 2. Dynamics of world grain production and exports, million tons, 2010–2023
Source: Compiled by the authors based on data [27].

Therefore, the increase in global demand for grain products necessitates the strengthening of Ukraine's position in the global ranking of grain producers.

In 2023, there were 102 countries that produced 2,805.3 million tons of grain [30]. Among the ten leading grain-producing countries, it is necessary to single out China, USA and India, which account for 30% of the world's grain production. Despite difficult conditions, in particular those caused by military operations, Ukraine took tenth place in the world ranking, ensuring the production of 59.8 million tons of grain, or 2% of the total world volume. Ukraine also maintained its position among the top ten global producers, producing 21.6 million tons of wheat, or 3% of the global total. In addition, Ukraine ranked seventh in corn production and eighth in barley production. Thus, despite the decrease in production, compared to previous years, Ukraine has maintained its leading position in the world grain market. This indicates the stability of the country's agrarian sector even in difficult conditions.

In 2023, the top ten grain exporting countries, including the USA, Brazil, and the EU, accounted for 87% of global grain exports [27]. Despite the challenges posed by the war and the blockade of ports, Ukraine maintained its status as one of the leading exporters of grain crops on the global market. In particular, it ranked sixth in the world for grain and wheat exports, accounting for 7% of global output. In addition, Ukraine remained the fourth largest global exporter of corn, although corn exports in 2023 decreased slightly due to logistical difficulties and reduced yields. Ukraine also ranked third in the world for barley exports.

In general, during 2020–2023, grain exports from Ukraine were carried out in four groups. The first group includes three leading grain crops – wheat, corn and barley, which are exported from Ukraine in volumes of over 1 million tons. The second group consists of three grain crops – peas, sorghum and millet, which are exported in volumes of over 100 thousand tons. The third group includes four grain crops – chickpeas, beans, oats, rye, which are supplied to the foreign market mainly in volumes of over 10 thousand tons. The fourth group consists of six grain crops, which are supplied abroad in volumes of up to 10 thousand tons – these are rice, lentils, triticale, fodder beans, buckwheat and canary seed [28]. Thus, despite the difficulties, Ukraine has maintained its leading position in the global grain crops market, providing a significant part of global demand. The restoration of logistics routes and adaptation to new conditions ensured that Ukraine maintained high volumes of grain crops exports.

Let's analyze the Ukrainian wheat market, which remains one of the leading crops in Ukraine’s agrarian sector, occupying a significant share in the structure of grain exports.

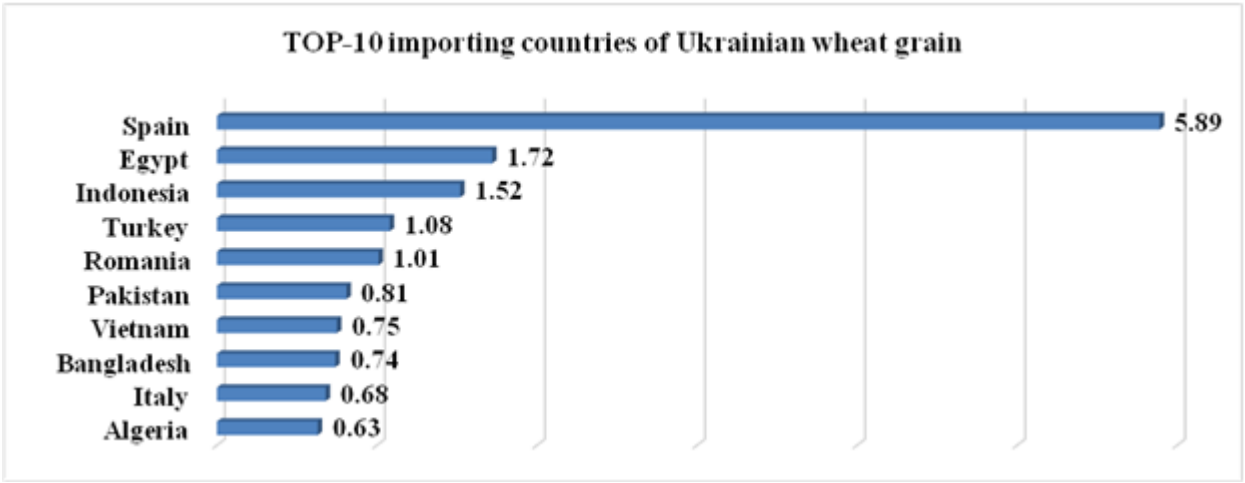


Fig. 3. World ranking of importing countries of Ukrainian wheat grain, million tons, 2023.
Source: Compiled by the authors based on data [27].

In 2023, the main importers of Ukrainian wheat were three EU countries (Spain – 36.4%, Romania – 6.2%, Italy – 4.2%), which imported 46.8% of grain, as well as countries of Asia and the Middle East with an import share of 44.7% (Fig. 3) [27]. Thus, Ukraine is the largest exporter of wheat to the European Union, which necessitates the technological modernization of the grain industry.

Let us analyze the dynamics of grain crops production and export in Ukraine during 2010–2023. In 2010, production amounted to 39.3 million tons, exports – 20.9 million tons, which are the lowest indicators for the study period (Fig. 4) [28]. This decrease was due to a number of factors, in particular, negative weather and economic conditions.

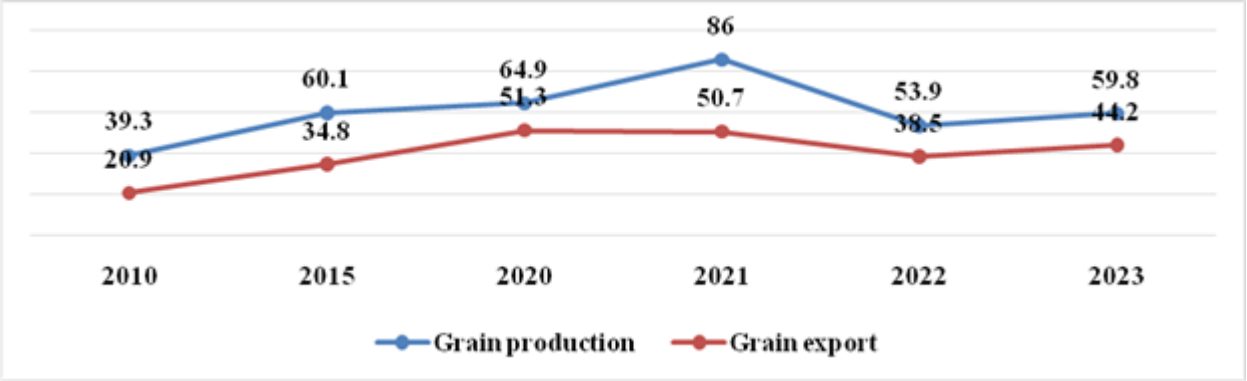


Fig. 4. Dynamics of grain production and export in Ukraine, million tons, 2010–2023.
Source: Compiled by the authors based on data [28].

In 2010, Ukraine experienced a drought, which caused a significant decrease in the yield and quality of grain crops. There was also a significant transformation of the structure of sown areas of different groups of crops: grain, technical and fodder crops, which was due to changes in their profitability, demand level and price situation on the foreign market. Thus, during 1990–2010, due to increased demand, the sown areas of high-yielding corn increased by 2.2 times. At the same time, as a result of the increased intensity of competition pressure, the has been a 15% decreased in wheat acreage. As a result of the increase demand for rapeseed and sunflower, there has been a doubling of the acreage of technical crops. At the same time, as a result of a significant reduction in demand for perennial and annual grasses, as well as corn for silage and green fodder, the area sown with forage crops decreased by 4.5 times. Such a chaotic change led to a violation of the regulated periods of returning grain crops to their previous place of cultivation in crop rotations and the principles of rational selection of predecessors, which resulted in a decrease in moisture and nutrient reserves in the soil, the accumulation and spread of pests, diseases and weeds, which caused a decrease in grain crop yields [14; 41].

During 2015–2020, due to favorable weather conditions that ensured high grain yields, there was a stable increase in grain production to 60.1–64.9 million tons. In 2021, a record 86.0 million tons were received. During 2020–2021, thanks to stabilization in the grain market, Ukraine exported record volumes of grain – 50.7–51.3 million tons, which was a significant achievement of the country's agrarian sector. These figures indicate a significant increase in exports compared to previous years, which was achieved thanks to increased crops yields and production under favorable weather and economic conditions.

This confirms Ukraine's status as one of the world's leading grain exporters. Overall, these years have been an important stage in the development of Ukraine's agricultural sector, confirming its leading position in the world grain market. In 2022, due to the hostilities and the blockade of ports, grain production and exports decreased significantly – to 53.9 million tons and 38.5 million tons, respectively. In 2023, grain production recovered to 59.8 million tons, which was a positive moment for the country's agrarian

sector. Thanks to the opening of the "grain corridor", new export routes and adaptation of logistics, grain exports recovered to 44.2 million tons. These data indicate significant fluctuations are observed in the production and export of Ukrainian grain, which are due to the combined influence of abiotic and anthropogenic factors: natural and climatic conditions, as well as economic and geopolitical factors. At the same time, analytical data show that the country's agrarian sector is gradually recovering and stabilizing. In particular, Ukraine is among the world's leading producers and exporters of grain crops, and its agrarian sector is characterized by a tendency towards stable development.

Among the main negative factors that affected grain production in Ukraine was the decrease in the area sown with agricultural crops by 29.6% during 1990–2023 (Fig. 5) [28]. Although during 1990–2021 the area sown with grain crops increased by 8.9% and amounted to 15.9 million hectares, due to the military actions in 2022 it decreased by 23.3% and amounted to 12.2 million hectares, in 2023 it decreased by another 8.1% and amounted to 10.9 million hectares.

Due to the reduction in sown areas during 2022–2023, which was caused by military operations, occupation, mining of fields, as well as logistical difficulties, only 53.9–59.8 million tons of grain crops were harvested with a yield of 4.58–5.52 t/ha [28].

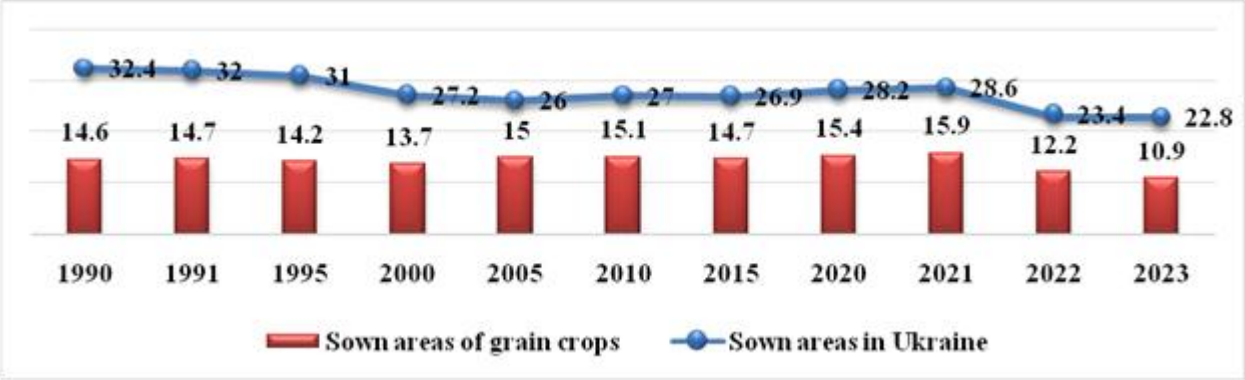


Fig. 5. Dynamics of sown areas of grain crops in Ukraine, million hectares, 1990–2023.
Source: Compiled by the authors based on data [28].

Analyzing the world ranking of countries by wheat yield for 2023, we can conclude about the high level of agricultural efficiency in Europe and Oceania. In particular, in New Zealand, Ireland, the Netherlands, Belgium and the United Kingdom, wheat yields were the highest and amounted to 8.13–9.67 t/ha; in Denmark, France, Germany, Sweden, Chile, wheat yields were quite high and amounted to 6.70–7.82 t/ha (Fig. 6) [27].

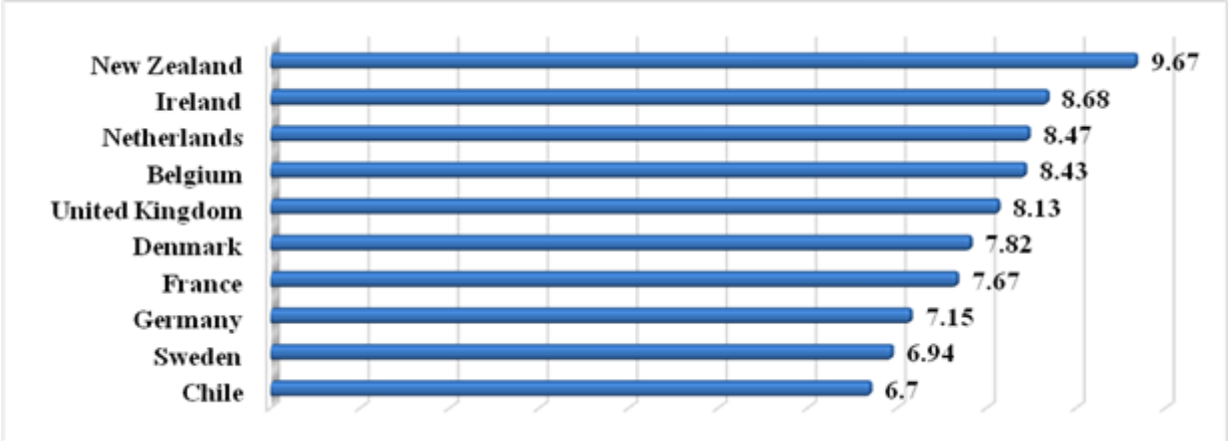


Fig. 6. World ranking of countries by wheat yield, t/ha, 2023.
Source: Compiled by the authors based on data [27].

In Ukraine, during 1990–2023, wheat yields increased only 1.2 times and amounted to 4.64 t/ha, which is characterized by a significant deviation from the potentially achievable level. It can be concluded that, occupying an average position in the world ranking, Ukraine has significant potential for increase the yield of grain crops, including wheat, through the development and practical implementation of alternative technologies for their cultivation in conditions of negative consequences of global warming and other stress factors.

III. Prospects for the development and practical implementation of a complex of alternative technologies for grain crops production. In order to minimize the negative consequences of global warming, the need for practical implementation of alternative technologies for growing grain crops, which include a complex of anthropogenic factors in the direction of creating and applying scientifically based measures, is becoming more urgent:

- selective creation and further introduction of competitive varieties and hybrids of grain crops, which are characterized by complex resistance to abiotic and biotic factors: lodging, diseases and pests, temperature and water stress factors, which have low transpiration coefficients, are able to stabilize the formation of high yields under conditions of drought and elevated temperatures, as well as other negative ecological factors [23; 25; 40];
- rational formation of the structure of sown areas aimed at increasing the efficiency of grain, technical, fodder and vegetable production, as well as the introduction of a system of scientifically based crop rotations that combine the cultivation of agricultural crops with compliance with optimal predecessors and permissible periods of their re-cultivation [13; 14];
- application of a soil protection tillage system with mulching to create favorable conditions for the accumulation of moisture and organic matter in the soil [5; 18; 38];
- use of an organo-mineral fertilizer system with elements of biologization, which include balanced amounts of organic and mineral fertilizers, the use of sideral crops for green manure and plant residues with the use of biodestructors to accelerate the decomposition of organic matter [4; 7; 8; 30];
- implementation of an effective irrigation system that will improve the unstable conditions of natural moisture supply in more than half of the territory of Ukraine [19; 22].

Thus, the integrated application of these elements of alternative technologies will counteract the negative effects of global warming and contribute to the accumulation, preservation and rational use of soil moisture, especially in drought conditions.

CONCLUSIONS

It can be concluded that due to the negative impact of global warming and other stress factors, environmental problems are spreading: ecological and phytosanitary crisis, soil degradation and pollution, as well as loss of its fertile layer. In addition, there is an increase in extreme climatic phenomena that affect grain production and export: droughts, dry spells, storms, dust storms, downpours, hail, frosts and frostbite, snowfalls, freezing and icing, floods, flooding and submersion, which are associated with climate change.

Based on the calculations, it was established that during 2010–2023, a steady trend towards an increase in grain production by 24% and its exports by 74% is observed in the world. The analysis results show that Ukraine holds a high competitive position in the global production and export of grain products. Analytical calculations confirm that in 2023, despite the negative impact of climatic, economic and geopolitical factors, Ukraine retained its position as one of the key grain exporters, taking sixth place in the world ranking and accounting for 7% of global exports. Ukraine also belongs to the group of ten leading global producers of grain products, providing 2% of the world's volume. Thus, Ukraine has maintained a leading position in the world grain market, which demonstrates the stable functioning of the country's agricultural sector even under increased challenges and adverse circumstances.

But due to the negative impact of anthropogenic factors: significant changes in the structure of sown areas of grain, technical and fodder crops, there was a reduction in the scientifically based selection of optimal predecessors, as well as a violation of the permissible periods of repeated cultivation of grain crops in crop rotations, as a result of which the negative impact of abiotic and biotic factors developed: moisture and nutrient reserves in the soil decreased, the accumulation of infectious diseases increased, and the spread of weeds and pests increased, which led to a decrease in grain production to 59.8 million tons and exports to 44.2 million tons.

Based on the calculations performed, it was proven that, along with the negative consequences of global warming, economic conditions, and chaotic changes in the structure of sown areas, the following factors contributed to the decrease in grain crops productivity: military actions, occupation, mining of fields, which led to a decrease in sown areas, as well as to the complication of logistical processes. These arguments are confirmed by analytical results, which show that during 1990–2023, wheat yield in Ukraine increased only 1.2 times and amounted to 4.64 t/ha, which is characterized by a significant deviation from the potentially achievable level.

To guarantee food security and sustainable development of grain production and export in the context of climate change, martial law, and to ensure further integration of Ukraine into the EU, the introduction of alternative technologies is proposed to better utilize the biological capabilities of grain crops in drought conditions.

The use of such alternative technologies will help protect the environment from pollution and land resources from degradation, while simultaneously solving the food problem and providing consumers on the world market with high-quality grain products, which will contribute to improving the health of the population and the harmonious development of rural areas, especially in the context of global warming.

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IMPACT OF SOLAR ENERGY ADOPTION ON FARM PRODUCTIVITY AND INCOME AMONG RURAL HOUSEHOLDS: CASE OF ENTASOPIA, KAJIADO, KENYA

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Abstract

This study examined the impact of solar energy adoption on farm productivity and household income among rural households in Entasopia, Kajiado County, Kenya. A mixed-methods design was employed. Data were collected from 120 households (60 adopters, 60 non-adopters) via surveys, 20 semi-structured interviews, and three focus groups. Multiple regression analysis and thematic analysis were applied. Results showed adopters achieved 50% higher maize yields (2,100 kg/ha vs. 1,400 kg/ha), 50% higher bean yields, and 58% higher tomato yields compared to non-adopters ($p < .001$). Irrigation efficiency improved by 33%, and labor hours decreased by 32%. Annual energy costs fell by 55% ($120 vs. $270), with surplus income rising to $850 (vs. $450; $p < .001$). Regression confirmed solar adoption explained 35–42% of variance in yields and income ($p < .001$). Barriers included high upfront costs and limited technical knowledge. Solar energy significantly enhances productivity and income in semi-arid regions, though policy support is needed to overcome adoption constraints.

Key words**:** *solar energy, farm productivity, household income, semi-arid agriculture, Kenya*

INTRODUCTION

Readily available and affordable energy is important for economic development and agricultural productivity. In Kenya agriculture is rated at 33% of the national gross domestic product (GDP). Over 70% of the population is employed in the sector (Kenya National Bureau of Statistics, 2020) [18] and this indicates its importance in the Kenyan context. Critically, energy access is considered as vital to agricultural productivity [12]. This happens to be a major issue in remote areas where access to the national grid is limited. The sun light and heat is a renewable and sustainable energy source which could be used in many domains of activity, agriculture being included [4]. Its utilization in aspects such as in lighting, solar-powered irrigation, and post-harvest processing helps to enhance farm productivity and improvement of household income [9]. In the rural Kenyan setup, there is increased solar energy adoption due to declining technology costs and supportive policies [20]. However, the specific impact of this effort is not explored in different areas such as in Entasopia, Kajiado. Entasopia, located in Kajiado County in Kenya, is a semi-arid region characterized mainly by smallholder farming and pastoralist livelihoods. The areas is characterized by significant energy access challenges that force most households to rely in traditional energy such as firewood and kerosene, a common factor in many remote areas [22]. Note that these alternative options are costly and environmentally unsustainable [23]. These sources are inadequate as far as modern agricultural needs are concerned such as powered irrigation systems and cold storage facilities [16]. Yet, these mentioned needs are critical in helping reduce post-harvest losses and improve on crop yields. As noted by Ockwell and Byrne, the decentralized nature of solar energy makes it the ideal solution to the mentioned challenges especially where the national grid has not reached [21]. For example, research has it that crop yields can be increased by 50% when solar-powered irrigation is applied [11].

The energy access challenge in Entasopia is worsened by socio-economic and environmental factors. The semi-arid climatic

condition found in the region limits the agricultural output this forcing the farmers to rely in the erratic rainfall and other traditional farming methods [19, 14]. The high cost of grid electricity and remoteness of the region makes conventional energy solutions impractical. These challenges can be addressed by solar energy through provision of affordable power for agricultural activities such as processing and irrigation that lead to enhanced productivity and reduced costs of labor [6]. Moreover, the proposed solar energy can be used to power the households and reduce energy expenditures thereby freeing up the resources that can then be used for investment in other income generating activities of in farming inputs [3]. However, the high costs associated with the solar energy, lack of financing and technical knowledge can hinder its adoption in the remote setup [22].

This study considers the impact of solar energy adoption with regards to household income and farm productivity. Three main objectives support the study. Firstly, it seeks to check on how solar energy utilization influences farm productivity. The focus in this context is with regards to irrigation efficiency, labor savings, and increased crop yields. Secondly, the study evaluates how household income is affected by the technology. The author considers the possibility of cost savings and increased income due to increased production. Thirdly, it seeks to identify the facilitators and barriers to solar energy adoption. Factors such as associated costs, awareness, and access to technology are deemed relevant in this case. The objectives are designed such that crucial gaps in understanding regarding solar energy are cleared. Mainly, focus is accorded semi-arid regions.

The study addresses the following research questions:

(i)How does solar energy adoption affect farm productivity in Entasopia?

(ii)What is the impact of solar energy adoption on household income in Entasopia?

(iii)What factors influence the adoption of solar energy among rural households in Entasopia?

The structure of the study has a literature review and methodology sections. The results are then presented with findings on adoption factors, productivity, and income. The discussion section follows contextualizing the findings and a conclusion with policy recommendations and direction for future research ensues.

Literature review

Solar Energy in Agriculture: Applications

Solar energy is classified as a transformative technology in the agriculture sector. Mainly, in the rural settings where the access to the grid is limited, it is the preferred source of energy. It is mainly applied in farming as detailed by different scholars who consider aspects such as irrigation, lighting, and post-harvest processing [9]. Solar-powered irrigation systems are designed to enable efficient water delivery helping to improve on crop yield thereafter [8]. Researches on solar indicating that solar-powered drip irrigation helped to increase yields by up to 50% in Sudano-Sahel region [8]. The researcher confirms in their study that the technology enabled the farmers to cultivate high-value crops year round. Past research also determined that solar lighting extends the working hours for the farmers thereby facilitating their tasks such as packaging and sorting after sunset [3]. Post-harvest processing, such as milling and solar drying is researched upon and determined to help reduce losses and also improve on product quality and thus improving on product quality and enabling the farmer to access better markets [16]. These applications demonstrate that solar energy has potential to address common challenges experienced in the remote areas with regard to energy constraints.

Empirical Studies: Productivity and Income Impacts of Solar Energy

Documentation on the productivity benefits and significant income from solar energy utilization in agriculture is noted in empirical studies. An example is in Yourn et al. who report that solar photovoltaic (PV) systems for irrigation in Senegal facilitated increased agricultural output [26]. The positive outcome is resultant of the enablement of multiple cropping cycles resulting in boosted household

income [26]. In India it was discovered that solar-powered pumps were being used and this led to lowered irrigation costs by around 60% compared to using diesel [2]. Consequently, the farmers were able to reinvest in purchasing better seeds and fertilizer. It was also confirmed that solar electrification in Kenya led to income diversification [15]. They found that small enterprises were cropping up due to reduced energy costs. However, other studies also concluded that high maintenance and upfront costs were a challenge to low-income households [22]. Such provide that local conditions and adoption barriers are the main factors that influence adoption

Regional Context: Solar Adoption in Sub-Saharan Africa

In the Sub-Saharan Africa context, energy poverty and abundant solar resources have driven solar adoption. Approximately 70% of the population in the region lacks access to electricity with the rural areas being highly affected [5]. Based on statistics, Kenya is determined to be a leader in the solar adoption agenda with effort such as supporting policies being developed like the Kenya National Electrification Strategy that was designed to promote off-grid solar solutions [17]. Studies suggests that electricity has been spread significantly across Kenya through solar home systems and microgrids thereby supporting agricultural and other economic activities [15]. In Tanzania, a study on solar energy determined that solar PV systems are increasingly being adopted in for the purpose of small-scale farming [22]. The adoption is noted to take place despite the high related costs as a major barrier [22]. Solar energy decentralization across the region makes it a suitable solution to remote areas. However, there are studies that indicate the adoption rates vary due to differences in awareness, financing models and policy support [21]. These regional aspects suggests the related challenges and potentials of scaling solar energy.

Research Gap: Limited Focus on Semi-Arid Regions like Kajiado

Despite the growing body of research on solar energy in agriculture, semi-arid regions like Kajiado, Kenya are majorly ignored. Such areas face unique challenges such as water scarcity and low agricultural productivity, factors which could be addressed through provision of solar energy to facilitate irrigation [14]. Most studies focus on peri-urban and high-end rainfall areas thus leaving a gap in understanding solar energy's role in the semi-arid areas [1]. For example, there is focus on the Sudano-Sahel area [8]. Their recommendations might not be suitable to Kajiado's pastoralist-dominated economy. Additionally, there is the lack of context-specific studies that are designed to examine how socio-economic factors, such as access to credit and income levels, influence solar adoption in semi-arid regions [24]. This study is designed to cover the ignored areas through focus on Entaspia, Kajiado, a semi-arid region with unique agricultural and energy challenges.

Theoretical Framework: Diffusion of Innovations Theory

The researcher selected to utilize the diffusion of innovations theory, developed by Rogers which provides a framework suitable to help create understanding on the study matter [23]. The theory posits that technology adoption is influenced by five main attributes. These are listed as complexity, relative advantage, trialability, observability, and compatibility. In relation to solar energy, relative advantage would be taken to mean the benefits associated with its usage compared to traditional energy sources [3]. Compartibility would be taken to reflect the quality of alignment between the technology and local farming practices while complexity would focus on the technical knowledge that is required to use the solution. Trialability allows the farmers to test the solar systems before full adoption to check its performance and productivity. Observability refers to the visible benefits associated with its use such as increased yields. This framework guides the analysis of adoption barriers and facilitates in the target region.

MATERIALS AND METHODS

Study Area: Entasopia, Kajiado

The study area was Entasopia, located in Kajiado County, Kenya approximately 150

kilometers south of Nairobi. The setup is characterize by a semi-arid climate where annual rainfall is recorded to average between 450 – 1,454 mm as recorded for 44 year (1070-2013) [7]. The researchers determined the region had two distinct rain seasons [7]. The agricultural practices are dominated by smallholder farming and pastoralism. The farming of vegetables, maize, and beans is the primary farming in the region. According to Burney et al. water scarcity limits crop production thus making irrigation critical for productivity [8]. Socio-economically, the location has a population of approximately 10,000. These persons are majorly from the Maasai community which is noted to have low household incomes ranging between $1,500 annually [18]. In the region, it was determined that less than 20% of the households are connected to the national grid [22]. Many households in such remote areas in Kenya depend majorly on firewood and kerosene for their energy needs.

Research Design

A mixed-methods research design was considered in the study where a combination of quantitative and qualitative approaches was applied. The focus was to provide a comprehensive approach to understanding solar energy adoption and its impact on household income and farm productivity. The quantitative aspect measured the tangible outcomes while the qualitative measured the farmer perceptions, adoption barriers, and community dynamics. The tangible outcomes included the income changes and crop yields. The elected approach was in line with past studies on technology adoption in rural settings that are designed focused on triangulation of findings [12].

Data Collection

Household surveys were undertaken in October 2025 for 15 days to provide qualitative data on solar energy usage. The considered associated income and farm productivity. Questions were included in the survey instrument regarding different solar technology types mainly lighting and pumps. Frequency of use was also measured related to crop yields, input costs and household income sources. Focus was on beans, maize and vegetables. The measurement unit was in kilograms per hectare. Income data regarding agricultural earning and energy cost savings was measured. 120 households were targeted thereby a robust sample.

Semi-structured interviews were conducted with 20 farmers and 10 stakeholders. Those interviewed also included agricultural extension officers, and solar technology providers. They were required to express their perspectives on solar energy benefits, adoption factors and associated challenges. Technical performance, cost barriers, and socio-cultural influences were addressed in the questions. They were audio-recorded and lasted an average of 40 minutes. Participant consent was prerequisite. The focus groups had between 8-10 members. In the groups, information regarding solar energy adoption was recorded. The discussion topics included barriers, perceived benefits, and community attitudes. It was not compulsory that the respondents in the group own solar equipment. They focused on how solar energy benefits, related barriers, and community attitudes.

Sampling was performed on 120 households. The sample size was reached upon based on Cochran's formula for finite populations. Cochran recommended the researcher to ensure a 95% confidence level and 5% margin error [10]. The respondents were classified as either adopters or non-adopters, meaning those using solar energy, and those who do not respectively.

Data Analysis

Regression analysis was utilized to analyze the effects of solar energy on households income and farm productivity. Multiple regression was applied on the variables. The dependent variables were crop yield (kg/ha) and annual household income (USD). The independent variables were the household characteristics, mainly the family size and education level among others, and the solar adoption status. Confounding factors included rainfall availability and market access. Analysis was carried out using Strata software. Thematic analysis was carried out on the qualitative data.

Triangulation with quantitative findings enhanced the reliability.

Ethical Considerations

The researcher was critical regarding ethics and ensured that all participants were required to give their informed consent. They were informed about the scope, context, purpose and procedures of the study. Anonymity was assured as no personal identifiable information was recorded. They were also allowed to withdraw from the study at their wish.

RESULTS AND DISCUSSIONS

Descriptive Statistics: Household Characteristics and Solar Adoption Rates

Of the 120 sampled households, 60 were adopters and the rest were non-adopters. They had a mean size of 5.8 members household members (SD = 1.9). 62% of the members were headed by males. As confirmed by Kenya National Bureau of Statistics (2020), the average age of the household heads was 42 years (SD = 10.2) 48% of these heads had completed primary school education or higher. The landholding rates were recorded at an average of 2.3 hectares (SD = 1.1). The primary crops were vegetables, beans, and maize.

Table 1. Household Characteristics

Characteristic	Adopters (n=60)	Non-Adopters (n=60)	Total (N=120)
Household Size (M, SD)	5.9 (1.8)	5.7 (2.0)	5.8 (1.9)
Male-Headed (%)	60%	64%	62%
Age of Head (years, M, SD)	43 (9.8)	41 (10.5)	42 (10.2)
Primary Education or Higher (%)	50%	46%	48%
Land Size (ha, M, SD)	2.7 (1.2)	1.9 (0.9)	2.3 (1.1)

Source: Data from sampled households

Solar energy usage was at 50% of the surveyed households. 65% of the adopters used solar energy for irrigation purposes. 25% used for lighting, and 10% for solar dryers. Adoption was higher among households with larger landholdings (M = 2.7 ha, SD = 1.2) compared to non-adopters (M = 1.9 ha, SD = 0.9), $t(118) = 3.45$, $p < .01$. 78% of the adopters had used the technology for 1-3 years.

Productivity Outcomes: Crop Yields, Irrigation Efficiency, Labor Savings

With regards to productivity, adopters reported higher maize yields (M = 2,100 kg/ha, SD = 450) compared to non-adopters (M = 1,400 kg/ha, SD = 380), $t(118) = 5.62$, $p < .001$. Bean yields followed a similar trend, with adopters achieving 900 kg/ha (SD = 200) versus 600 kg/ha (SD = 180) for non-adopters, $t(118) = 4.87$, $p < .001$. Tomato yields, a high-value crop, were significantly higher among adopters (M = 15,000 kg/ha, SD = 3,200) than non-adopters (M = 9,500 kg/ha, SD = 2,800), $t(118) = 5.19$, $p < .001$.

Irrigation efficiency, measured as water use per hectare, improved among adopters (M = 300 m^3/ha, SD = 80) compared to non-adopters (M = 450 m^3/ha, SD = 100), $t(118) = 4.12$, $p < .01$. Labor savings were significant, with adopters spending 15 hours/ha/week (SD = 4) on irrigation versus 22 hours/ha/week (SD = 5) for non-adopters, $t(118) = 3.98$, $p < .01$.

Calculation Example: Yield Increase

For the maize, the yield increase for the adopters is calculated as follows: The yield increase for maize (ΔY) due to solar energy adoption is calculated as the difference between the mean yield for adopters and non-adopters:

$$\Delta Y = Y_{adopters} - y_{non-adopters} \text{.....(1)}$$

Given:

- $Y_{adopters} = 2{,}100\ kg/ha$
- $Y_{non-adopters} = 1{,}400\ kg/ha$

$$\Delta Y = 2{,}100\frac{kg}{ha} - 1{,}400\frac{kg}{ha} = 700\ kg/ha$$

Percentage increase calculation

The percentage increase in maize yield (%ΔY) is calculated as follows:

$$\%\Delta\mathbf{Y} = \left(\frac{\Delta\mathbf{Y}}{Y_{non-adopters}}\right) \times 100 \text{ .....(2)}$$

Substituting the values:

$$\%\Delta \mathbf{Y} = \left(\frac{700}{1{,}400}\right) \times 100$$

$$\%\Delta \mathbf{Y} = 0.5 \times 100 = 50\%$$

Here, the percentage increase is confirmed to be 50% as stated. Productivity differences between the adopters and non-adopters are summarized in Table 2 (means, SD, t-test, coefficient of variation, and percentage yield increase)

Table 2. Productivity Outcomes for Adopters and Non-Adopters

Indicator	Adopters (n=60) M (SD)	Non-Adopters (n=60) M (SD)	t-test (df=118) p-value	CV Adopters (%)	CV Non-Adopters (%)
Maize **Yield (kg/ha)**	2,100 (450)	1,400 (380)	t = 5.62, p < .001	21.4	27.1
Bean Yield (kg/ha)	900 (200)	600 (180)	t = 4.87, p < .001	22.2	30.0
Tomato Yield (kg/ha)	15,000 (3,200)	9,500 (2,800)	t = 5.19, p < .001	21.3	29.5
Irrigation Efficiency (m^3/ha)	300 (80)	450 (100)	t = 4.12, p < .01	26.7	22.2
Labor Savings (hours/ ha/week)	15 (4)	22 (5)	t = 3.98, p < .01	26.7	22.7

Source: Survey data (October 2025).
Note. CV = Coefficient of Variation = (SD / M) × 100. Lower CV indicates greater consistency.

Income Effects: Cost Savings, Market Access, Income from Surplus

Solar adoption enhanced household income through cost savings, improved market access, and surplus produce.

Adopters saved 55% on energy costs, averaging $120/year (SD = $30) compared to $270/year (SD = $50) for non-adopters, t(118) = 6.43, p < .001. Table 3 summarizes income effects.

Table 3. Income Effects by Solar Adoption Status

Metric	Adopters (n=60) M (SD)	Non-Adopters (n=60) M (SD)	t-test (df=118) p-value	CV Adopters (%)	CV Non-Adopters (%)
Energy Costs ($/year)	120 (30)	270 (50)	t = 6.43, p < .001	25.0	18.5
Surplus Income ($/year)	850 (220)	450 (180)	t = 5.87, p < .001	25.9	40.0
Market Access (% selling produce)	65%	40%	χ^2 = 8.76, p < .01	–	–

Source: Survey data (October 2025).
Note. CV = Coefficient of Variation = (SD / M) × 100. Lower CV indicates greater consistency. Market access reported as percentage; CV not applicable.).

Sales of farm products was at 65% in local and regional markets. The non-adopters sold 40%, $\chi^2(1, N = 120) = 8.76$, $p < .01$. Income from surplus produce was significantly higher among adopters (M = $850/year, SD = $220) than non-adopters (M = $450/year, SD = $180), t(118) = 5.87, p < .001.

Qualitative Findings: Farmer Perceptions, Challenges, Benefits

Data from the three focus groups and 20 interviews gave insights into farmer challenges, perceptions, and benefits of solar energy adoption. The thematic analysis identified there were three key themes: financial gain adoption barriers, and

productivity gains. The farmers were noted to perceive solar energy as a facilitator of enhanced productivity. A 40 year old farmer noted "with the solar pump, I am able to irrigate my crops even during the dry season. The farmer noted that they were able to double their harvests as a result.

The interviewees indicated there were associated financial benefits. Farmers reported they saved money as there was lower reliance on diesel and kerosene which are costlier. The indicated that they used the money they saved to purchase better seeds and in their household expenses. However, there was indication that there were major fluctuations that influenced the benefits.

Addition barriers included high initial costs. Maintenance services and limited related technical knowledge was a barrier to adoption. The costs, such as the solar pump costs averaged at $800 was too high for the low-income households. Those who had installed solar systems confirmed the maintenance challenge.

Statistical Results: Significance of Solar Energy Impacts

Through multiple linear regression analysis, it was confirmed that solar energy adoption impacted farm productivity and income, controlled for education level, farm size, and household size. For productivity, solar adoption was a significant predictor of maize yield ($\beta = 0.62$, $p < .001$), explaining 38% of variance ($R^2 = 0.38$, $F(4, 115) = 17.45$, $p < .001$). Similar results were found for beans ($\beta = 0.58$, $p < .001$, $R^2 = 0.35$) and tomatoes ($\beta = 0.65$, $p < .001$, $R^2 = 0.40$). Irrigation efficiency was also significantly associated with solar adoption ($\beta = 0.52$, $p < .01$), explaining 30% of variance in water use ($R^2 = 0.30$, $F(4, 115) = 12.89$, $p < .01$). Results showed solar adoption as a significant predictor ($\beta_1 = 0.62$, $p < .001$), explaining 38% of variance ($R^2 = 0.38$, $F(4, 115) = 17.45$, $p < .001$).

For income, solar adoption significantly predicted annual household income ($\beta = 0.60$, $p < .001$), accounting for 42% of variance ($R^2 = 0.42$, $F(4, 115) = 20.67$, $p < .001$). Solar adopters had 50% higher income growth compared to non-adopters.

Table 4. Multiple Linear Regression Results: Impact of Solar Energy Adoption on Yields, Irrigation Efficiency, and Income

Dependent Variable	β (Solar Adoption)	SE	t-value	p-value	R^2	Adjusted R^2	F(df)	p-value (model)
Maize Yield (kg/ha)	0.62	0.11	5.64	< .001	0.38	0.36	F(4, 115) = 17.45	< .001
Bean Yield (kg/ha)	0.58	0.12	4.83	< .001	0.35	0.33	F(4, 115) = 15.62	< .001
Tomato Yield (kg/ha)	0.65	0.10	6.50	< .001	0.40	0.38	F(4, 115) = 19.21	< .001
Irrigation Efficiency (m^3/ha)	-0.52*	0.13	-4.00	< .01	0.30	0.28	F(4, 115) = 12.89	< .01
Annual Household Income (USD)	0.60	0.09	6.67	< .001	0.42	0.40	F(4, 115) = 20.67	< .001

Source: Survey data (October 2025). Analyzed using Stata.
Note.
-**Solar Adoption** coded as 1 = Adopter, 0 = Non-Adopter.
-**β** = Standardized regression coefficient (indicates strength and direction of effect).
-Negative β for irrigation efficiency reflects **lower water use** (improved efficiency).
-Models control for: farm size (ha), household size, education level of head, and rainfall variability.
-**SE** = Standard Error; **R^2** = Proportion of variance explained by the model.

Discussions

Interpretation: Results in Context of Literature

Based on the findings, it is plausible to conclude that solar energy adoption does significantly improve farm productivity and

income in the sampled region. This determination was in alignment with past research on the use of renewable energy in agriculture. The observed increases in tomato yields, maize, bean and other vegetables among solar adopters were consistent with the findings from Burney et al. [8]. In their study, they determined there was a 50% increase in maize yield where solar-powered drip irrigation systems were installed in Sudano-Sahel [8]. The improved irrigation efficiency was a confirmation of the vital role played by solar energy in irrigation as confirmed on solar pumps in India [2]. There were recorded labor savings where the adopters spent fewer hours carrying out irrigation as they were assisted by the solar-powered pumps. It was also determined that solar lighting and mechanization helped reduce labor burdens in the rural settings [3].

There was the noted income impact of using solar energy specifically the noted 55% reduction in energy costs and increase in surplus income. The finding was in line with the determinations on solar electrification in Kenya found to enable cost savings and income diversification [15]. Also, it was determined that farmer were able to have better access to markets due to the utilization of renewable energy [21]. The findings collaborated what was discovered in this study that solar energy adopters were able to access premium markets due to the improved crop quality. Qualitative findings on farmer perceptions of financial and productivity benefits worked to reinforce the quantitative findings. This was consistent with findings related to Diffusion of Innovations Theory that emphasizes technology adoption is highly influenced by associated perceived relative advantage [23]. There were challenges that were also identified in this study in relation to the adoption such as limited technical knowledge and high costs. These reflected related challenges also identified in with relation to Kenya and Tanzania [22]. This suggested these were persistent obstacles.

Adoption Factors: Cost, Awareness, Infrastructure

Infrastructure, awareness, and cost were the major factors that influenced solar adoption in the region. The cost of installing solar pumps, estimated at $800, was a high initial cost. 70% of the respondents, the non-adopters, quoted this cost as a major hindrance. There was support to this findings in connection to low-income households in past research [24]. It was recommended that subsidies and microloans were a plausible solution to the challenge [2].

Awareness was the other critical limiting factors as established through the focus groups. In the groups, the participants claimed limited knowledge about solar energy and the related benefits. It was also determined similarly thereby recommencing that extension services be used to educate the rural farmers [16]. It would also be plausible to have local technicians to help deal with the infrastructure challenges. The respondents in the study claimed that maintenance and associated costs were major hindrances to adoption. Robust supply chains are recommended as they minimize infrastructure challenges [22].

Limitations: Sample Size, Data Constraints, Study Scope

Several limitations were experienced in relation to this study. The sample size of 120 households might not have fully captured the diversity of the farming community in the region, despite it being statistically robust. As recommended by Adesina and Zinnah, a larger sample size could enhance the generalizability [1]. Data constraints included reliance on self-reporting on yield data and income where bias is possible. Cross-verification with agricultural extension data and market records would also improve on accuracy though not very feasible in this study due to resource limitations. The study's scope was limited to households that used solar technologies for 1-3 years. Potentially, the focus on this period would have possibly underestimated the long-term impacts or sustained growth. Applicability of recommendations might be limited to the Entasopia region as other Kenyan regions are likely to have different socio-economic and agro-ecological conditions. These limitations could be addressed in future studies in consideration of long-term outcomes.

CONCLUSIONS

This study clearly confirms the findings of past studies on solar power adoption and its impact on households. The results demonstrated that solar energy significantly enhances agricultural productivity. Those who used the technology claimed that their crop yield increased as a result. It was also determined herein that water loss was reduced and the farmers worked for fewer hours due to mechanization facilitated by the adoption of solar energy. The outcome of this experience was the improvement of the household income as the adopters were able to save on some of the money they used initially with other energy sources. Also, they got better yields with resultant increased sales. Some of the respondents noted they got better market access as they had improved product quality.
Based on the qualitative data, it was clear that solar technology was highly regarded in the community. The respondents mentioned their preference for the technology was due to the resultant productivity and financial benefits. However, they noted the high initial costs and limited technical knowledge as main limiting factors to adoption. Based on the regression analysis carried out, the researcher was able to confirm that adoption significantly increased yields and income. This was as expected and described under the diffusion of innovations theory. Overall, the relative advantage of solar energy adoption was highlighted and noted to be compatible to the local community. Its transformative influence on remote households was confirmed.

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UKRAINIAN AGRICULTURAL PRODUCTS EXPORT ISSUE IN THE FRAME OF EUROPEAN TRADE PREFERENCES WITHDRAWAL

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Abstract

This paper aims to provide evaluation of the Ukrainian agricultural products export issue in the frame of European trade preferences withdrawal and to estimate the forecast of the agricultural export. The research analyzed data obtained from the State Statistics Service of Ukraine, Ministry of Agrarian Policy and Food of Ukraine, Ukrainian Agribusiness Club, APK Inform and USDA. The methodological framework of the paper relies on statistical data on agricultural exports and involves a descriptive analysis of the dynamics of grain and oilseed indicators, including production volumes, export, and ending stocks. To foresee further export opportunities there is polynomial dynamic model for grain used and for oilseeds export dynamic model with linear trend is applied. To conduct purposes in the article, main tendencies in agriculture export were evaluated to highlight the importance of stable logistics that in turn significant to further assessing the economic feasibility of exports, finding of alternative sales markets, determining the industry's sensitivity to external changes, adaptation policy formation, optimization of logistics and contract strategies. Since 2022 following export logistics changes were occurred: (1)diversification of export routes; (2) Grain Initiative Agreement was launched that allowed Ukraine to export grain and other foodstuffs from three key Black Sea ports (Odesa, Chornomorsk, and Pivdennyi); (3) infrastructure overload and delays; (4) EU Temporary Trade Liberalization (Autonomous Trade Measures (ATMs));(4) investment in temporary storage and handling; (5) use a mixed modal transport (i.e. combined logistics solutions). ATMs started in force in 2022 and was important because provided trade liberalization for Ukraine, suspending import duties, quotas, and trade defence measures on a temporary basis. Since its action finished June 5, 2025, in the article there are analysed consequences and forecasts for Ukrainian agricultural products export. Getting results showed the withdrawal of EU trade preferences will lead to a decrease the competitiveness of Ukrainian agricultural products on the European market due to the reintroduction of tariffs, quotas, and non-tariff barriers, which will increase the final cost of goods. A partial reorientation of exports is expected toward countries in Asia, the Middle East, and Africa, where demand for Ukrainian products already exists and further expansion is possible. In the frame of these circumstances, the development of domestic processing may increase in value-added exports, reducing reliance on raw commodity trade, and stimulating structural transformation in the agricultural sector. Analysis of main grain crops (i.e. wheat, barley and corn) showed that in 2025/2026 MY their production would increase on 5%, where export is forecasted at the same level as previous marketing year to approximately 40,500 thousand tons. In contrast to grains, in 2025/2026 MY oilseeds production (i.e. rapeseed and soybean) will decrease on 4.6%, where their export will decrease on 2%. These outcomes could explained mainly by the withdrawal of EU trade preferences and domestic increase of soybean processing.

Key words**:** *agricultural products, export, analysis, forecast, European trade preferences, Ukraine*

INTRODUCTION

Over the past decades, Ukraine has been confidently ensuring its own food safety and actively developing the export potential of its agricultural industries. At the beginning 2022, Ukraine was a major player in some global agricultural markets, in particular sunflower oil and meal; rapeseed; rapeseed oil and meal; corn; barley; wheat; soybean; oats; poultry meat; honey, walnut; etc. In the condition of Russia invasion, the past three years Ukraine has maintained its position as an important exporter of agricultural products on the world market. At the same time, the war undoubtedly affects the level of Ukrainian market integration with the world markets and the possibilities of conducting foreign economic operations [8]. The results of the research conducted by Hamulczuk et al. (2023) show that the strength of the integration of Ukrainian grain markets with world markets has deteriorated due to the war [7]. It is confirmed

by the decrease in the grain export volumes from Ukraine, the increase in price differences, and the lack of significant price transmission between Ukrainian and global grain markets since the war started. It can be observed a growing role of the European Union countries in the Ukrainian grain export share and changes in the Ukrainian grain export concentration.

An important component of supporting Ukrainian agricultural exports was the decision of the EU countries in June 2022 to lift all restrictions on the Ukrainian products import to support Ukrainian economy during the war [16]. In 2023, the free trade regime was extended for one year. Through the introduction of the Solidarity Lanes, the EU played a key role in facilitating trade during the crisis, helping to maintain trade flows and reduce market pressures, volatility, and adverse impacts on global food security [4]. However, in 2024 the import of a number of Ukrainian goods (i.e. poultry, eggs, sugar, oats, corn, grains and honey) was restricted to protect the most sensitive EU agricultural markets. Since June 6, 2025, the preferential trade regime for the supply of Ukrainian agricultural products to the EU countries was terminated [3].

There are distinguish factors, which influence the agricultural products export, i.e. the level of harvest of leading global agricultural producers, taking into account weather conditions and climate change, world prices fluctuations and market conditions changes, competition on the world market. Humeniuk (2023) in its paper used a multifactor regression model and identified that the state of agricultural exports, where in addition to the volume of agricultural production, is influenced by the following factors: the exchange rate of the US dollar, the availability of fixed assets, labor productivity; and investments in the industry [9].

Since 2022 logistics problems have been added to factors mentioned above, affecting Ukrainian export opportunities. According to Kotvytskaet al. (2025), a special attention should be paid to the issues of adapting Ukrainian exporters to European logistics standards. She indicated that it should be assess the impact of digitalization on the efficiency of foreign trade operations and clearly defining the prospects for the development of Ukraine's transportoinfrastructure [10].

Nechyporuket al. (2023) analyzed changes in the commodity structure of exports and its reorientation to EU countries in the first year and a half of the war in Ukraine [12]. The main prerequisites for this were the signing of the Black Sea Grain Initiative (BSGI) and the creation of Solidarity Lanes by the European Commission to increase the throughout capacity between Ukraine and EU countries. At the same time, they emphasized the relevance of analyzing all alternative directions for agricultural products sale with the possibility of using various types of transport, i.e. rail, road, and marine [12].

Thus, the development of Ukrainian agricultural exports requires further research, taking into account the factors of instability and the negative consequences of the war in Ukraine; the importance of the export to Ukrainian economy.

The novelty of conducting research is to evaluate the influence of European trade preferences withdrawal on Ukrainian export, in particular grain and oilseeds. Taking into account the fact the war in Ukraine is continuing, the forecast of further export possibilities will be considered.

MATERIALS AND METHODS

The purpose of the article is to evaluate the Ukrainian agricultural products export issue in the frame of European trade preferences withdrawal and to establish the forecast of the agricultural export.

The methodical basis of the paper is the provision of statistical data on agricultural export, descriptive analysis of changes in grain and oilseed indices as main exported products, i.e. production, export and ending stocks.

Since the largest export revenues to Ukraine in 2024 belonged to wheat, barley, corn, rapeseed and soybeans, in the article is predicted their future exports.

To forecast export of grains, a polynomial dynamic model was used, i.e.

$Yt=\beta_1+\beta_2 t+\beta_3 t^2+\varepsilon_t$, ...(1)

where: Y – export in time t; β_1 - starting point; β_2, β_3- rates of change; ε_t-inherent noise in the data.

To forecast export of oilseeds, a dynamic model with linear trend for one period ahead was applied, i.e.

$Yt = \beta_1 + \beta_2 t + \varepsilon t$, ...(2)

where:

Y – export in time t; β_1 - starting point; β_2 - rate of change; εt-inherent noise in the data.

In both models, the value of R-squared indicates how reliable the model's predictions fit the actual data.

R-squared value that is close to 1 suggests a better fit and means the model's predictions accuracy.

In the paper distinguish following hypothesis in the frame of withdraw export preferences to Ukrainian products that should be proved and substantiate:

(1) decrease in competitiveness. The abolition of EU trade preferences will lead to a decrease in the competitiveness of Ukrainian agricultural products on the European market;

(2)exports reorientation. As a result of the abolition of preferences, part of Ukrainian agricultural exports will be reoriented to alternative markets, e.g. Asia, the Middle East, and Africa;

(3) domestic processing growth. The abolition of export privileges stimulates the development of domestic processing of agricultural products in Ukraine.

RESULTS AND DISCUSSIONS

According to the Ministry of Agrarian Policy and Food of Ukraine, in 2024, Ukraine almost reached the pre-war level of agri-food exports – 24.5 bln US dollar, which evaluated to 59% of total exports.

In terms of export value, the largest share is accounted for sunflower oil, i.e. 21%, where almost 6 mln t were exported for 5.1 bln US dollar, corn – 21% (29.6 mln t for 5 bln US dollar) and wheat – 15% (20.6 mln t for 3.7 bln US dollar) (Table 1).

Table 1. Ukrainian export earnings in 2024, mln US dollar

Products	Export, mln US dollar
Sunflower oil	5.1
Corn	5.0
Wheat	3.7
Rapeseed	1.8
Soybeans	1.3
Sunflower meal	1.0
Poultry	0.9
Barley	0.5
White sugar	0.4
Soybean oil	0.3
Soybean meal	0.3
Rapeseed oil	0.2
Walnuts	0.1
Powdered milk, cream	0.07
Beef	0.07
Cheese	0.05
Butter	0.04
Apples	0.02

Source: [13].

Among the export products a significant share belong to: rapeseed – 7% (3.8 mln t for 1.8 bln US dollar); soybeans – 5% (3.4 mln t for 1.3 bln US dollar); meal and residues obtained during the extraction of vegetable fats and oils – 4% (4.7 mln t for 1 bln US dollar). The share of meat and edible poultry products is accounted to 4%, where 447 thousand t of these products were exported for 958 mln US dollar. Barley was exported for 3.3 mln t that is in value equal to 557 mln US dollar [2, 19].

Analysis of the structure of the main directions of Ukrainian agricultural products exports during 2020-2024 characterizes an increase in the specific share of the EU countries markets. Indeed, in 2022, the specific share of European markets increased to 55.2% compared to 2021 with a share of 28%. Accordingly, this share remained high both in 2023 this was equaled 56.8%, and in 2024 - 52% (Fig. 1).

In our opinion, the analyzed changes in Ukrainian agricultural products exports destinations during last three years are primarily due to logistic problems. Before 2022, seaports remained the main way of Ukrainian agricultural exports, i.e. in the average approximatly 98 % of agricultural goods were exported by sea [1].

The most significant issue in export activity was the disruption marine logistics in the period from March to July 2022, which led to

the further accumulation of large stocks and the transfer of Ukrainian goods to neighboring EU countries.

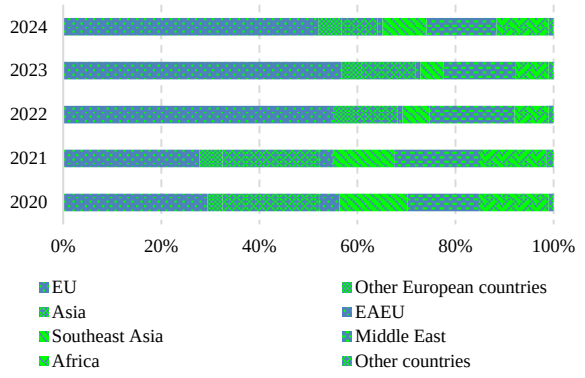


Fig. 1. Ukrainian agricultural products exports destinations during the period of 2020-2024
Source: [13].

In March-June 2022, against the backdrop of the blockade of ports, the share of marine use for goods export fell by more than half (Fig. 2). Marine logistics are more crucial important for grains due to limited domestic market capacity and the need for timely exports of large product volumes. Changes in logistic costs immediately affect farm gate prices, shifting the balance between grain and oilseed areas each marketing year.

Due to the blockade of the Black Sea and the termination of the grain agreement, agricultural products logistics through the Danube ports in 2023 almost doubled compared to 2022.

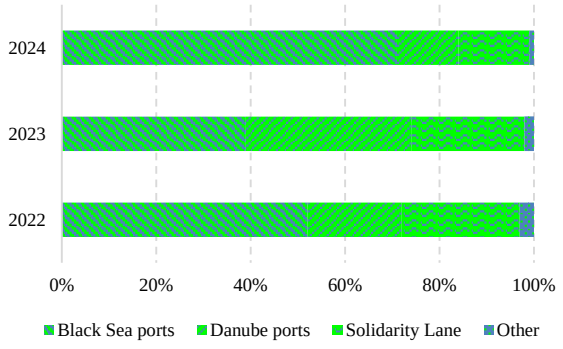


Fig. 2. Share of export logistics channels in Ukraine during 2022-2024, %
Source: [13].

However, after the launch on August 2023 "The Ukrainian corridor", cargo flows shifted in favor of marine, i.e. the Odessa port. Despite the constant shelling of port infrastructure, the total turnover of agricultural cargo in 2024 increased by 32% compared to 2023.

In May 2022, the European Commission launched the Solidarity Lanes Action Plan to establish alternative logistics routes via rail, road, and inland waterways. Since their introduction, the Solidarity Lanes have enabled Ukraine to export around 187 million tonnes of goods. Of this total, approximately 93 million tonnes consisted of agricultural products, including about 86 million tonnes of grain, oilseeds, and related products, while around 94 million tonnes were non-agricultural goods such as ores, steel, and related products [5].

By ensuring the continuity of Ukrainian exports under conditions of disrupted traditional routes and restricted access to global markets, the Solidarity Lanes, together with EU trade support measures and elevated logistics costs, have accelerated the geographical reorientation of Ukraine's agrifood exports toward the EU market. Consequently, the EU's share in Ukraine's agrifood exports increased from 28% in 2021 to 52% in 2024.

This growing concentration of Ukrainian agrifood exports in the EU has substantially increased Ukraine's role in EU agrifood trade and food security. In 2024, Ukraine became the third-largest supplier of agrifood products to the EU, accounting for 8% of the total EU agrifood import value (13 billion Euro), compared to 5% (6.9 billion Euro) in 2021. For selected commodities, Ukraine's share of EU imports was particularly high, including sugar (37%), wheat (68%), eggs (47%), and honey (31%) [14].

At the same time, the rapid expansion of Ukrainian agrifood supplies to the EU market has intensified competitive pressures on certain EU agricultural sectors, contributing to growing political and economic debates regarding the sustainability of temporary trade liberalisation measures and the potential withdrawal or adjustment of EU trade preferences for Ukraine.

Having had a temporary action of the Solidarity Lanes, on June 5, 2025 it was abolished.

In turn, the withdrawal of EU trade preferences will lead to a decrease in the competitiveness of Ukrainian agricultural products on the European market. Indeed, it will significantly undermine the price advantages of Ukrainian agricultural products. Under the preferential trade regime, Ukrainian producers benefited from duty-free and quota-free access to markets, which allowed them to offer competitive prices and increase their market share in EU countries.

Due to the fact that these preferences are withdrawn, customs duties and non-tariff barriers are expected to be reinstated. In these circumstances it will increase the final cost of Ukrainian goods, making them less attractive compared to products from EU countries (Hypothesis 1).

Furthermore, Ukrainian agricultural products exports, in particular wheat, corn, sunflower oil, poultry, honey, and berries often compete in price-sensitive segments of the EU market. The loss of zero-tariff access will hit these segments hardest, taking into account the fact of rising domestic production costs in Ukraine due to war-related risks, logistics disruptions, and energy price increase.

Second hypothesis states that the abolition of EU trade preferences is expected to prompt a partial reorientation of Ukrainian agricultural exports toward alternative markets, particularly in Asia, the Middle East, and Africa. This strategic shift arises from the necessity to maintain export volumes and revenue in the face of reduced competitiveness on the European market. Given the fact that the EU will reintroduce tariffs, quotas, and regulatory barriers, many Ukrainian producers may find it more economically viable to redirect their products to markets with lower entry thresholds, growing demand, or established trade relations. Countries such as China, India, Egypt, Turkey, Saudi Arabia, and countries of Sub-Saharan Africa already import significant volumes of Ukrainian grain, oilseeds, and other agri-food products. Indeed, these regions offer opportunities for further expansion, especially in light of rising global food insecurity and population growth.

At the same time, such diversification of export geography helps to reduce the dependence on a single market and enhances Ukraine's trade resilience. For instance, during temporary EU trade restrictions in 2023, Ukraine successfully increased grain exports to Indonesia, Pakistan, and Tunisia, illustrating the feasibility of market reorientation.

Thus, while the loss of EU preferences poses short-term difficulties, the strategic reorientation of exports toward emerging and developing markets offers a long-term opportunity for market diversification and sustainable trade growth for Ukraine's agricultural sector.

According to Table 1, the highest share in export earnings in Ukraine in 2024 were belonged to wheat, barley, corn, rapeseed and soybean. In this regard, further we analyse dynamics of production, export and ending stocks for these main agriculture products.

Production of grain, i.e. wheat, barley and corn for last 5 years decrease in average on 2921.1 thousand t and the forecast for 2026/2027 MY indicate on its reduction (Fig. 3).

This is mainly caused by weather conditions and decrease of the land bank due to occupied or mined territory increase. In 2021/2022 MY could be observed the highest value of ending stocks, which was influenced by logistic problems through the marine.

A combination of improved logistics and lower production of these grains leads to minimal ending stocks starting from 2023/2024 MY to 2025/2026 MY As additional factor that has influenced on minimal stocks in 2024/2025 MY is growing domestic prices [17]. Grain exports for last two marketing years remain stable and equals approximately to 40,500 thousand tonnes.

In turn, the polynomial trend model shows the decrease in export volume for predicted period 2026/2027 MY, however the determination coefficient (R^2) is equalled to 0.65 that explained a not enough reliable forecast.

Indeed, improved logistics have made Ukrainian farmers more confident in growing high yield, high volume crops such as corn, which could affect the balance between grains and oilseeds in 2025/2026 MY [18].

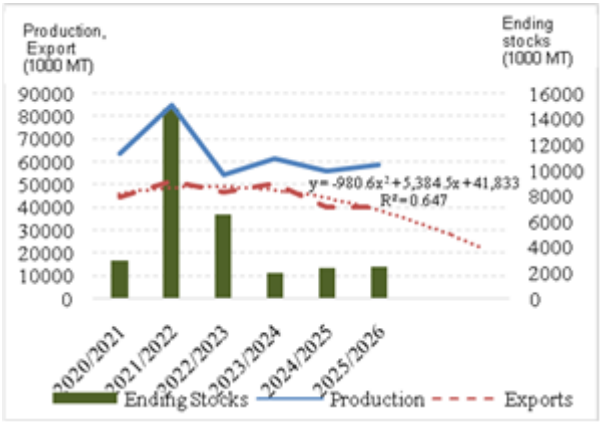


Fig. 3. Dynamics of Ukraine's stocks versus production and exports for wheat, barley and corn
Source: author's calculations based on State Statistics Service of Ukraine and USDA data, 2025 [15, 17].

Regarding the production area for the 2025/2026 MY, forecasts decrease of rapeseed area due to the drought in the fall of 2024. In 2025/2026 MY sunflower areas down compared to its value in 2024/2025 MY. This is primarily caused by farmers rotate away from the crop to limit the spread of diseases and loss of soil nutrients. USDA forecast confirmed by the decreased sunflower planting seed imports.

In Fig. 4, it is presented the dynamics of Ukraine's stocks, production and exports for rapeseed and soybean, where sunflower seed was not taken into account due to its completely domestic consumption for processing purposes. In 2021/2022 MY there is observed highest value of ending stocks of rapeseed and soybean and it accounted to 1,037 thousand tones. Next two years there were decrease in ending stocks due to stabilized in logistics as mentioned above. However, in 2024/2025 MY and 2024/2025 MY there were observed increase in ending stocks to 419 thousand tones and for 2024/2025 MY to 541 thousand tones.

There are three factors that influenced on soybean stocks increased: (1) record harvest, (2) increased domestic processing, and (3) limited logistics capabilities [11]. Rapeseed remained in storage due to reduced domestic consumption and exports, as well as increased support policies for processing plants.

Taking into account the linear trend model, there is could be observed export increase of rapeseed and soybean to 8,000 thousand t in 2026/2027 MY, where R^2=0.72, which indicates that the model's predictions are quite accurate.

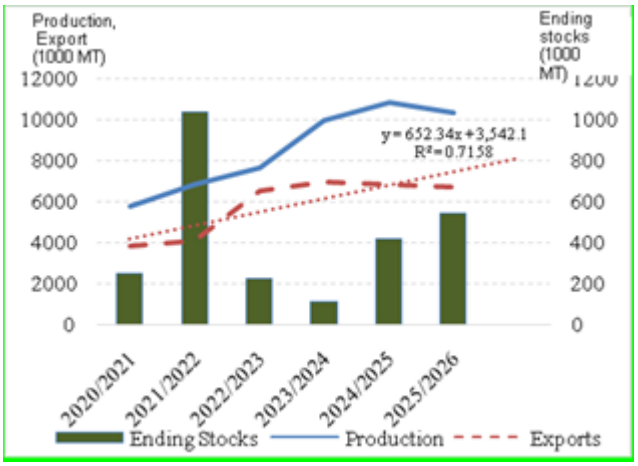


Fig. 4. Dynamics of Ukraine's stocks versus production and exports for rapeseed and soybean
Source: author's calculations based on State Statistics Service of Ukraine and USDA data, 2025 [15, 18].

In the frame of the Solidarity Lanes finished, the further enhance of the export for agricultural crops, in particular analyzed above, could concern to domestic processing growth, which in turn stimulate structural changes within the sector. Value-added products, such as flour, vegetable oils, canned vegetables, or processed meat, are often subject to lower tariffs or benefit from alternative trade frameworks. In this term, Ukrainian producers to invest in processing infrastructure, such as mills, oil extraction plants, and food packaging facilities. Instead of exporting low-margin raw materials, Ukraine retains more value within the country creating jobs, increasing tax revenues, and stimulating demand in related industries, in particular logistics, packaging, machinery, etc. For instance, in 2023, despite a decline in grain exports, Ukraine increased exports of sunflower oil and processed soybean, indicating a shift toward processed exports (Hypothesis 3).

In turn, Ukrainian government and donors plays a crucial role to develop domestic processing plants, where in response to EU trade restrictions, Ukraine and partner's countries have launched programs to support agrarian food processing enterprises, offering

grants and technical assistance to small and medium-sized producers. Indeed, the shift from raw exports to processing is not only a survival mechanism for Ukrainian producers; it is a long-term development opportunity that strengthens Ukraine's agro-industrial potential and the whole country's economy.

CONCLUSIONS

In the paper is analyzed Ukrainian agricultural products export issue in the conditions of European trade preferences withdrawal; considered further agricultural export.

In 2022, due to the blockade of seaports, Ukraine redirected its agricultural exports to land routes, particularly with the support of the EU's Solidarity Lanes initiative. EU autonomous trade preferences temporarily ensured the access of Ukrainian agricultural products in the European market. However, in 2023, import restrictions that was imposed by several EU countries (Poland, Hungary, Slovakia, Romania and Bulgaria) highlighted the need for geographical diversification of Ukrainian exports. As a results, in 2024 Ukraine expanded exports to Asia, the Middle East, and Africa.

By 2025 the EU countries were the main export destination, importing approximately half of Ukraine's total grain and oilseed exports. In 2024, Ukraine's agricultural exports to the EU accounted for 55% of the total export. The termination of trade preferences in June 2025 is foreseen: (1) decrease competition of Ukrainian products on EU markets; (2) partial reorientation of exports to alternative markets; (2) the development of domestic processing.

The restrictions are expected to reduce exports by about 10%, which will negatively affect economic growth. Indeed, the restrictions affect export potential by 3–3.5 billion Euro, it is the value that exporters could lose [6]. In turn, according to the Ministry of Economy the negative impact on Ukraine's GDP will be about 1%.

On our opinion, agricultural exports from Ukraine are expected to remain relatively stable over the period 2025–2028, where fluctuations could mainly depend on harvest volumes, global market dynamics, safety situation in the country and logistics capacity.

Considering on trade changes with EU countries, there are key influencing factors could enhance export potential from Ukraine, i.e. global commodity prices increase and demand; changes in trade policy of importing countries; logistics improvements, in particular construction of terminals, cross-border capacity expansion.

Further research could concern question about deterioration of the trade balance, where the loss of EU preferences will negatively affect Ukraine's overall trade balance in the agricultural sector; sectoral vulnerability.

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A NEW TREATMENT METHOD WITH AN ECOLOGICAL INSECTICIDE USED FOR THE FIRST TIME IN ROMANIA FOR SUNFLOWER CROPS IN THE SOUTHERN DOBROGEA AREA, ROMANIA

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Abstract

The paper aimed to present the results obtained after applying a new soil and seed treatment with the diatomite product for protecting maize and sunflower crops against insects attack. Diatomite, also known as diatomaceous earth, is actually almost pure amorphous silicon dioxide, made up of fossilized diatoms. It acts as an insecticide by absorbing epicuticular lipids and fatty acids, leading to dehydration of arthropod tissues and ultimately causing their death. The product has no effect on amphibians, reptiles, birds and mammals and is considered a biological insecticide from this point of view. This experiment is made for the first time in field conditions in Romania. The utilization of this ecological productis in line with the need for sustainable use of phytosanitary control products against the main pests of these crops in the indicated area. The results showed that under field conditions, diatomite significantly reduces the density of harmful insect populations (target species being Tanymecus dilaticollis Gyll.), but also of other species from genera with intense harmful activity in certain areas and conditions, such as species from the genus Agriotes.

Key words**:** *sunflower crop, ecological insecticide, diatomaceus earth, Romania*

INTRODUCTION

Concerns regarding food quality and environmental protection have led to the search for alternative and integrated insect control measures. Biological control is a highly effective pest management strategy in grain storage and supply; among the new methods used, diatomaceous earth can be an effective and cost-efficient alternative for preventing attacks by insects or pathogenic fungi and for creating conditions for the safe storage of cereals [30, 27]. Among the many types of inert dusts, diatomaceous earth holds a great potential for controlling pests in urban and stored products and has been studied by numerous researchers worldwide [3, 4, 34, 5, 6, 26, 31, 45, 24, 39, 41]. The use of diatomaceous earth is a very effective insect control measure in Integrated Pest Management (IPM) for stored grains due to its low cost, ease of application, reduction of active ingredient residues, low environmental contamination, and operator safety [14]. According to some authors, interest in diatomaceous earth has increased because the number of active ingredients for controlling insects in stored products has been reduced to only four or five products, mainly due to insecticide resistance issues [42, 5]. The insecticidal effect of natural diatomaceous earth has already been demonstrated [23, 8, 54, 9, 22]. Nevertheless, a series of formulated, patented products have been developed and launched on the organic pesticide market, such as Dryacide, Kenite 2-I, Perma-Guard, and

SilicoSec. Although the insecticidal efficacy of several diatomaceous earth formulations has already been sufficiently confirmed, a series of laboratory experiments were conducted at ICDPP Bucharest in which these products were combined with various essential oils to reduce residues and contaminants in the food chain [38]. According to data from scientific literature, the diatomite product has been used in various fields either as a natural product (diatomite extracted as powder from various quarries) or in various formulations depending on the intended use. A series of experiments were conducted using diatomite as a natural fertilizer in rice crops in Southern India. Pot experiments were performed with graded levels (0, 150, 300, 600 kg ha^{-1}) of diatomite along with the recommended doses of N, P, and K, across three types of soil (acidic, neutral, and alkaline) in Southern India, under two moisture conditions (field capacity and submergence), using rice as the test crop. The chosen diatomite consisted of biogenic silica, smectite, kaolinite, and quartz. Grain yield was lower in plants grown under moderate moisture conditions than under favorable moisture conditions, regardless of soil type or the added product. A higher grain yield was observed with various applications of diatomite under submerged (SUB) moisture conditions across all the three soils [28]. The application of diatomaceous earth (DE) could improve soil quality, but its agricultural application as a silicon fertilizer requires further research. Most experiments conducted with natural or formulated diatomite products took place under controlled conditions against pests in food warehouses or grain silos [12, 13, 37, 32, 40]. The safety of such treatments for human and animal health is fully justified by the fact that DE has no toxic effects on mammals (oral LD50 in rats> 5,000 mg/kg body weight) and leaves no toxic residues in the product [35, 50, 51]. Furthermore, diatomaceous earth is classified by the EPA (Environmental Protection Agency) in the GRAS category (Generally Recognized As Safe), as it is used as an additive in food or animal feed [25]. The most important pests against which the natural or formulated product has been used include: *Acanthoscelides obtectus* Say (Coleoptera: Bruchidae), *Sitophilus granarius* L., *Sitophilus oryzae* L. (Coleoptera: Curculionidae), *Tribolium castaneum* Herbst. (Coleoptera: Tenebrionidae), and even *Amblyomma americanum* L. (Ixodida: Ixodidae). This experiment represented the first use of a formulated natural diatomite insecticide under field conditions in sunflower crops in Romania. The study addressed both the efficacy of this product against the primary soil pests of sunflower (*Tanymecus dilaticollis* Gyll., *Tanymecus palliatus* F., *Opatrum sabulosum* L.) and its effect on the beneficial biodiversity within the crop. The mineral product diatomite was first introduced for testing in 2013 at Research and Development Institute for Plant Protection, ICDPP Bucharest, within the project PN-II-PT-PCCA-2013-4-0425 - "Ecological products based on diatomite and essential oils for reducing residues and contaminants in the food chain/PEDIOL" [49]. Subsequently, it was used in other projects carried out within the institute [36, 1, 2, 7]. In these projects, however, the product was used in laboratory experiments against stored product pests such as *Sitophilus granarius* L., *Callosobruchus chinensis* L., and *Acanthoscelides obtectus* Say [16, 37, 13, 15]. Internationally, a series of studies have also been conducted on the action of this product under laboratory conditions against stored product pests (those already mentioned) as well as other species such as *Sitophilus oryzae* L., *Tribolium confusum* duVal, *Rhyzopertha dominica* F., *Tribolium castaneum* Herbst, *Oryzaephilus surinamensis* L., *Ephestia kuehniella* Zell., *Plodia interpunctella* Hub., *Blattella germanica* L., *Acarus siro* L., *Lepidoglyphus destructor* Schrank, *Tenebrio molitor* L., *Callosobruchus maculatus* F., *Cryptolestes ferrugineus* Steph., *Lasioderma serricorne* F., and *Sitophilus zeamais* Motsch [8, 9, 10, 11, 12, 29, 30, 31, 33, 32, 24, 17, 18].

Diatomite or diatomaceous earth (DE) is physically an inert dust derived from amorphous sediments and composed of the fossilized shells of single-celled algae species.

It is a light weight material with low density, and its color ranges from white to dark grey. It consists of approximately 80-93% silicon dioxide (SiO_2), with the remainder being clay minerals, organic matter, quartz, calcium carbonate, and magnesium [31, 43]. Given the numerous studies conducted since the 1980s, the ecological insecticide contained within the mineral diatomite has been perceived as a solid option for controlling pests in grain warehouses. Furthermore, in its physical state, diatomite is abrasive and highly absorbent; the dust particles adhere to the insect's cuticle and, in doing so, remove the lipid monolayer, causing severe dehydration of the insect [31, 45].

The origin of this mineral was fully clarified by numerous studies following the discovery of its properties. A well-documented fossil source of diatoms dates back to the Mid-Cretaceous period, but the vast majority of deposits originate from the Eocene/Miocene. Approximately 20 to 80 million years ago, particularly during the Eocene and Miocene epochs, various diatomee species extracted silica from the water, producing a skeleton of hydrated amorphous silica.When the diatoms died, the tiny shells sank, and over the years, these shells formed thick layers [47]. Eventually, these deposits were fossilized and compressed into a soft, chalky rock now called diatomaceous earth. The mineral diatomite is extremely stable, produces no toxic chemical residues, and does not react with other substances in the environment.

According to the United States Environmental Protection Agency (EPA), the natural product is described as amorphous silicon dioxide and is classified as "Generally Recognized as Safe" (GRAS) as an anti-caking agent and animal feed additive [56]. The estimated world production in 2024 ranged from around 50.1 to 52.1 million metric tons (MMT) [53]. World reserves are estimated at nearly 1 billion metric tons, of which approximately 250 million metric tons (25% of the total) are in the United States [19]. The United States is the leading producer of diatomite, accounting for 39% of total global production, followed by China (21%), Denmark (11%), and Japan (5%). Given that approximately 10-30% of global grain production is lost each year due to pests affecting stored grains [52] and that the use of chemical protective agents presents several disadvantages, as they are generally toxic to mammals and leave residues in the product, and, additionally, many insect species are resistant to certain chemical agents [5], all these limitations have led researchers to evaluate the potential of alternative control methods, such as plants, insect growth regulators, biological control, microbial control, and inert dusts.

One of the most promising alternatives to contact insecticides is the application of diatomaceous earth. In the world scientific literature, there are no studies regarding the use of this product in the field. However, its wide spread introduction for field pest control has been limited by two factors: the need to find a solution that ensures the persistence of the product as an inert dust (given its high absorbent properties) and the fact that, in its raw state and large quantities, it has been used as a soil quality adjuvant (due to its clay content) and as a fertilizer to supply the soil with silicon. In Romania, four major diatomite deposits are known in different counties (Pătîrlagele, Urloaia, Adamclisi, and Pecinișca).

This reserach work has the purpose to present the results of experiments conducted for the first time in Romania under field conditions at the Production and Research Center in Amzacea (Constanța County) on sunflower under non-irrigated conditions during the 2019-2022 periods.

The sunflower is one of the main agricultural crops in Romania, with a cultivation area covering all low land regions, but especially the Southern and South-Eastern plains. Although the cultivated area for most of the agricultural crops has steadily decreased, for sunflowers, starting since 2017, the cultivated area increased by 12.6% (1.3 million ha in 2019), and production increased by 3.4%, achieving a record production of 3,450 million tons in 2019 (1st place in the EU).

The sunflower crop is moderately vulnerable to stress factors (more drought-tolerant than

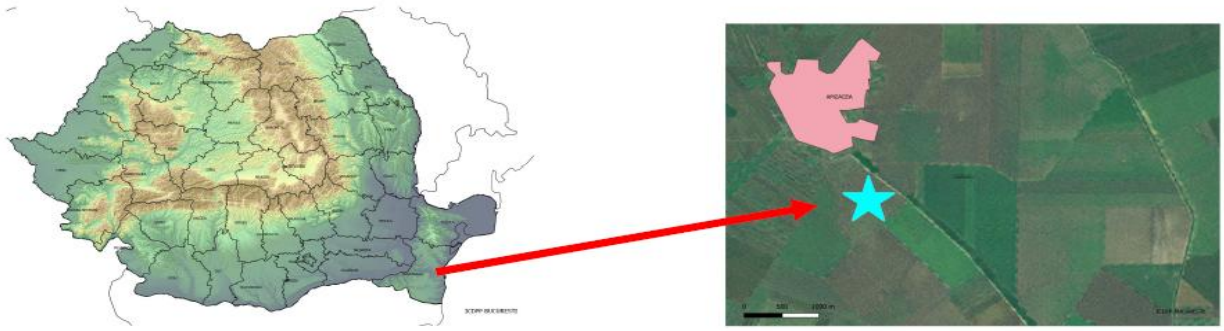
corn), but it is very sensitive to attack by pathogens and certain pest species (especially insects). Additionally, the sunflower is one of the highly frequented melliferous plants for many pollinating species, especially from the Apoidea Superfamily.

MATERIALS AND METHODS

The study was conducted between 2019 and 2022 on an experimental plot established within a sunflower crop at Sport Agra SRL Amzacea, Constanța County. The site was georeferenced (Amzacea lat.: 43.57749; long.: 028.25823) between the localities of Amzacea and Topraisar (Map 1).

The total area of the experimental field was 700 m², divided into 5 plots of 140 m² each, representing the following experimental variants: **V1** - Untreated control, **V2** - Diatomite 2,000 ppm, **V3** - Diatomite 2,000 ppm, **V4** - Diatomite 2,000 ppm and **V5** - MIF-type azosulfocalcic fertilizer 2% (Table 1).

Each variant consisted of 3 replicates of three rows each, with two lateral rows for demarcation and protection against the influence of other variants (Photo 1). The variant involving the application of the ecological diatomite treatment at a dose of 2,000 ppm was replicated both to eliminate potential errors or unwanted influences and to alternate between three different treatment methods.



Map 1. Locality and place of experimentation: Amzacea, Constanţa County, Romania, sunflower experimental field
Source: Own design.

Applied technology

In August 2018, plowing was performed to prepare the soil at a depth of 23–25 cm. Following the plowing, glyphosate herbicide was applied to the experimental plot at a rate of 2 liters/ha. The preceding crop was wheat. Sowing of the Genesis hybrid was carried out in two periods: Period 1 on March 28, 2019, and Period 2 on April 22, 2019. The sowing depth in the spring of 2019 was 7 cm. Before sowing, the seeds were treated with the following product: Apron XL (Metalaxyl 339 g/l) – 3 l/t. For fertilization (exclusively for the plot in variant 4), the following products were used: Granoro 10.20.0 + 20SO_3 2Norg. – 300 kg/ha (21% soluble phosphorus; the presence of humic acids facilitates nutrient absorption) and Nitroslows 40 - 40.0.0 + 13SO_3 – 150 kg/ha (35.5% urea nitrogen, 4.5% controlled-release ammoniacal nitrogen, which reduces losses). In preemergent season, there were applied herbicide treatments using Frontier Forte (dimethenamid-P) – 1.5 l/ha, Racer 25 EC (fluorochloridone) – 2 l/ha. Pulsar Plus (25 g/l imazamox) – 2 l/ha was an additional herbicide used in the vegetation period. For the protection of sunflower crop against disesases there were applied at 6-8 leaves: Mirage 45 EC (prochloraz 45%) at 1 l/ha mixture up with foliar fertilizer Dr. Green Start – 2 kg/ha (N120/P600/kg) + Dr. Green Sunflower – 2 kg/ha (145 g/kg SO_3, 5 g/kg MgO, 100 g/kg Boron, 2 g/kg Cu, 25 g/kg Fe, 50 g/kg Mn, 0.5 g/kg Mo, 20 g/kg Zn), and on the stage of buton Pictor (200 g/l dimoxystrobin + 200 g/l boscalid) at 0.5 l/ha.

Conditioning and application of the mineral diatomite treatment

Diatomite (or *kieselgur* in German, where it was first discovered) is a siliceous sedimentary rock composed of stratiform rocks containing 50% diatom remains.

It ranges in color from yellowish-white to brown, is friable and rough to the touch, and features a homogeneous texture and high porosity. These rocks are light with low density.

The material consists of silicon dioxide, which is chemically neutral, it does not dissolve in water, and exhibits various crystalline forms under a microscope.

In 1836 or 1837, the peasant Peter Kasten, a farmer and carter, discovered diatomite while digging a wellon the Northern slopes of the Haußelberg hill in the Lüneburg Heath in Northern Germany [20].

Table 1. Main characteristics of the experimental variants

	V1 Control	**V2 Experiment**	**V3 Experiment**	**V4 Experiment**	**V5 Experiment**
Amount of Ecological insecticide	No	Diatomite 2,000 ppm	Diatomite 2,000 ppm	Diatomite 2,000 ppm	MIF 5 type azosulfocalcic fertilizer 2%
Application mode		Foliar application	Foliar and in the soil at the plant basis	Application into the soil at the plant basis	
No. of replicates	3 rows/140sq.m	3 rows/140sq.m	3 rows/140sq.m	3 rows/140sq.m	3 rows/140sq.m
No. of traps for insect collection from 10 to 10 m/2 times/year	18	18	18	18	18
Diatomite preparation		Diatomite powder mixed into 10 litres water with carboxilmethyl cellulose CMC 83 g	Diatomite powder mixed into 10 litres water with carboxilmethyl cellulose CMC 83 g	Diatomite powder mixed into 10 litres water with carboxilmethyl cellulose CMC 83 g	

Source: Own conception.

Initially, it was thought to be limestone that could be used as fertilizer. Because this mineral is highly porous, it can be easily ground into a fine powder, which is why it is also called diatomaceous earth.

Diatomite can be used as an insecticide due to its abrasive and physico-sorptive properties. The fine powder absorbs lipids from the waxy outerlayer of insect skeletons, causing them to dehydrate. Arthropods die as a result of water pressure deficiency, based on Fick's law of diffusion.

To be effective as an insecticide, diatomaceous earth must be uncalcined (meaning it must not be heat-treated before application) and have an average particle size below approximately 12 μm.



Photo 1. Ready-to-use diatomaceous earth powder
Source: Original photo.



Photo 2. Sunflower experimental field at Amzacea, Constanta County, Dobrogea Region, Romania.
Source: Original photo.

Although pesticides containing diatomaceous earth are considered relatively safe, they are not exempt from regulation in the United States under the Federal Insecticide, Fungicide, and Rodenticide Act and must be registered with the Environmental Protection Agency. In the experiment conducted at Amzacea, the diatomite powder (2,000 ppm) was prepared as an aqueous dispersion (10 liters) by homogenization with carboxymethyl cellulose (CMC-83 g). The CMC is soaked separately in portions of 10-20 grams with cold water. A small amount of water is added over the CMC and mixed with a glass rod until homogenized. The process is repeated until the solution reaches a semi-liquid, but not gelatinous, consistency. It is then added to the remaining water up to a total volume of 10 liters. Finally, the diatomite powder is added and mixed thoroughly. The application was performed using a SOLO 417 battery-powered sprayer.



Photo 3. Applying diatomaceous earth treatment
Source: Original photo.

The treatment with the diatomite product was carried out at the same dose in three different ways during the phenophase when the plants had 3-5 leaves (BBCH12-14): in variant **V2**, the product was applied foliarly; in **V3**, it was applied both foliarly and to the soil; and in **V4**, it was applied only to the soil at the base of the plants (Photo 3).

Method of collecting biological material

The working methodology was established in accordance with operational procedures for sampling biological material and identifying pests from arthropod and invertebrate groups in field crops (PO-OD-03, 1st edition, revision 0/24.10.2014); in the case of the present study, we refer only to the invertebrate fauna found in and on the soil surface, collected using pitfall traps. The soil traps used in this study were Barber-type traps installed on the ground to capture mobile soil and surface-dwelling arthropod fauna over a period of time. Biological material was collected at two-week intervals from a total of 6 traps per replicate (18 traps per variant). Such a trap consists of a 300 cm³ glass container, which was inserted into the soil with the opening at ground level. A 4% formaldehyde solution, filling the container to 50–70% capacity, is placed inside. The opening of the vessel is covered with a plastic lid, leaving a gap of 4 to 5 cm between the opening and the lid. The traps were positioned so that the collection area of one did not intersect with another (the minimum distance between them was 10 m) (Photo 4). The minimum collection time for such a trap is 48 hours after installation. The biological material was collected and preserved in 70% alcohol and studied in the laboratory.



Photo 4. Location method (top) and operating range of a Barber type soil trap
Source: Original photo and design

Experimental conditions

The experiment was carried out under conditions of non-irrigation and prolonged drought (Table 2).

Table 2. Monthly precipitation recorded at Amzacea in 2019*

Year/ month	Monthly precipitation (mm)												Total year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2019	36	8	16	35.5	18	14	44	7	37	44	-	-	**259.5**
Multi annual average	77.6	37.1	46.5	30.5	56	54.9	96.2	21.5	24.8	65.5	29.6	44.6	**615.53 9 years**

*It should be noted that 2019 was an excessively dry year, with a precipitation value of 259.5 mm until November, compared to the multiannual average for the area of 615.53 mm.
Source: Local weather station.

Calculation methodology and interpretation of statistical data

Indices of ecological diversity are, within the framework of current ecological research established within the operational framework of ecosystem and adaptive management MEA [55], the most frequent parameters used to characterize the state of the analyzed ecosystems. We initially calculated the Simpson diversity index (D) [44]:

$$ {}^{q}D = \frac{1}{M_{q-1}} = \frac{1}{\sqrt[q-1]{\sum_{i=1}^{R} p_i p_i^{q-1}}} = \left(\sum_{i=1}^{R} p_i^q \right)^{1/(1-q)} \quad \text{.....(1)} $$

$$ {}^{1}D = \frac{1}{\prod_{i=1}^{R} p_i^{p_i}} = \exp\left(-\sum_{i=1}^{R} p_i \ln(p_i) \right) \quad \text{.....(2)} $$

$$ {}^{q}D = \left(\sum_{i=1}^{R} p_i^q \right)^{1/(1-q)} \quad \text{.....(3)} $$

or when 1/(1-q) = 0 şi s = (n_i.....n_x) we get:

$$ D = 1 - \sum_{i=1}^{S} \left(\frac{ni}{N} \right)^2 \quad \text{..... (4)} $$

where:
S= number of species from sample;
i= target species;
n= number of individuals of the respective species from sample;
N= total number of individuals from sample.

We considered calculating the index Shannon-Wiener according to the method used by Pielou, (1975) in which according to the function H'(p_1,.....p_s) for a certain value of s, we can consider the index H' as having the greatest value when q_i = 1/s for any i. So, for any q the natural logarithm applied to the index D will be:

$$ {}^{q}H = \ln\left(\frac{1}{\sqrt[q-1]{\sum_{i=1}^{R} p_i p_i^{q-1}}} \right) = \ln({}^{q}D) \quad \text{.....(5)} $$

Simplifying,

$$ {}^{q}H = \frac{1}{1-q} \ln\left(\sum_{i=1}^{R} p_i^q \right) \quad \text{.....(6)} $$

The series of values is obtained by summing the proportions (p_1.....p_r) and we get,

$$H' = -\ln p_1^{p_1} p_2^{p_2} p_3^{p_3} \cdots p_R^{p_R} = \ln\left(\frac{1}{p_1^{p_1} p_2^{p_2} p_3^{p_3} \cdots p_R^{p_R}}\right) = \ln\left(\frac{1}{\prod_{i=1}^{R} p_i^{p_i}}\right) \quad .....(7)$$

or,

$$H' = -(\ln p_1^{p_1} + \ln p_2^{p_2} + \ln p_3^{p_3} + \cdots + \ln p_R^{p_R}) \quad .....(8)$$

and by summing and taking the logarithm of the proportions we obtain the formula for the Shannon-Wiener index, where the proportions represent the values of the relative abundance of the component species:

$$H' = -\sum_{i=1}^{R} p_i \ln p_i = -\sum_{i=1}^{R} \ln p_i^{p_i} \quad .....(9)$$

or,

$H = -\sum_{i=1}^{S} pi\ x \ln pi$.....(10)

where:
S= number of species from sample;
pi= the relative proportion (relative abundance) of respective species from sample;
Relative abundance is:

$Ar = \frac{\mathrm{n}}{\mathrm{N}}\ x\ 100$.....(11)

where:
n= number of individuals of the respective species from sample;
N= total number of individuals from sample.
To test the differences between the variants (the averages of the non-parametric variation series obtained by calculating the Simpson index) we used the ANOVA analysis of variance and for the Shannon index values, which only represent an estimate of diversity, it was necessary to calculate the standard deviation associated with the estimated value using the relation:

$$S = \sqrt{\frac{\sum_{i=1}^{N}(x_1 - \overline{x})}{N-1}}^{2} \quad .....(12)$$

where:
x_1 = number of individuals from sample i;
$\bar{x}$ = the average value of the individuals in the sample i;
N = total number of individuals.
For the series of values obtained from the 25 samples of each variant, we applied the t (Student) test [21], using the previously calculated standard deviation values:

$$S^2p = \frac{(n_1-1)\cdot S_1^2 + (n_2-1)\cdot S_2^2}{n_1+n_2-2}$$.....(13)

So we get:

$$t = \frac{\overline{x}-\overline{y}}{\sqrt{\frac{S^2p}{n_1}+\frac{S^2p}{n_2}}}$$.....(14)

where:
$\bar{x}$ and $\bar{y}$ = averages of the tested values;

n_1 = number of values from variant 1;
n_2 = number of values from variant 2;
S_1 = standard deviation for the mean values in the variant 1;
S_2 = standard deviation for the mean values in the variant 2.
Since spread sheets of these parameters assemble too many values and would take up too much space in the paper, the final comparison of Shannon-Wiener biodiversity values was tested using the Tukey multiple comparisons test.

RESULTS AND DISCUSSIONS

The formulation of the product, combined with the climatic conditions in the experimental area, particularly during the first year of application (2020), favoured its insecticidal action against pests active on the soil or on plants near the root collar and stem. To express the abundance values of insect communities throughout the critical period of plant vulnerability and intense pest activity, and due to the immense quantity of fauna collected (as detailed in the Materials and Methods chapter), statistical methods of ecological analysis were applied, specifically the calculation of biodiversity indices and the expression of total density values for each experimental variant. During the three years of experimentation, samples were collected weekly immediately after plant emergence (which occurred around April 13th each year) and the application of the diatomite treatment. The scope of the program can be easily deduced considering that the critical period during which plants can suffer damage lasts until approximately June 20th (totalling 36 weeks per year x 25 traps per plot), resulting in a total of 2,700 samples over the three-year study period. After collection, the samples were brought to the laboratory, washed, and prepared for species-level identification.
A single sample is illustrated in Table 3, which presents the calculation diagrams for relative abundance and, ultimately, for biodiversity indices.To calculate the diversity indices (Shannon-Wiener, Simpson, Equitability, Jaccard, etc.), we employed a method of grouping Excel spread sheets using software developed in a Visual Basic environment, utilizing a third-degree polynomial equation to eliminate negative values of the Shannon-Wiener index. In the case of ecological plant protection products, a critical issue to consider is their non-selective nature. Therefore, this experiment monitored both the efficacy against the primary soil pests of sunflower and the global impact on the biodiversity of beneficial arthropod fauna within the agricultural ecosystem.

Table 3. Locality: Amzacea – jud. Constanţa, Culture: sunflower V1, Collection method: CB1, Collection data: 26.07.2020

Species	Number of specimens	Relative abundance
Fridericiabulbosa Rosa	1	0.21
Porcellioscaber L.	5	1.08
Geophilusflavus De Geer	2	0.44
Bdelladispar (C.L.) Koch	5	1.08
Agynetaramosa Jack.	34	7.32
Phalangiumopilio L.	13	2.80
Grylluscampestris L.	88	18.96
Melanogryllusdesertus Pall.	3	0.64
Entomobryiaarborea Tullb.	12	2.58
Hypogastruraarmata Nicol.	3	0.64
Forficulaauricularia L.	1	0.21
Aphisgossypii Glover	2	0.44
Adelphocorislineolatus Goeze	1	0.21
Coptosomamucronatum Sciden.	1	0.21
*Formica rufa*L.	38	8.19
Microglossapulla Gyll.	2	0.44
Oxytelustetracarinatus Block	2	0.44
Athetasordidula Er.	2	0.44
Caloderanigrita Mnnh.	10	2.15
Neobisniusvillosulus Steph.	1	0.21
Tachyporushypnorum F.	10	2.15
Limnebiusnitidus Marsh.	2	0.44
Anthelephilacyanea Hope	10	2.15
Anthicusfloralis L.	2	0.44
Bembidionproperans Steph.	4	0.86
Idiochromadorsalis Pontopp.	8	1.72
Carabushortensis L.	11	2.37
Pseudoophonusrufipes De Geer	13	2.80
Poeciluscupreus L.	5	1.08
Acupalpusluteatus Duft.	1	0.21
Microlestesmaurus Sturm.	1	0.21
Calathusmelanocephalus L.	15	3.24
Blitophagaundata Müll.	3	0.64

Rhagonychafulva Scop.	5	1.08
Drasteriusbimaculatus Rossi	7	1.50
Heteroderescrucifer Rossi	45	9.69
Betarmonferrugineus Scop.	1	0.21
Hypnoidusdermestoides Herbst.	2	0.44
Dermesteslardarius L.(lv.)	5	1.08
DermestesFrischi Kug.	2	0.44
Coccinella 7 punctata L.(lv.)	2	0.44
Scymnusferrugatus Moll.	1	0.21
Rhizophagusparvulus Payk.	1	0.21
Atomariaatricapilla Steph.	2	0.44
Ephistemusglobulus Payk. a. *dimidiatus* Sturm.	2	0.44
Emphylusglaber Gyll.	1	0.21
Pteryngiumcrenatum F.	1	0.21
Sericoderuslateralis Gyll.	1	0.21
Phytobiusmuricatus Bris.	1	0.21
Aphidiusmatricariae Hal.	2	0.44
Trimorusangustipennis Kieffer	6	1.30
Chloropspumilionis Bjerk.	1	0.21
Agromyza nana Meig.	21	4.52
Sciaraanalis Schiner	11	2.38
Calliphoravomitoria L.	33	7.11
Total	**464**	**100.00**

Source: Own results.

In Romania, there is only one approach to estimating biodiversity in agricultural ecosystems (cereal crops) [48]. Other studies are both general and theoretical or are applications for the forestry sector, all based on an audit by the European Court of Auditors commissioned bythe European Commission. This was done in the context of the Commission's 2011 biodiversity strategy, which aimed to halt biodiversity loss and ecosystem degradation by 2020 and restore them where possible, particularly by increasing the contribution of agriculture and forestry. This strategy aligns with the international commitment stemming from the ratification of the United Nations Convention on Biological Diversity by all member states and the European Union (Aichi, Japan 2020) [46].

Regarding the first objective addressed in the study, the treatment applied to the soil and plants at the BBCH 12-14 stage with the conditioned diatomaceous earth product had a major impact on soil pests of sunflower crops (especially on insects from the Order Coleoptera) compared to the control variant in which increased values of the density of the main pest *Tanymecus dilaticollis* Gyll are observed (Figure 1).

The density values of arthropods are similar in the variant treated with the MIF 2% azosulfocalcic fertilizer, with *T. dilaticollis* reaching densities above the economic threshold (PED) in this case as well (Figure 2).

The variant treated with the ecological diatomite product shows increased efficacy against soil pests while maintaining high values for beneficial fauna species, especially those mobile by flight at the plant level that do not come into contact (except accidentally) with the insecticide product (Figure 3).

The structure by arthropod groups also indicates the level of sensitivity to the diatomite-based product; species that appear sporadically on the soil surface are less affected by the insecticidal effect. In the control variant, arthropods from the four major classes of fauna present in agricultural ecosystems were present, particularly in field cereal crops; generally, on the cultivated areas at Amzacea, the leached chernozem soil type favors a rich diversity of species. In this case, the *Insecta* class held a dominant position in terms of density and diversity at a rate of 77% (Figure 4).

In the case of the variant treated with the MIF 2% azosulfocalcic fertilizer, the *Insecta* class was well-represented by species from four orders, with coleopteran species showing high densities (35%) after the *Orthoptera* order (Figure 5).

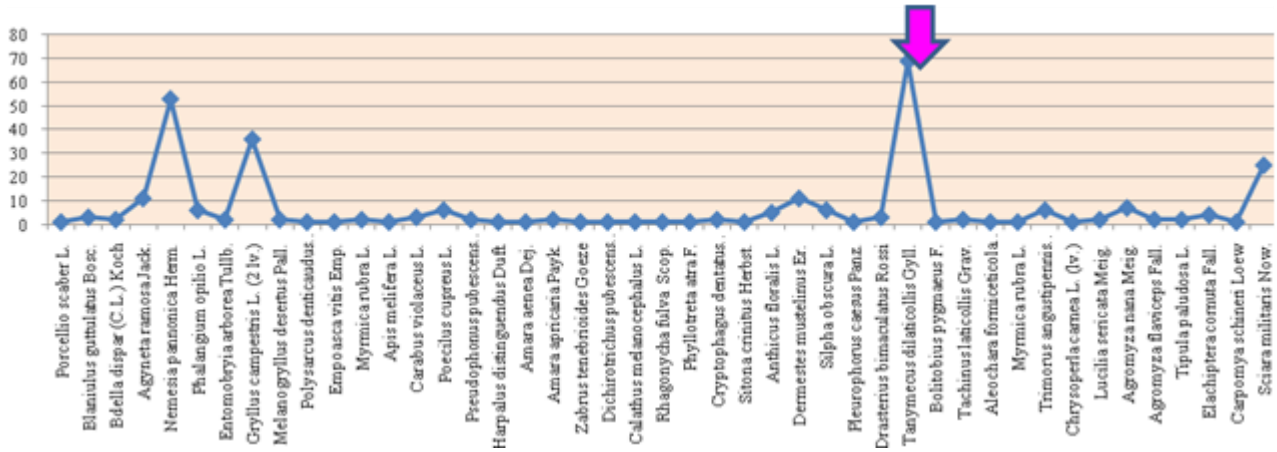


Fig. 1. Arthropod community densities (mean values) in the sunflower control plot (3 replicates)
Source: Own results.

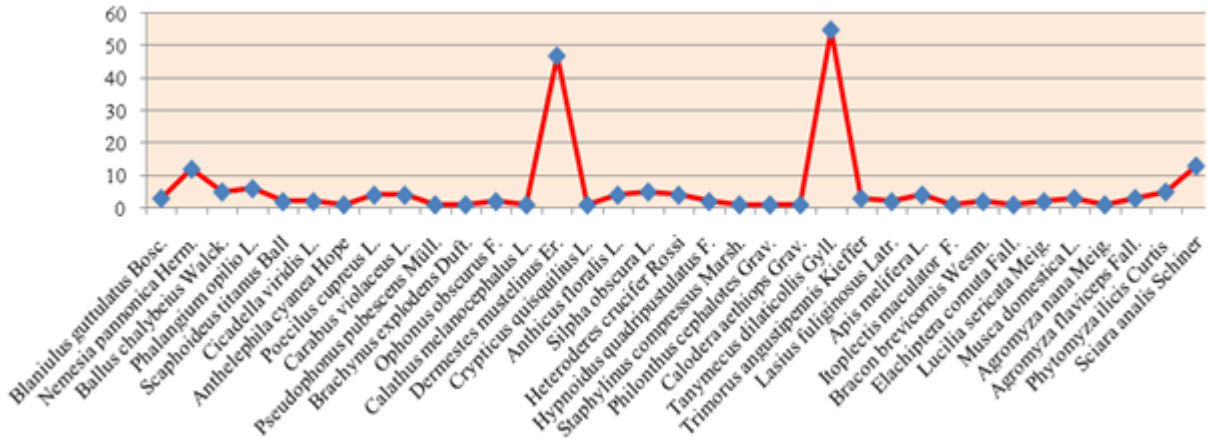


Fig. 2. Arthropod community densities (mean values) in the sunflower plot (3 replicates), withMIF-type azosulfocalcic fertilizer 2%
Source: Own results.

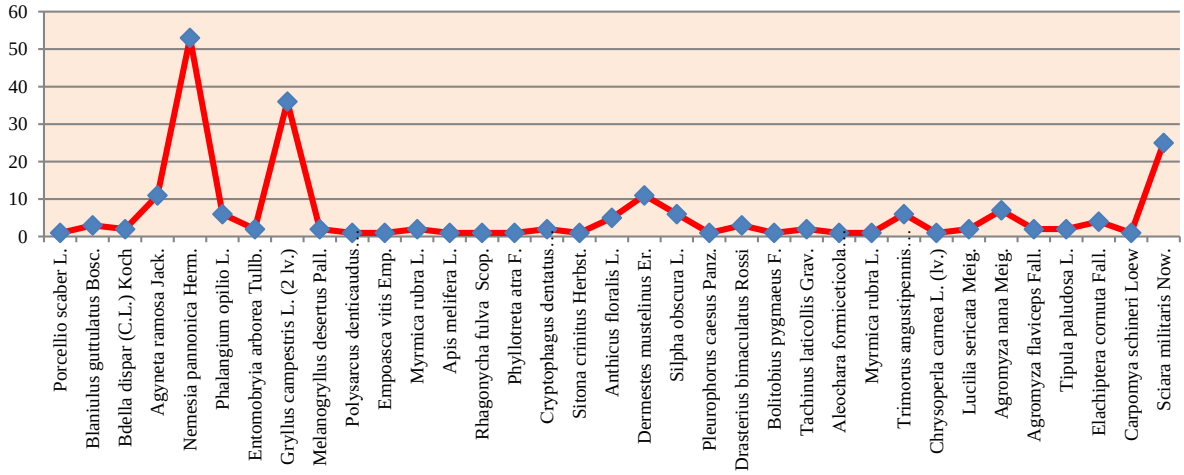


Fig. 3. Arthropod community densities (mean values) in the sunflower plot (3 replicates), treated with diatomaceous earth 2,000 ppm
Source: Own results.

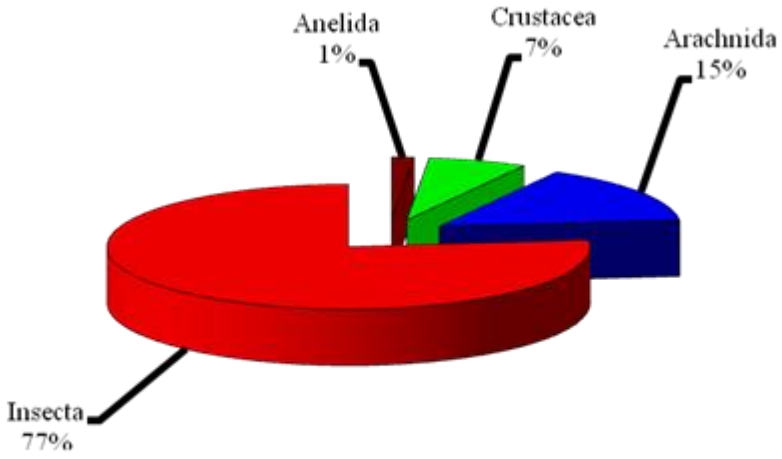


Fig. 4. Structure of the arthropod fauna in the control plot
Source: Own results.

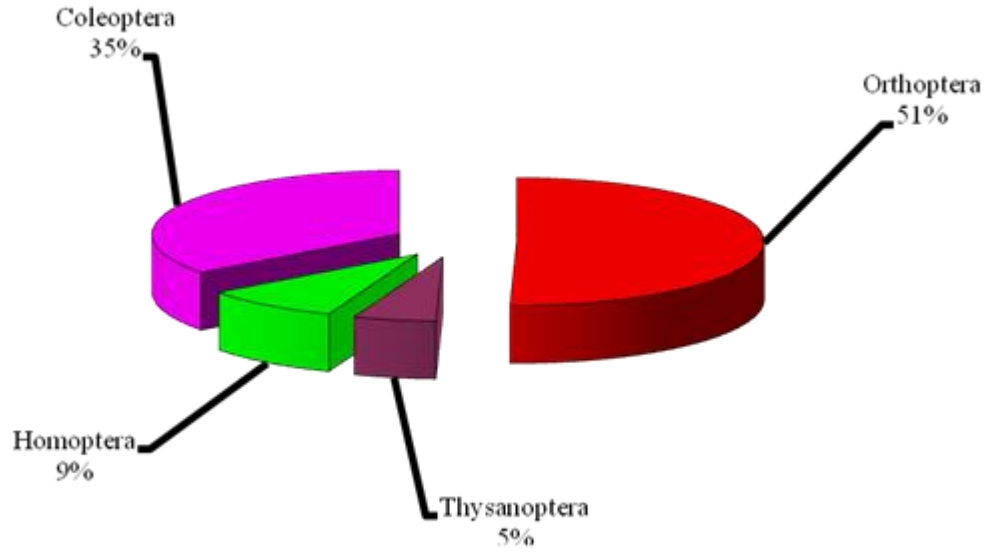


Fig. 5. Structure of insect fauna in the plot treated with the azosulphosphating fertilizer product type MIF 2%
Source: Own results.

The most interesting aspect of the study was highlighted after the 2,000 ppm diatomite treatment, where it was observed that harmful insects—especially the most important soil pests are efficiently controlled by the insecticide product, even though the biodiversity of beneficial fauna present at the plant level was not majorly affected (Figure 6). The total fauna captured throughout the investigation period and from all variants (mean log values) expresses a biodiversity typical of agricultural ecosystems, practically unaffected by the treatment performed (Figure 7). Based on statistical analysis and multi-factor testing (Tukey's multiple comparisons test), it resulted that the ecological diatomite product applied at a dose of 2,000 ppm (conditioned in the laboratory) was efficient in controlling the main soil pests of sunflower crops. However, the impact on the biodiversity of the arthropod fauna is relatively low and amplifies only with repeated applications over time on the same surface (Figure 8). The most important aspect is that mobile fauna at the

plant level, generally beneficial species (wild bees from the *Apoidea* superfamily), are not affected by the treatment

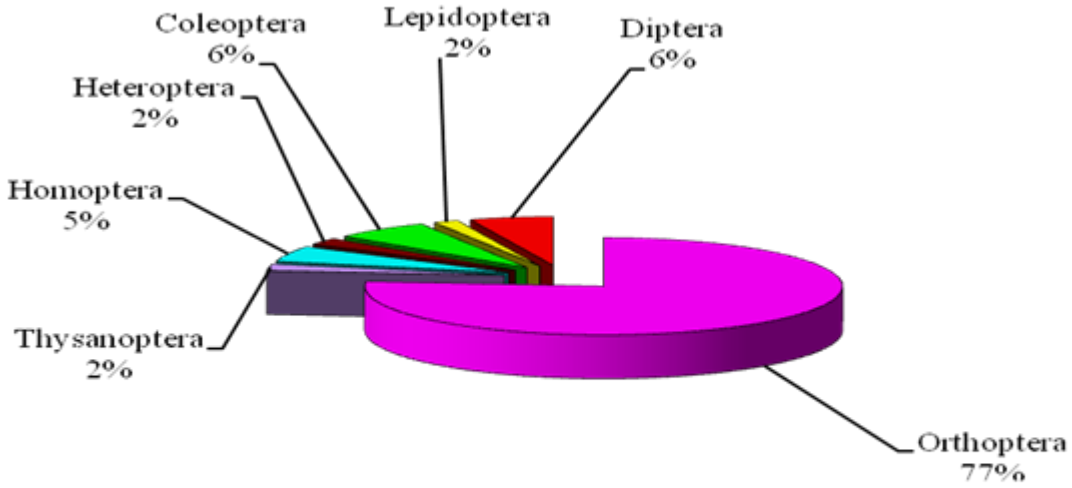


Fig. 6. Structure of insect fauna in the plot treated with diatomite 400 ppm
Source: Own results.

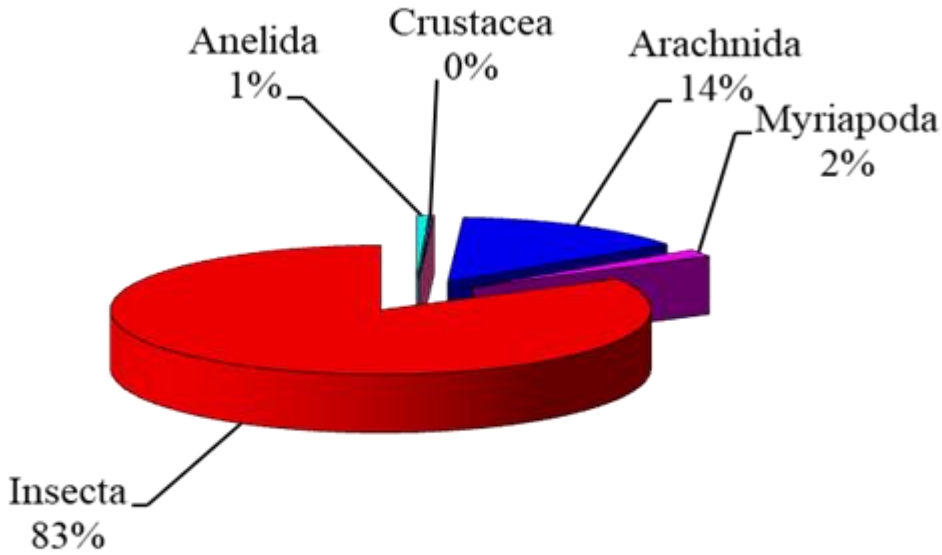


Fig. 7. Structure of the arthropod fauna throughout the study period
Source: Own results.

2020 **2021** **2022**

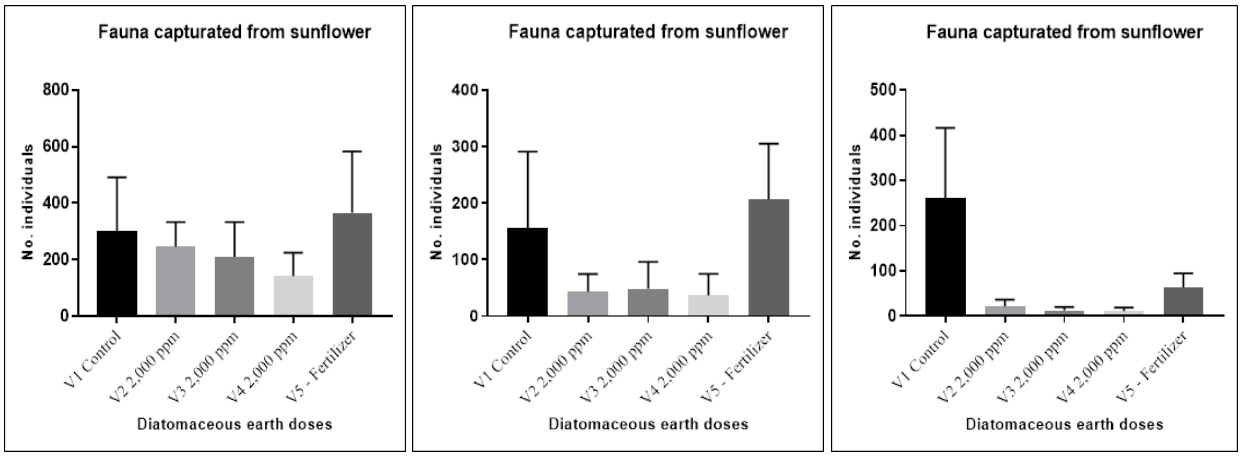


Fig. 8. Statistical analysis of the arthropod fauna during the three years of study (polynomial ANOVA)
Source: Own results.

As we mention in Materials and Methods chapter, in the paper it was performed a complex mathematical and statistical analysis about a biodiversity (individuals, relative density, and diversity indexes) that will be valorized on the further papers. For now relevant results are concerning two important diversity indexes which offers the best evaluation about the impact of the new ecological product on ecological arthropod biodiversity from sunflower crop in the area.

Two indexes are very important: The Shannon-Wiener index (H′) and Simpson index (D).The Shannon-Wiener index (H′) measures biological diversity, with values typically ranging from 0 to 5. A value close to 0 indicates low diversity (a single species), while values greater than 3 indicate high diversity and stable ecosystems. Common values in ecological studies can be below 2, such as 1.62–1.89 in different monitored areas.

H'=0 Community with a single species (no diversity).

H'< 1 Very low diversity.

H'=1−3 Moderate diversity.

H' > 3 High diversity.

Our study on this two indexes confirmed the analysis made by statistical polynomial ANOVA calculations (Fig. 8) on total fauna individuals on each variants about the main impact of global biodiversity of the diatomite product. It seems that this impact are not involved the beneficial insect fauna (meaning Apoidea wild species and domestic bees but many other useful species).

The data presented in Table 4 and 5 confirms the results obtained through the statistical analysis performed on the global fauna. In the systemic ecology analyses the Shannon index gives more weight to rare species, capturing situations where many species are present but not as abundant. If a species is added or removed from the community, this will have a more noticeable impact on the Shannon index. The Simpson index, on the other hand, is less sensitive to rare species and more focused on how many individuals belong to the dominant species, meaning that a few dominant species can significantly reduce the value of the Simpson index, even if the richness is high. So, Shannon gives you an insight into how uniform the diversity is on a plot, while Simpson highlights whether there are dominant species on a plot. For example, a burned plot has a higher value of the Shannon & Simpson indices, which means that that plot has more diverse species, with no obvious dominant species well, it is diverse and uniform. If the Shannon is high but the Simpson is low, it means that although there is a wide range of species, there is one dominant species taking over that plot of land. In the table is obviously that the values of H′ ranging between 2.2 and 2.5 in the control and fertilizer plots but ranging of the 1.3 and 2.0 in the diatomite variants (Table 4). Similarly regarding Simpson (D) index the averages values ranging between 0.2 and 0.5 in the nontreated variants more close to 0 (which indicates high diversity (several species with similar abundances) but between 0.2 and 0.9 shows low diversity or high dominance of a single species (Table 5).

Table 4. Comparison of averages values of Shanon-Wiener biodiversity index in the sunflower experiment

	Control	**V_2- diatomite 2,000**	**V_3 - diatomite 2,000**	**V_4- diatomite 2,000**	**V_5 – fertilizer**
	Year 2020 (Shanon-Wiener (H′) averages values)				
	2.3	**1.6**	**1.5**	**1.7**	**2.5**
	Year 2021 (Shanon-Wiener (H′) averages values)				
	2.5	**1.9**	**1.7**	**2,0**	**2.2**
	Year 2022 (Shanon-Wiener(H′) averages values)				
	2.5	**1.4**	**1.3**	**1.4**	**2.4**
Tukey's multiple comparisons test	Mean Diff.	95.00% CI of diff.	Below threshold?	Summary	Adjusted P Value
V1-Control-2020 vs. V1-2,000-2020	-0.1761	-0.6779 to 0.3257	No	ns	0.9815
V1-Control-2020 vs. V2-2,000-2020	0.7578	0.2559 to 1.260	Yes	***	0.0001
V1-Control-2021 vs. V3-2,000-2020	0.5606	0.05873 to 1.062	Yes	*	0.0158
V1-Control-2020 vs. V4-2,000-2020	0.335	-0.1668 to 0.8368	No	ns	0.502
V1-Control-2020 vs. V5-Fertilizer-2020	-0.04444	-0.5463 to 0.4574	No	ns	>0.9999
V1-Control-2021 vs. V1-2,000-2021	0.5606	0.05873 to 1.062	Yes	*	0.0158
V1-Control-2021 vs. V2-2,000-2021	0.235	-0.1432 to 0.6543	No	ns	0.202
V1-Control-2021 vs. V3-2,000-2021	0.7367	0.2348 to 1.238	Yes	***	0.0002
V1-Control-2021 vs. V4-2,000-2021	0.8201	0.3182 to 1.322	Yes	****	<0.0001
V1-Control-2021 vs. V5-Fertilizer-2021	-0.04444	-0.5463 to 0.4574	No	ns	>0.9999
V1-Control-2022 vs. V1-2000-2022	0.9339	0.4321 to 1.436	Yes	****	<0.0001
V1-Control-2022 vs. V2-2000-2022	0.5111	0.009282 to 1.013	Yes	*	0.0421
V1-Control-2022 vs. V3-2000-2022	0.4713	-0.03050 to 0.9732	No	ns	0.0855
V1-Control-2022 vs. V4-2000-2022	-0.4228	-0.9246 to 0.07905	No	ns	0.1817
V1-Control-2022 vs. V5-Fertilizer-2022	0.01222	-0.4896 to 0.5141	No	ns	>0.9999

Source: Own conception and results.

Table 5. Comparison of averages values of Simpson index in the sunflower experiment

Control	**V_2- diatomite 2,000**	**V_3 - diatomite 2,000**	**V_4- diatomite 2,000**	**V_5 - fertilizer**
Year 2020 (Simpson index averages values)				
0.2	**0.6**	**0.6**	**0.7**	**0.5**
Year 2021 (Simpson index averages values)				
0.5	**0.7**	**0.9**	**0.2**	**0.2**
Year 2022 (Simpson index averages values)				
0.5	**0.4**	**0.3**	**0.4**	**0.4**

Source: Own conception and results.

CONCLUSIONS

-The ecological diatomite product, formulated in the laboratory and applied at a dose of 2,000

ppm, was effective in controlling the primary soil pests of the sunflower crop;
-The impact on the biodiversity of arthropod fauna is relatively low and intensifies only with repeated applications over time on the same surface also confirmed by the averages values of two important diversity indexes Shannon-Wiener index (H′) and Simpson index (D);
-Mobile fauna at the plant level (especially beneficial species to sunflower plants) is not affected by the treatment performed;
-Soil fauna captured during the surveys (specifically beneficial species from the class Annelida) is also not affected by the treatment with the ecological product, due to its reduced efficiency under soil moisture conditions;
-In the context of controversies regarding the use of neonicotinoid plant protection products for agricultural pest control in Romanian cereal crops, it is necessary to continue testing this product on both sunflower and maize crops.

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ASSESSMENT OF ECO-EFFICIENCY AND CLIMATE RESILIENCE IN EUROPEAN UNION AGRICULTURE

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Abstract

The main objective of the research was to assess and compare the eco-efficiency of agriculture in the European Union Member States during the period 2016–2023, by integrating economic performance with environmental pressures. The analysis was conducted using the input-oriented Data Envelopment Analysis (DEA) method, which allowed for the measurement of each nation's ability to reduce energy, water, nutrients (nitrogen and phosphorus), and greenhouse gas emissions while maintaining a consistent level of economic results. The model was complemented by a spatial analysis based on Moran's I and LISA indices, to identify regional performance patterns and spatial associations of efficiency. The results highlighted the existence of a stable efficiency frontier, represented by countries such as Spain, Romania, the Netherlands, Hungary and Lithuania, which have reached the optimal level of resource use. The countries of Central and Eastern Europe are below the frontier, with a significant potential to reduce energy intensity and GHG emissions. Sensitivity analysis confirmed the robustness of the model and the determining role of environmental pressures, while spatial analysis revealed a fragmented distribution of performance, without the formation of compact regions of efficiency. The conclusions obtained underline that European agricultural eco-efficiency is determined by institutional, technological and administrative capacity to manage resources rather than by geographical factors. Efficient countries demonstrate the compatibility between sustainability and competitiveness, and future progress depends on the differentiated adaptation of agricultural and environmental policies. Overall, the results confirm that the transition towards a sustainable and competitive agricultural system is not based on uniformity, but on an adaptive convergence between the Member States of the European Union.

Key words: *eco-efficiency, sustainable agriculture, DEA analysis,GHG emissions, technical efficiency, European Union*

INTRODUCTION

Agriculture is a crucial economic activity within the European Union, contributing significantly to food security and employment, as well as exerting a direct influence on the environment and the utilization of natural resources [16]. In recent decades, economic, technological and climate changes have generated increasing pressure on agricultural systems, leading to a paradigm shift: from productivity and intensive growth, to sustainability, efficiency and decarbonisation. In this regard, the idea of eco-efficiency—which refers to a production system's ability to produce equivalent economic outcomes with reduced resource consumption and minimal environmental impact—is emerging as a crucial component of the green transition of European agriculture [21].

Recent studies in the specialized literature confirm the importance of eco-efficiency assessment as a tool for integrated sustainability analysis. Various international studies [18, 19, 25] have used non-parametric analysis methods, such as Data Envelopment Analysis - DEA or Stochastic Frontier Analysis - SFA, to measure the ecological performance of agriculture, industry or the energy sector [22]. At the European level, most studies focus on the level of greenhouse gas emissions and energy intensity, emphasizing the relationship between input consumption and economic value added. However, numerous studies highlight the existence of persistent gaps between Western European countries, where green technologies are integrated into agricultural processes, and Central and Eastern European countries, where the agricultural structure is more fragmented

and investments in sustainable infrastructure remain insufficient [4, 6, 15].

Although the established literature provides relevant models for estimating eco-efficiency, there are still limitations regarding the integration of the spatial and temporal dimensions of these processes. Many works focus on a single year of analysis or on a limited set of economic and environmental indicators, without correlating the results with the regional distribution of performances. In addition, the application of traditional productivity indicators does not correctly capture the relationship between ecological pressure and economic performance, as it does not take into account the quality of resources or the structural differences between economies. Hence the need for a complex approach, capable of correlating economic performance with environmental impact, in a comparative and dynamic framework.

The present paper aims to respond to this need, through an integrated analysis of the eco-efficiency of agriculture in the Member States of the European Union for the period 2016–2023. By applying the DEA method and spatial analysis tools, the research aims to measure the efficiency of agricultural resource use and identify the performance frontiers that define a sustainable model of agricultural development. This approach combines the quantitative assessment of inputs - energy, water, nutrients, GHG emissions - with the qualitative analysis of the regional context, allowing to highlight the links between efficiency, agricultural policy and ecological transition.

In recent literature, the analysis of the eco-efficiency of European agriculture has diversified considerably. Studies by Beltrán-Esteve and Picazo-Tadeo (2017) or Sueyoshi and Goto (2018) [18, 21] have demonstrated the applicability of DEA models in assessing the sustainability of the agricultural sector, and research by Yilmaz D.I. (2025) [24] introduced the spatial dimension in the assessment of ecological efficiency, by integrating the Moran's I and LISA indices. Also, the works of Latruffe and Desjeux (2016) and Reinhard et al. (2002) [14, 20] have highlighted the impact of institutional and structural factors on agricultural performance, emphasizing that technical efficiency is closely linked to support policies, investment in innovation and the adoption of ecological practices. However, there is still a lack of research on longitudinal comparative analysis at the EU level, particularly with regard to the spatial interdependence of performances and the emergence of ecological convergence [1]. The subject matter is significant from both a scientific and practical standpoint. On the one hand, by providing a longitudinal and comparative viewpoint, the study adds to the body of knowledge about the evaluation of sustainable agricultural performance. However, the findings directly affect public policy, particularly when it comes to the execution of the European Green Deal and the new Common Agricultural Policy [3, 13], which promote eco-schemes, efficient nutrient management and reduced emissions from agriculture. The assessment of eco-efficiency provides an empirical basis for defining realistic targets to reduce environmental pressures, without diminishing the economic competitiveness of farmers [5, 23].

The need for this research also stems from the fact that, currently, the European Union is facing complex challenges – price volatility, soil degradation, biodiversity loss and climate pressures – which require a redefinition of agricultural performance. It is no longer enough for agriculture to be productive; it must be sustainable, resilient and resource-efficient [2, 17]. Eco-efficiency assessment thus becomes a strategic diagnostic tool, capable of guiding national and European policies towards smarter investments and agricultural practices that reduce the ecological footprint.

The paper is part of recent research that aims to integrate the eco-economic dimension into the analysis of the performance of the agricultural sector. Unlike studies based solely on financial or ecological indicators, the present approach simultaneously treats the two components, using a frontier model that compares countries with each other and highlights the potential for adjustment. This method offers a more realistic picture of how agricultural and environmental

policies interact and influence the overall efficiency of the system.

Therefore, the topic of the paper is current, relevant and necessary from both a scientific and practical point of view. It contributes to understanding the mechanisms by which European agriculture can become simultaneously competitive and environmentally responsible. Eco-efficiency analysis using the DEA method, complemented by spatial assessment, provides a robust tool for measuring agricultural performance, able to highlight where and how agricultural policies and practices can be improved to achieve the objectives of the European Green Deal. The research confirms that sustainability is not a marginal option, but a basic condition for future agricultural development, and eco-efficiency becomes the central criterion for assessing real progress in the transition towards a competitive and sustainable European agriculture.

MATERIALS AND METHODS

The eco-efficiency of agriculture in the EU was examined using the input-oriented Data Envelopment Analysis (DEA) method to determine each Member State's capacity to transform the resources consumed into sustainable economic outcomes. The model was developed for the years 2016–2023 using both the constant returns to scale (CRS) and variable returns to scale (VRS) hypotheses in order to represent the differences between pure and scale efficiency. In formal terms, for each decision unit (country–year), the technical efficiency score was determined by minimizing the input reduction ratio (θ) such that the weighted combination of efficient units does not exceed the current level of outputs:

$$\min \theta \text{ s.t. } Y\lambda \geq Yk,\ X\lambda \leq \theta Xk,\ \lambda \geq 0$$

Efficiency values between 0 and 1 express the distance of each country from the DEA frontier, and a value equal to 1 defines an optimal positioning – that is, the use of resources without waste at the level of economic performance achieved.

The model integrated a set of ecological pressure and economic performance indicators extracted from Eurostat databases, harmonized and expressed in unitary intensities for comparability between countries. The inputs considered were: energy intensity of agriculture (toe/million €), water use intensity (m^3/€), nitrogen balance and phosphorus balance (kg/ha) and greenhouse gas emission intensity (t CO_2/million €). The outputs were represented by: factor income and gross value added of agriculture. This approach allowed the correlation of economic performance with environmental pressures, providing an integrated picture of the sustainability of the European agricultural system.

To test the model, we applied the "leave-one-input-out" procedure, whereby the DEA scores were recalculated several times, successively excluding one input indicator. The mean changes and Pearson correlations between the full and recalibrated results were used to assess the stability of the model. The high values of the correlations confirmed the methodological coherence, and the larger variations observed in the case of GHG emission intensity and phosphorus balance indicated the major role of these factors in determining the efficiency frontiers.

The analysis was extended with a spatial component, to assess the geographical distribution of efficiency. Spatial autocorrelation was measured by the Moran's I index, according to the formula:

$$I = (n/W) * (\Sigma i\ \Sigma j\ w_{ij}(x_i - \bar{x})(x_j - \bar{x})) / \Sigma i(x_i - \bar{x})^2,$$

where:
w_{ij} - neighborly relations between states
W - the sum of the weights.

Positive values of the index reflect groupings of countries with similar performance, while negative values indicate spatial discontinuities. In addition, Local Indicators of Spatial Association -LISA, were used to identify regional clusters of high efficiency and low performance areas, providing a detailed insight

into how eco-efficient performance is distributed across Europe.

The methodology applied combined non-parametric performance assessment tools with spatial analysis techniques, providing a comprehensive framework for interpreting the relationship between resources, economic performance and sustainability. This approach allowed not only the ranking of Member States according to agricultural efficiency, but also the identification of territorial patterns of performance, supporting an integrated analysis of the ecological transition in EU agriculture.

RESULTS AND DISCUSSIONS

An examination of the eco-efficiency of agriculture in EU member states from 2016 to 2023 reveals a notable degree of performance variation. The application of the input-oriented DEA model, VRS and CRS, allowed the identification of the efficiency frontiers and the potential for reducing environmental pressures at the same level of economic results. Overall, the high scores obtained by some countries confirm the existence of agricultural systems capable of integrating sustainability into economic productivity, while other economies maintain high resource dependencies and an increased level of emissions. The results summarized in the following tables show that the differences in eco-efficiency correlate with the structure of agricultural production, the technological level and the way in which environmental policies within the CAP are implemented. Countries with intensively capitalized agriculture and modern resource management, especially Spain, the Netherlands and Sweden, reach maximum efficiency values, placing themselves on the DEA frontier, while Central and Eastern European states remain, on average, at a considerable distance from this limit, although they have been recording gradual progress in recent years.

Table 1. Average DEA scores and annual trend of agricultural eco-efficiency in the EU-27 for the period 2016–2023

Country	Average DEA score (VRS)	Average DEA score (CRS)	Annual trend of DEA score - VRS
Spain	1.000	0.941	-6.643
Romania	1.000	0.961	-7.004
Sweden	0.975	0.922	0.011
Poland	0.954	0.814	-0.005
Hungary	0.897	0.854	-0.008
Croatia	0.738	0.681	0.079
Germany	0.722	0.646	0.063
Latvia	0.602	0.568	0.041
Slovenia	0.492	0.406	0.017
Czechia	0.490	0.475	0.041

Source: own processing, Eurostat, [7, 8, 9, 10].

The results show a clear differentiation between countries that reach the eco-efficiency frontier and those that remain significantly below the optimal level. Countries in southern and northern Europe have consistently high efficiency values, thanks to a combination of technological modernization, the application of good agricultural practices and efficient resource management policies. In these economies, energy and water use is optimized through investments in high-performance equipment and digitalization, and nutrient losses are reduced through careful control of fertilization. At the bottom of the ranking are countries with a more fragmented agricultural structure and a high share of traditional farms. Here, the intensity of resource use remains high, and the economic returns associated with these inputs are lower. The positive evolution of trends for some of these countries, however, suggests a gradual recovery dynamic, supported by the adaptation to the sustainability standards imposed by the new

instruments of the Common Agricultural Policy.

The contrast between the group of countries on the efficiency frontier and that of emerging economies shows that the ecological transition is underway, but not uniform. The high-performing countries demonstrate that the balance between productivity and resource conservation is achievable, while the less efficient regions indicate the need for additional investments in agricultural infrastructure, clean technologies and farmer training.

Table 2. Input reduction targets and DEA scores

Country	DEA score (VRS)	DEA score (CRS)	Recommended intensity reduction (%)					Target intensity level				
			Energy	Water	Surplus N	Surplus P	GHG	Energy toe/mil. €	Water m³/€	Surplus N Kg/ha	Surplus P Kg/ha	GHG t CO_2e/ mil. €
Lithuania	1	0.915	0	0	0	0	0	1,359.14	0.000012	22.800	-3.100	947.247
Romania	1	1	0	0	0	0	0	1,173.8	0.000082	-1.700	-0.900	902.106
Spain	1	1	0	0	0	0	0	1,242.33	0.000259	36.900	4.200	506.996
Netherlands	1	1	0	0	0	0	0	1,063.78	0.001062	132.700	-3.200	478.383
Hungary	1	1	0	0	0	0	0	1,470.69	0.000269	44.900	-1.300	526.416
Croatia	1	0.955	0	0	0	0	0	2,556.20	0.000719	48.600	0.900	842.528
Poland	1	0.943	0	0	0	0	0	1,899.81	0.000021	35.900	-2.700	935.516
Germany	0.974	0.908	2.600	2.600	2.600	2.600	2.600	2,459.89	0.000165	26.398	-3.604	720.774
Bulgaria	0.730	0.726	27.000	27.000	27.000	27.000	27.000	1,335.02	0.000464	32.203	0.730	827.439
Czechia	0.665	0.581	33.500	33.500	33.500	33.500	33.500	2,117.26	0.000684	29.014	-2.263	652.498
Latvia	0.648	0.487	35.200	35.200	35.200	35.200	35.200	1,455.31	0.000052	15.301	1.167	795

Source: own processing, Eurostat [7, 8, 9, 10, 11].

The findings for 2023 demonstrate distinct disparities in the ability of EU member states to use agricultural resources in an economically and environmentally sound manner. The input-oriented DEA analysis allowed the identification of efficiency frontiers and the estimation of the potential for reducing resource intensity at a constant level of economic performance.

The countries that achieve the maximum score (Spain, Romania, the Netherlands, Lithuania, Hungary) represent the reference frontier of European agricultural eco-efficiency. These economies demonstrate a favourable combination of economic returns and the controlled use of natural resources. In these cases, energy intensity, water consumption and nutrient surpluses are already maintained at levels compatible with the achieved economic performance, so the potential for further reduction is practically nil.

A second group consists of countries with high efficiency but below optimal, such as Germany, Croatia and Poland. They present moderate deviations from the DEA frontier, which can be explained by the structural characteristics of national agriculture. In general, these economies have large farms, but with an energy intensity and water consumption higher than the theoretical efficiency level. These results show that future improvements do not depend so much on the volume of resources used, but on the efficiency of their conversion into added value — by modernizing equipment, integrating renewable energies and optimizing fertilization.

The countries in the low-efficiency group (Bulgaria, the Czech Republic and Latvia) are significantly below the performance frontier. The agriculture of these states is more fragmented, with a high share of traditional farms and a lower degree of mechanization. Energy consumption and nutrient losses remain high in relation to economic output, which explains the need for significant reductions, of over a quarter of current levels. These variations show the institutional and investment divide between the east and west of the European Union in addition to the structural idiosyncrasies of the agriculture sector.

The model demonstrates that ecological and economic performance can be compatible when there are continuous investments in technology and resource management. Countries on the efficiency frontier are not necessarily those with the lowest absolute consumption of inputs, but those that make the

best use of available resources. At the same time, the results highlight the convergence potential of Central and Eastern European countries, which can catch up through innovation, diversification and the implementation of ecological transition measures in the new Common Agricultural Policy.

Table 3. Sensitivity analysis of the DEA model (leave-one-input-out, year 2023)

Indicator excluded from the model	Mean change	Median change	Abs. mean change	Pearson Correlation
GHG emissions intensity	-0.097	-1.110	0.097	0.805
Phosphorus balance (P)	-0.034	0.000	0.034	0.885
Energy intensity	-0.027	-2.220	0.027	0.77
Nitrogen balance (N)	-0.015	-1.887	0.015	0.985
Water use intensity	-0.011	-2.220	0.011	0.98

Source: own processing.

The sensitivity analysis confirms the overall stability of the DEA model applied to agriculture in the European Union. The results show that successively excluding input variables does not significantly change the overall efficiency ranking across countries, demonstrating the consistency of the model structure and the validity of the indicators selected to measure eco-efficiency.

However, the magnitude of the observed changes highlights the different role of each input in determining the efficiency scores. The exclusion of greenhouse gas intensity and phosphorus balance produces the largest variations in the scores, indicating the central importance of environmental pressures in defining the efficiency frontiers. This result suggests that, beyond economic performance, the ecological dimension — in particular emission reduction and nutrient control — is decisive for the positioning of countries in relation to the DEA frontier.

In contrast, the elimination of energy intensity, water consumption or nitrogen balance generates minor variations, a sign of the partial redundancy of these indicators in an already ecologically correlated system. The statistical robustness of the method and the logical consistency of the relationship between the resources consumed and the economic outcomes are thus confirmed by the model's stability even in the absence of one of these components.

The analysis demonstrates that ecological and energy efficiency are interdependent, but the environmental pressures, reflected in GHG emissions and phosphorus losses, are the ones that really differentiate the performance between countries. The results reinforce the idea that emission reduction policies and sustainable nutrient management represent the most effective strategic directions for improving the eco-efficiency of European agriculture.

Table 4. Results of the Moran's I index for the spatial distribution of agricultural eco-efficiency in the E.U.

Metric	Value
Moran's I – average 2016–2023	-0.052
Moran's I – year 2023	-0.261

Source: own processing.

Moran's I measures the degree of spatial autocorrelation, i.e. the extent to which agricultural eco-efficiency values in a country are similar to or different from those in neighboring countries. Values close to +1 indicate positive spatial concentration, values close to 0 suggest random distribution, and negative ones signal negative autocorrelation, i.e. efficient areas surrounded by less performing regions.

The results show a weak and negative spatial correlation of agricultural eco-efficiency over the entire period, indicating that high performances are not necessarily concentrated in a specific geographical area. The more negative value in 2023 indicates a sharp fragmentation of spatial performance — i.e. efficient states increasingly coexist with less efficient neighbors, a sign that the ecological transition is unfolding at an uneven pace across regions. This pattern shows that environmental

and sustainable agriculture regulations have been implemented to varying degrees depending on the national and regional circumstances, and that there is currently no uniform regional model of agricultural eco-efficiency within the European Union.

Table 5. Local spatial autocorrelation indicators for average DEA scores of agriculture in the European Union, 2016-2023

Country	Local Moran's I index	Average neighborhood value
Bulgaria	0.016	0.193
Croatia	0.001	-0.010
Czechia	-0.010	0.031
Germany	0.004	-0.043
Hungary	-0.005	-0.061
Latvia	-0.014	0.071
Lithuania	-0.002	-0.029
Netherlands	-0.004	-0.084
Poland	-0.016	-0.110
Romania	0.017	0.087
Slovenia	-0.003	0.011
Spain	0.00	0.00
Sweden	0.00	0.00

Source: own processing.

The results show a poorly defined spatial structure of agricultural eco-efficiency at European level. Only a few countries – such as Romania and Bulgaria – have positive values of the local Moran's I index, indicating an association between similar performances. In contrast, a number of Central European countries, such as Poland, the Czech Republic, Germany, Hungary, have negative values, indicating spatial discontinuity: efficient countries coexist with less efficient neighbors. This pattern shows that agricultural eco-efficiency does not follow a uniform geographical pattern, but is influenced more by national factors such as the level of technology, environmental policies, farm structure, than by geographical proximity. The difference between the high-efficiency areas in northern and southern Europe and the low-efficiency clusters in central and eastern Europe confirms that agricultural performance in the EU is still spatially fragmented.

Table 6. Local spatial autocorrelation indicators for average DEA scores of agriculture in the European Union, in 2023

Country	Local Moran's I index	Average neighborhood value
Bulgaria	-0.016	0.089
Croatia	0.008	0.089
Czechia	-0.019	0.076
Germany	-0.001	-0.022
Hungary	0.008	0.089
Latvia	-0.023	0.089
Lithuania	-0.008	-0.087
Netherlands	0.006	0.063
Poland	-0.003	-0.031
Romania	-0.004	-0.046
Slovenia	0.000	0.000
Spain	-0.016	0.089
Sweden	0.008	0.089

Source: own processing.

The spatial distribution of eco-efficiency in 2023 shows a more pronounced fragmentation compared to the average of the period 2016–2023, confirming a recent dynamic of the performance differences between states. The low values of the local Moran's I index demonstrate that the transition towards sustainability has an uneven evolution, without the emergence of clearly consolidated regions of high efficiency.

However, the formation of micro-nuclei of coherence is noticeable in the south-eastern part of the European Union, where countries such as Romania and Bulgaria register positive correlations with their direct neighbors. Given the rise in public investments and the execution of agricultural modernization initiatives across Eastern Europe, these correlations may be seen as early indicators of a regional convergence. On the other hand, the negative values recorded in Central European states, especially Poland, the Czech Republic and Hungary, indicate a territorial discontinuity: efficient areas coexist with less performing neighbors, and environmental policies are applied with different intensities. In these regions, differences in access to agricultural infrastructure, technological capitalization and implementation of eco-schemes generate an internal polarization of performance.

In the western EU, the almost zero values for the Netherlands, Germany, France not included

in the table, but with a similar trend, show a local stability without neighborhood effects, which can be interpreted as a maturity of the system: each agricultural economy maintains its own level of efficiency, independent of the immediate geographical context.

The results for 2023 reflect a spatial reconfiguration of European agricultural eco-efficiency, in which homogeneous regional blocks are no longer outlined, but a patchwork distribution, dependent on internal factors of policy, technology and agricultural structure. This evolution confirms the transition towards a territorially differentiated European agriculture, where convergence depends more on the national capacity to implement green policies than on geographical proximity.

The results for 2023 confirm the stability of the eco-efficiency frontiers in EU agriculture. These results confirm the resilience of countries on the efficiency frontier and, at the same time, the persistence of the gaps between the east and west of the EU. However, the differences no longer stem only from the intensity of resource use, but above all from the capacity to strategically manage the ecological transition. After identifying the eco-efficiency frontiers and the performance differences between Member States, the detailed analysis focuses on the specific components of efficiency – resource intensity and their reduction potential. While the DEA scores (VRS and CRS) provide a global picture of each country's position relative to the efficiency frontier, the following analysis allows this performance to be broken down into specific resource indicators: energy, water, nutrients (nitrogen and phosphorus) and greenhouse gas emissions.

This shift from comparative to applied analysis is essential, as it highlights where significant improvements can be made and to what extent ecological efficiency can be increased without compromising economic results. Therefore, the following table does not only describe statistical differences between countries, but also constitutes a basis for public policies and managerial decisions, indicating specific directions of intervention to reduce resource consumption and environmental pressures.

Table 7. Current levels and targets for reducing agricultural inputs in the EU member states

Input	Current level	Target	Recommended reduction (%)
Lithuania			
Energy intensity (toe/mil.€)	1,359.1367	1,359.1367	0.0
Water intensity (m³/€)	0.0000	0.0000	0.0
N balance (kg/ha)	22.8000	22.8000	0.0
P balance (kg/ha)	-3.1000	-3.1000	0.0
GHG intensity (t CO_2e/mil.€)	947.2467	947.2467	0.0
Romania			
Energy intensity (toe/mil.€)	1,173.8033	1,173.8033	0.0
Water intensity (m³/€)	0.0001	0.0001	0.0
N balance (kg/ha)	-1.7000	-1.7000	0.0
P balance (kg/ha)	-0.9000	-0.9000	0.0
GHG intensity (t CO_2e/mil.€)	902.1063	902.1063	0.0
Spain			
Energy intensity (toe/mil.€)	1,242.3255	1,242.3255	0.0
Water intensity (m³/€)	0.0003	0.0003	0.0
N balance (kg/ha)	36.9000	36.9000	0.0
P balance (kg/ha)	4.2000	4.2000	0.0
GHG intensity (t CO_2e/mil.€)	506.9960	506.9960	0.0
Netherlands			
Energy intensity (toe/mil.€)	1,063.7799	1,063.7799	0.0
Water intensity (m³/€)	0.0011	0.0011	0.0
N balance (kg/ha)	132.7000	132.7000	0.0
P balance (kg/ha)	-3.2000	-3.2000	0.0
GHG intensity (t CO_2e/mil.€)	478.3831	478.3831	0.0
Hungary			

Energy intensity (toe/mil.€)	1,470.6878	1,470.6878	0.0
Water intensity (m³/€)	0.0003	0.0003	0.0
N balance (kg/ha)	44.9000	44.9000	0.0
P balance (kg/ha)	-1.3000	-1.3000	0.0
GHG intensity (t CO_2e/mil.€)	526.4161	526.4161	0.0
Croatia			
Energy intensity (toe/mil.€)	2,556.1995	2,556.1995	0.0
Water intensity (m³/€)	0.0007	0.0007	0.0
N balance (kg/ha)	48.6000	48.6000	0.0
P balance (kg/ha)	0.9000	0.9000	0.0
GHG intensity (t CO_2e/mil.€)	842.5280	842.5280	0.0
Poland			
Energy intensity (toe/mil.€)	1,899.8063	1,899.8063	0.0
Water intensity (m³/€)	0.0000	0.0000	0.0
N balance (kg/ha)	35.9000	35.9000	0.0
P balance (kg/ha)	-2.7000	-2.7000	0.0
GHG intensity (t CO_2e/mil.€)	935.5161	935.5161	0.0
Germany			
Energy intensity (toe/mil.€)	2,525.3356	2,459.8875	2.6
Water intensity (m³/€)	0.0002	0.0002	2.6
N balance (kg/ha)	27.1000	26.3977	2.6
P balance (kg/ha)	-3.7000	-3.6041	2.6
GHG intensity (t CO_2e/mil.€)	739.9511	720.7741	2.6
Bulgaria			
Energy intensity (toe/mil.€)	1,828.2192	1,335.0215	27.0
Water intensity (m³/€)	0.0006	0.0005	27.0
N balance (kg/ha)	44.1000	32.2032	27.0
P balance (kg/ha)	1.0000	0.7302	27.0
GHG intensity (t CO_2e/mil.€)	1,133.1206	827.4393	27.0
Czechia			
Energy intensity (toe/mil.€)	3,181.6911	2,117.2550	33.5
Water intensity (m³/€)	0.0010	0.0007	33.5
N balance (kg/ha)	43.6000	29.0136	33.5
P balance (kg/ha)	-3.4000	-2.2625	33.5
GHG intensity (t CO_2e/mil.€)	980.5377	652.4984	33.5
Latvia			
Energy intensity (toe/mil.€)	2,244.6342	1,455.3067	35.2
Water intensity (m³/€)	0.0001	0.0001	35.2
N balance (kg/ha)	23.6000	15.3010	35.2
P balance (kg/ha)	1.8000	1.1670	35.2
GHG intensity (t CO_2e/mil.€)	1,226.1905	794.9996	35.2

Source: own processing, Eurostat, [7, 8, 9, 10, 11, 12].

The structure of the eco-efficient performance of European agriculture is a direct result of the way in which resources are used and the intensity of environmental pressures. Countries that have managed to gradually reduce energy consumption and sustainably manage fertilization are now on the efficiency frontier, demonstrating that the ecological transition can be compatible with economic competitiveness. In these cases, the integration of modern technologies, process automation and coherent agricultural support policies have led to a structural optimization of resource use.

In contrast, low-efficiency countries face the cumulative effects of dependence on conventional inputs, outdated agricultural infrastructure and low administrative capacity to implement environmental measures. In these economies, high energy consumption and nutrient losses translate into lower economic performance and a pronounced ecological imbalance. The DEA model shows that these countries can achieve significant performance gains by reducing environmental pressures and adopting integrated resource management systems.

The overall result is a clear polarization between a core of high-performing countries – which use energy, water and nutrients efficiently – and a group of agricultural economies that are still in the process of adjustment. This polarization reflects not only environmental differences, but also gaps in technological modernization and access to green investments.

In terms of implications, the results suggest that agricultural and environmental policies need to be differentiated territorially. Countries on the efficiency frontier can function as models of good practice in implementing eco-schemes, while economies with low efficiency require targeted investments in irrigation infrastructure, energy efficiency and nutrient management. Overall, the analysis confirms that increasing eco-efficiency does not depend exclusively on reducing consumption, but on each country's capacity to convert resources into economic value in a sustainable way — a key direction for the convergence and resilience of European agriculture.

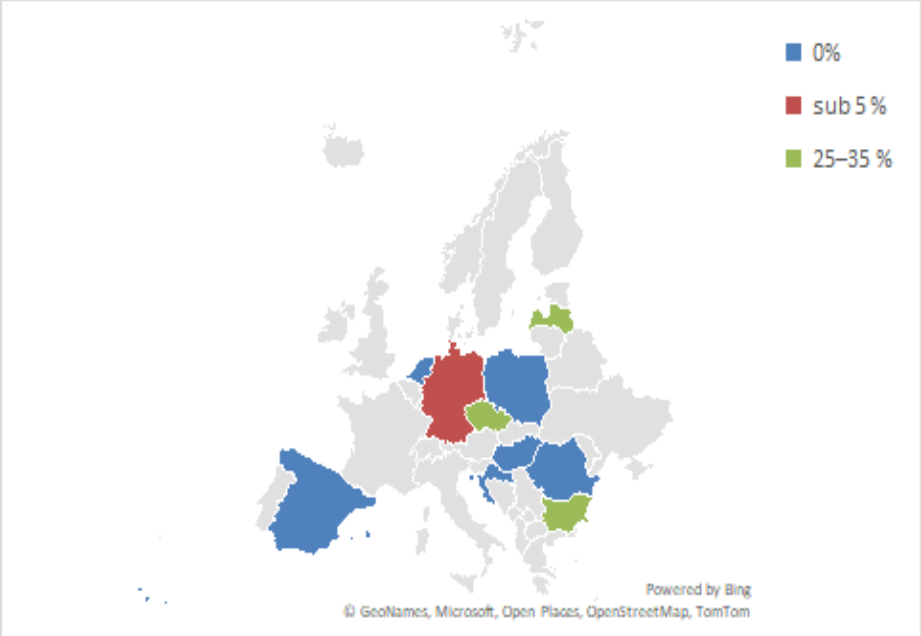


Fig. 1. Spatial distribution of agricultural efficiency categories in the European Union (2023)
Source: own processing.

The potential to reduce resource usage is reflected in Figure 1, which illustrates the regional variations in agricultural performance within the European Union. Countries with 0% are on the efficiency frontier, with balanced agricultural systems and optimal resource management. Those with values below 5% indicate high but not maximum efficiency, with limited possibilities for improving energy intensity and GHG emissions. In contrast, countries with 25–35% have the greatest potential for optimization, requiring investments in modern agricultural technologies and infrastructure to reduce resource losses. The spatial distribution demonstrates the existence of a western core of performance and eastern regions in ecological transition, as detailed in the following table.

A stable efficiency frontier is observed, dominated by countries in the West and South of the European Union, which have achieved maximum technical performance under both variable and constant yields. Countries in Central and Eastern Europe are below the frontier, confirming the persistence of productivity and eco-efficiency gaps. The differences between the VRS and CRS scores reflect, in particular, scale effects: some economies operate efficiently at the microeconomic level, but lose efficiency as the size of the agricultural system increases.

This synthesis supports the classification used subsequently to analyze policies and the possibility of ecological convergence and enables a direct comparison of performance across nations.

Table 9. DEA technical efficiency scores of agriculture in E.U. member states in 2023

Country	DEA Score (VRS)	DEA Score (CRS)
Romania	1	1
Spain	1	1
Netherlands	1	1
Hungary	1	1
Lithuania	1	0.915
Germany	0.974	0.908
Poland	1	0.943
Croatia	1	0.955
Bulgaria	0.73	0.726
Czech Republic	0.665	0.581
Latvia	0.648	0.487

Source: own processing, Eurostat, [7, 8, 9, 10].

CONCLUSIONS

The examination of the EU's agricultural eco-efficiency from 2016 to 2023 showed a complicated picture with notable national variations as well as distinct patterns of ecological and economic convergence. The DEA model demonstrated that a small number of countries – in particular Spain, Romania, the Netherlands and Hungary – are on the efficiency frontier, confirming the compatibility between sustainability and economic performance. Through technology, digitalization, and the coordinated implementation of green policies, these nations have been able to lessen their reliance on resources without sacrificing output. The results show that efficiency is not determined only by the level of resources used, but by the quality of their management. Countries with modern agricultural systems, high-performance infrastructure and high administrative capacity manage to convert energy, water and nutrients into higher added value. In contrast, countries with structural weaknesses and dependence on conventional inputs continue to experience high resource losses and emissions. This dissonance confirms that the transition to a sustainable agricultural model depends more on institutional and technological capacity than on geographical location or sector size.

The spatial analysis completed the global picture, revealing a fragmented distribution of eco-efficient performance. The negative values of the Moran's I and LISA indices show the absence of compact regions of performance and emphasize the individualized nature of agricultural progress. Instead of regional convergence, the results indicate a national dynamic, in which each country evolves according to domestic policies and the degree of absorption of funds intended for the green transition.

Overall, the research confirms that achieving the objectives of climate neutrality and efficient use of resources is only possible through the coherent integration of economic, ecological and technological dimensions. Eco-efficiency does not imply a uniform reduction in consumption, but a reorganization of the way resources are used, in which energy, water and nutrients become factors of competitiveness, not of pressure on the environment.

From the standpoint of public policy, the findings emphasize the necessity of a distinct approach to the Common Agricultural Policy: bolstering monitoring mechanisms and best practices in successful nations, while supporting innovation and green investments in underperforming ones. The European Union's ability to promote technological cooperation, lessen agricultural capital inequities, and profit from international innovation transfer is also necessary to preserve the efficiency frontiers.

In conclusion, European agriculture's eco-efficiency is now a sign of institutional and economic maturity rather than only a sustainability factor. The transition to a competitive and ecological agricultural system is not achieved through standardization, but through adaptive convergence – a process in which each state builds its own efficiency trajectory within a common European framework.

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THE ROLE OF GREEN FINANCIERS IN ACCELERATING THE ENERGY TRANSITION IN THE EUROPEAN UNION

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Abstract

This research study examines how greenhouse gas emissions, renewable energy usage, and green bond issuance have evolved in the European Union from 2015 to 2024. The study aims to evaluate the dynamics of the energy and climate transition. The main objective is to understand how these three dimensions interact and contribute to the structural transformation of the European economy. The methodological approach includes a descriptive analysis of the three indicators, an evaluation of the performance of the member states by classifying them into categories of climate and energy efficiency, and an estimation of regression models to identify causal relationships between variables. This approach allows for the identification of common trends, differences between states, and the intensity of connections between green financing, renewable energy, and reduced emissions. The results reveal a consistent decrease in greenhouse gas emissions across the EU-27, which coincides with a substantial increase in renewable energy's share of final consumption. The regression model confirms the relationship between these two variables, indicating a strong inverse correlation. These findings suggest that expanding renewable energy is an important decarbonization factor. Meanwhile, the accelerated growth of green bonds reflects the intensification of sustainable financing mechanisms. Statistical results demonstrate that these instruments directly contribute to expanding clean energy capacities. The comparative analysis reveals significant differences between EU states, as well as a general trend of convergence towards cleaner energy models, particularly among economies that have consistently accessed green financing. The conclusions emphasize the importance of integrating financial and energy policies to achieve European climate objectives. Sustainable financing, renewable infrastructure, and emission reductions form an interdependent system, in which interventions in any of these areas influence the performance of the entire system. The study provides a strategic perspective on the EU's green transition and highlights the need to strengthen financing mechanisms, coordinate policies, and accelerate investments to achieve climate neutrality.

Key words: *green bonds, renewable energy, GHG emissions, sustainable financing, energy transition, EU*

INTRODUCTION

The transition to a low-carbon economy is one of modern economies' most important strategic priorities. It has an impact on energy policies, industrial structures, and financial procedures. The European Union is driving this shift through the European Green Deal and the Fit-for-55 package [11, 13, 22]. In this context, three dimensions become central to evaluating climate progress: green financing, expansion of renewable energy, and reducing greenhouse gas emissions. The literature increasingly treats these elements as part of an interdependent system, in which decarbonization cannot be analyzed separately from the energy structure and financing mechanisms.

A primary conceptual pillar is represented by green bonds, which are defined as debt instruments through which issuers mobilize capital for projects with a positive environmental impact [3, 4]. Studies by Flammer, Gianfrate, and Ehlers show that green bonds are becoming a key mechanism for financing the energy transition, with three major theoretical functions [7, 12, 14]. First, they act as a catalyst for investments, directing substantial financial resources towards renewable energy, sustainable transportation, and energy efficiency. Second, the signaling role, whereby the issuance of these instruments conveys a clear message about the emitter's climate commitment, reducing informational asymmetries and the risk of greenwashing [23]. Third, the literature highlights the role of

reducing the cost of capital, manifested by the phenomenon of "greenium," where green bonds benefit from lower financing costs than traditional ones [16, 20, 24]. Thus, in the European financial architecture, green bonds become an essential link, facilitating the rapid mobilization of the necessary capital for accelerating energy transitions.

The second conceptual pillar is represented by the share of renewable energy in final consumption, a structural indicator of the progress of the energy transition. Specialized literature emphasizes that renewables are not only an energy alternative, but also the foundation of economic decarbonization [15, 28]. Studies show that wind and solar energy generate the fastest emissions reductions, while diverse energy mixes increase resilience to price shocks and reduce dependence on imports, as highlighted in IEA and REN21 reports [1, 2, 17, 27]. Technological innovation — through reducing levelized energy costs and digitalizing networks — strengthens the role of renewables as a driver of industrial competitiveness. Theoretical models of the transition show that states that consistently increase the share of renewable energy not only benefit from climate improvements, but also gain long-term economic advantages [6, 21].

The third conceptual pillar is GHG emissions, the final indicator of climate performance and the result of the interaction between the energy structure, the level of industrialization, energy efficiency, and investments in clean technologies. The literature on decarbonization confirms that reducing emissions depends directly on changes in the energy mix and the pace of adopting modern technologies in industry and transportation [5, 25]. IPCC and EEA reports show that states combining substantial green investments with ambitious energy policies experience the fastest decreases in emissions, strengthening the theoretical relationship between sustainable financing, energy transition, and climate performance [18].

An increasing number of studies highlight the emergence of a virtuous cycle between the three dimensions: green bonds stimulate investments in renewable energy; the growth of renewables reduces emissions; and the decrease in emissions intensifies investors' interest in green financing [19, 26]. These bidirectional relationships, highlighted in recent literature by Gianfrate and Peri, demonstrate that the green transition evolves as an integrated system, where sustainable financing and energy transformations are interdependent [14].

For the European Union, analyzing these relationships is not just a statistical exercise, but a strategic undertaking with major economic and geopolitical implications. The EU aims not only to reduce its own emissions, but also to strengthen its position as a global leader in defining sustainability and green financing standards. Understanding the dynamics between green bonds, renewable energy, and GHG emissions is essential for evaluating progress and shaping public policy in a context where climate transition becomes a defining factor of global competitiveness.

MATERIALS AND METHODS

The research methodology is based on an integrated analysis of three fundamental indicators for assessing climate and energy progress in the European Union: greenhouse gas (GHG) emissions, the share of renewable energy in final consumption (RES), and green bond issuance. These indicators capture three complementary dimensions of the green transition: climate pressure, energy restructuring, and sustainable finance intensity. GHG emissions, expressed in millions of tonnes of CO_2 equivalent, reflect the total pressure on the climate exerted by economic activities, while the share of renewable energy indicates the level of substitution of fossil fuels with clean technologies. Green bonds are the main financial mechanism through which states and private actors mobilise capital for climate projects, with the literature highlighting their role in accelerating green infrastructure and reducing financing costs.

For each of the three indicators, fundamental descriptive statistics were calculated: mean, median, extreme values, standard deviation,

and average annual growth rate. Standard deviation is defined by the formula:

$$\sigma = \text{sqrt}\left(\Sigma(x_i - \bar{x})^2 / (n - 1) \right) \quad (1)$$

and the average annual growth rate was calculated as follows:

$$CAGR = (X_n / X_1) \times (1/t) - 1 \quad (2)$$

These indicators allow for the assessment of stability, variability, and the general direction of developments during the period analyzed.
In order to understand the differences between Member States, a classification of energy and climate performance was also carried out. EU countries were grouped into low, medium, and high performance categories using statistical thresholds derived from the distributions of indicator values. This approach allows for the observation of convergence or divergence between economies in terms of the green transition and reveals the relative positioning of countries in relation to European targets.
To analyze the causal relationships between indicators, two linear regression models were estimated, formulated narratively as follows: GHG emissions are explained by the share of renewable energy, and the share of renewable energy is explained by the level of green bond emissions. The models are the mathematical expression of the theoretical relationships discussed in the literature. The general form of the regression used is:

$$Y = \alpha + \beta X + \varepsilon \quad (3)$$

where:
X- the independent variable
y- the dependent variable
α - a constant
β - the slope
ε- a random error

The coefficient of determination R^2 indicates the proportion of the dependent variable's variation in connection with the variation of the independent variable explained by the model:

$$R^2 = ESS / TSS \quad (4)$$

where:
ESS-Explained Sum of Squares
TSS-Total Sum of Squares
High R^2 values confirm the intensity of the relationships between indicators and support the hypothesis that green financing stimulates the expansion of renewable energy sources and that these sources contribute to GHG emissions reduction.
This integrated methodological approach allows for the simultaneous evaluation of trends, relationships, and differences among the EU-27 states, providing a solid empirical basis for interpreting results and formulating strategic conclusions.

RESULTS AND DISCUSSIONS

In the last decade, the European Union has accelerated the transition to a more sustainable energy and economic model, a process reflected directly in the evolution of the three central indicators analyzed in this study: greenhouse gas emissions, the share of renewable energy in final consumption, and the volume of green bonds. Between 2015 and 2023, the EU-27 combined ambitious climate policies with dedicated financial instruments, resulting in a visible change in the structure of energy production and consumption, as well as in the way member states finance projects with ecological impact.
This analysis examines the dynamics of these three indicators to highlight how the climate and energy profile of the EU-27 is changing. The reduction of the greenhiuse gas emmission, the extend of the renewable energy and the fast growth of the green bnds market are interconnected processes which offer a coherent image of the progress of Europe to the climate neutrality. By combining European statistical data with comparative analysis methods, the study provides a comprehensive perspective on the performance of the member states and the relationships between green investments, energy structure, and emission levels.

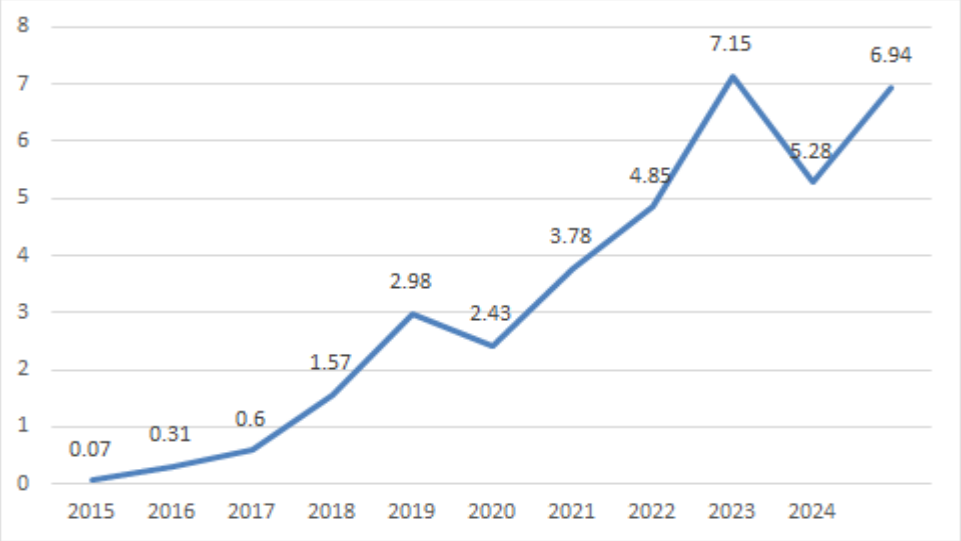


Fig. 1. Annual evolution of green bond issuances in the EU-27
Source: own processing, Eurostat [8].

Figure 1 highlights the transformation of green bonds into a primary financial instrument at the European Union level. The visible increase during the analyzed period reflects the integration of this type of financing into European mechanisms that support the energy and climate transition. As member states, European institutions, and private actors adopted common standards for sustainable financing, green bonds became a preferred channel for mobilizing capital for projects with ecological impact, ranging from renewable energy to environmental infrastructure and the modernization of high-emission sectors.

The evolution of green bond issuances observed in the graph confirms the consolidation of a market that no longer functions on the margins of the financial system, but occupies a central position in the EU's strategy of aligning investments with climate objectives. Through increased issuance volumes, green bonds contribute to expanding the capacity of member states to finance sustainable projects, standardizing ESG criteria, and increasing transparency in the use of funds. Thus, the dynamics reflected in the figure underscore the strategic role of these instruments in the European effort to accelerate the transition to a low-emission economic model and modernized energy structure.

The data in Table 1 show how the European Union's member states adjust their climate profile in a period marked by increasingly ambitious emission reduction targets. The values presented for each country paint a complex picture, in which large, highly industrialized economies maintain high emission levels, while smaller states or those with rapid restructuring in the energy and industrial sectors present significantly lower volumes. The general dynamic indicates a progressive decrease in emissions in most states, suggesting that the energy transition and European climate policies are beginning to produce visible effects.

The differences between countries reflect structural particularities — from the energy mix and the share of fossil fuels to the pace of industrial modernization and the capacity to integrate low-emission technologies. This variability has an important analytical function: it allows for the identification of states that are advancing rapidly and those that are evolving more slowly, providing clues about the efficiency of national strategies. The table also highlights divergent trends over time, with some states experiencing consistent reductions in emissions while others undergo periods of stagnation or fluctuation. Overall, the data show that the climate transition is proceeding at an uneven pace within the EU-27, but with a clear general direction towards reducing the climate impact.

Table 1. Evolution of Greenhouse Gas Emissions in the European Union from 2015 to 2024 (Mt CO_2-eq)

Country	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Belgium	117.82	116.45	115.95	116.74	115.94	106.57	109.43	102.46	97.92	98.65
Bulgaria	52.85	48.42	50.23	45.79	44.76	38.72	44.90	49.31	36.76	35.43
Czechia	117.90	120.79	123.14	125.68	126.30	119.49	121.83	116.45	98.92	92.55
Denmark	50.54	53.42	50.92	52.56	47.58	44.70	44.53	42.36	38.79	36.75
Germany	907.56	906.16	886.22	936.06	870.17	809.65	824.51	824.40	740.67	700.35
Estonia	18.62	21.18	22.32	23.26	17.63	12.48	13.42	14.35	12.99	12.56
Greece	92.60	88.35	92.44	88.37	81.22	70.73	72.97	72.59	67.83	65.07
Spain	280.26	268.30	280.77	274.10	256.95	218.72	235.79	241.68	218.93	218.51
France	420.44	426.67	436.95	407.60	401.04	358.33	384.80	369.47	339.02	331.77
Croatia	19.07	19.23	20.89	19.16	19.09	18.24	18.67	19.66	19.89	18.84
Italy	401.57	396.02	406.75	379.59	369.72	340.17	374.09	373.69	331.15	319.54
Cyprus	8.03	8.58	8.63	8.52	8.13	7.77	7.95	8.04	8.19	8.58
Latvia	11.04	9.22	7.82	10.79	8.93	11.04	12.70	15.82	14.61	12.72
Lithuania	12.24	13.21	13.98	14.73	14.61	14.44	14.35	12.61	12.63	13.98
Luxembourg	9.88	9.54	9.81	10.25	10.29	8.52	8.70	7.47	7.09	6.99
Hungary	56.75	58.50	59.91	60.39	59.57	55.86	56.85	52.95	48.50	48.20
Malta	2.15	1.85	2.02	2.02	2.13	2.09	2.10	2.26	2.25	2.18
Netherlands	199.93	200.25	196.70	191.43	185.25	168.30	170.59	157.02	146.44	145.61
Austria	75.27	72.19	78.21	81.27	86.64	73.73	74.71	73.31	76.23	74.47
Poland	348.11	352.16	366.10	366.67	362.95	347.20	374.39	344.39	315.78	298.81
Portugal	64.99	65.43	85.94	63.21	60.32	53.98	53.54	55.98	51.22	51.49
Romania	68.39	64.33	69.10	71.77	68.58	62.41	67.58	63.98	57.44	68.51
Slovenia	17.43	18.46	18.54	18.48	12.60	11.57	11.73	11.34	10.51	11.28
Slovakia	35.22	35.69	36.94	37.77	34.66	29.78	33.71	29.65	28.34	27.96
Finland	43.75	51.27	51.96	63.31	56.07	49.58	59.16	57.76	53.10	52.35
Sweden	-2.03	0.76	5.92	11.65	10.43	6.63	11.06	10.59	13.16	16.25

Source: own processing, Eurostat, [9].

Table 2 illustrates the European Union's gradual shift towards renewable energy sources as a central element of its climate strategy. The data highlight significant differences between member states, indicating that the energy transition is influenced by specific national factors, such as available resources, internal policies, industrial structure, and the pace of investments in green infrastructure. Thus, the transition is not uniform. Countries with a history of renewable energy are strengthening their position and achieving high levels of clean energy integration. Meanwhile, economies undergoing technological transformation are experiencing gradual but steady growth. These findings suggest a progressive adaptation to European climate objectives.

The data show how renewable energy is becoming a strategic pillar for the energy security and decarbonization of European economies. Increased use of renewable energy sources alters the structure of energy production, decreasing reliance on fossil fuels and strengthening national energy systems. At the same time, the evolutions in the table suggest a process of technological maturation, in which investments in solar, wind, hydro, and biomass are integrated more efficiently into the energy mix. The result is a slow but visible convergence among states, with a general trend of growth at the EU-27 level, confirming the consolidation of the European direction of transition towards cleaner and more sustainable energy.

Table 2. Evolution of the renewable energy in the EU in the period 2015–2024 (%)

Country	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
European Union - 27	17.82	17.978	18.411	19.096	19.887	22.038	21.897	23.03	24.631	:
Belgium	8.06	8.744	9.136	9.472	9.929	13	13.076	13.816	14.741	:
Bulgaria	18.261	18.76	18.695	20.581	21.545	23.319	19.394	19.079	23.151	23.21
Czechia	15.07	14.926	14.799	15.139	16.239	17.303	17.614	18.123	18.586	:
Denmark	30.469	31.715	34.387	35.159	37.02	31.681	41.495	41.37	43.73	46.759
Germany	14.901	14.885	15.472	16.66	17.266	19.09	19.3	20.814	21.562	:
Estonia	28.987	29.232	29.538	29.97	31.73	30.069	37.342	38.542	40.95	:
Greece	15.69	15.39	17.3	18.001	19.633	21.749	22.001	22.671	25.269	:
Spain	16.221	17.015	17.118	17.023	17.852	21.22	20.552	21.837	24.981	25.423
France	14.803	15.451	15.847	16.384	17.174	19.109	19.391	20.33	22.462	23.229
Croatia	28.969	28.266	27.28	28.047	28.466	31.023	31.285	28.088	28.088	27.497
Italy	17.525	17.415	18.267	17.796	18.181	20.359	18.883	19.131	19.594	:
Cyprus	9.903	9.833	10.478	13.873	13.777	16.879	19.069	19.427	20.213	:
Latvia	37.538	37.138	39.008	40.019	40.929	42.132	42.096	43.72	43.223	:
Lithuania	25.748	25.612	26.038	24.695	25.474	26.773	28.166	29.599	31.926	:
Luxembourg	4.987	5.364	6.194	8.942	7.046	11.699	11.713	14.286	14.312	14.742
Hungary	14.495	14.377	13.556	12.548	12.634	13.85	14.134	15.128	17.117	18.329
Malta	5.119	6.208	7.219	7.914	8.23	10.714	12.631	14.04	15.111	17.21
Netherlands	5.714	5.846	6.507	7.394	8.886	13.999	13.117	15.291	17.588	20.18
Austria	33.497	33.37	33.136	33.784	33.755	36.545	34.643	34.057	41.6	42.951
Poland	11.881	11.396	11.059	14.936	15.377	16.102	15.604	16.644	16.651	17.745
Portugal	30.514	30.864	30.611	30.203	30.623	33.982	33.982	34.675	35.154	36.49
Romania	24.785	25.032	24.454	23.875	24.29	24.478	23.871	24.229	25.782	:
Slovenia	22.879	21.975	21.658	21.378	21.968	25	25	25.002	25.066	24.635
Slovakia	12.882	12.029	11.465	11.896	16.894	17.345	17.419	17.482	16.991	18.092
Finland	39.23	38.943	40.857	41.185	42.807	43.939	42.819	47.74	50.75	:
Sweden	52.22	52.597	53.39	53.916	55.785	60.124	62.527	66.287	66.393	:

Source: own processing, Eurostat, [10].

Comparing the data shown in the tables for GHG emissions and renewable energy share reveals a converging relationship between climate change and energy transitions in the EU-27 member states. As more and more countries improve their renewable energy resources and diversify their energy mix, pressure on emissions steadily reduces and the climate profile becomes more stable. This complementarity reflects the essential role of renewable energies in reducing the carbon intensity of the economy, demonstrating that the energy transition is not only a technical component, but also a direct mechanism for reducing the climate impact. Countries with accelerated growth in renewable energy tend to see a decline in emissions, while countries dependent on conventional sources experience a slower decarbonization process.

The relationship between the two indicators highlights the diversity of trajectories within the EU-27.

For some states, the expansion of renewable energy produces rapid effects on reducing emissions, indicating an efficient integration of new technologies. For others, the growth of renewable energy coexists with high emissions, either due to the industrial mix or the difficulty of decarbonizing certain economic sectors. The correlation between the two series of data confirms the EU general trend to orient its climate policies by strenghtening the renewables, which will become the main factor shaping the emission trajectory in the next years. Individual analysis will be destined to green bonds, greenhiuse gas (GHG) and the share of the renewable energy have highlighted distinct but converging developments towards the EU climate objectives. Each indicator captures a specific dimension of the transition — financing, climate performance, and the structural transformation of the energy mix — but understanding their common dynamics requires an overview of their variation, amplitude, and consistency during the analyzed period. Table 3 summarizes these elements, combining information on the dispersion of values, centralized trends, and the average rate of evolution for each indicator.

This perspective consolidates the theoretical and empirical image built in the previous

sections. The descriptive indicators allow for the evaluation of the stability of each series, the comparison of the intensity of the variations, and the identification of the common points that will be explored in the subsequent stages of the analysis.

Table 3. Descriptive indicators for GHG, renewable energy, and green bonds

Indicator	Min	Max	Mean	Median	Std	CAGR
GHG	2848.36	3498.16	3265.60	3331.56	224.97	-0.02
Renewables	20.78	27.73	23.51	22.83	2.55	0.04
Green Bonds	0.31	7.15	3.22	2.98	2.27	0.43

Source: own processing, Eurostat, [7].

The data in Table 3 allows for a comparative evaluation of their stability and role in the dynamics of the European climate transition. The statistical values show that GHG emissions exhibit relatively moderate variation overall, reflecting the structural inertia of European economies and the constant, yet gradual, pace of the decarbonization process. In contrast, renewable energy shows more consistent growth and lower variability. This suggests that clean energy sources are gradually becoming more consolidated in the energy mix of member states. In contrast, green bonds stand out due to their accelerated dynamics, indicated by a higher amplitude of variations and a rapid growth rate, typical of a financial instrument in expansion. Overall, descriptive statistics clarify the relationship between the three indicators: while GHG reflects the volume of emissions and the structural limits of each economy, renewable energy expresses the technological transformation capacity, and green bonds signal the intensity of investments oriented towards sustainability.

The differences in the mean level, dispersion, and rate of evolution among these series confirm that the European transition is taking place on multiple levels, at different speeds, but in the direction of progressive convergence towards climate objectives. Table 3 thus becomes an important reference for interpreting the performance of each indicator and identifying the interdependencies that will be analyzed in the next section.

Table 4 groups the member states according to their level of energy and climate performance, offering an integrated perspective on how they are advancing towards European green transition objectives. These three categories — low, medium, and high performers — reveal structural differences among countries resulting from the recent evolution of renewable energy shares and greenhouse gas emission management.

High performers are those that have successfully combined a modern energy mix with a substantial amount of renewable energy sources and an improving climate profile.

Table 4. Classification of the energy and climate performance of the UE-27 member states

Low Performers	Medium Performers	High Performers
Belgium	Bulgaria	Denmark
Czechia	Germany	Estonia
Italy	Greece	Croatia
Luxembourg	Spain	Latvia
Hungary	France	Lithuania
Malta	Cyprus	Austria
Netherlands	Romania	Portugal
Poland	Slovenia	Finland
Slovakia		Sweden

Source: own processing, Eurostat, [10].

This positioning reflects the maturity of their energy strategies and the effectiveness of their emissions reduction measures.

The intermediate group comprises states in a process of adjustment and consolidation, where the energy transition is ongoing but at a slower pace. These countries maintain a moderate level of performance, with the potential to intensify as investments and energy reforms increase. Conversely, the low performance category includes states that remain dependent on traditional energy structures or that struggle to reduce emissions. Their positioning in this category reflects not only their current level of achievement, but also the systemic challenges that could slow the pace of the green transition. Overall, the table highlights the internal diversity of the EU-27 and emphasizes the importance of adapting energy and climate policies to national realities to ensure sustainable convergence at the European level.

The descriptive results and the classification of the energy and climate performance of the EU-27 states have highlighted significant differences between countries and distinct evolutions in the analyzed areas. However, to understand how these indicators are structurally linked to each other and to what extent the evolution of one influences the dynamics of the others, an analysis of the functional relationships between variables is necessary. The data in Table 5 present regression models that capture either the effect of renewable energy on GHG emissions levels or the role of green bonds in accelerating the energy transition, providing information on the internal mechanisms of the green transition at the European level.

Table 5. Regression model between GHG, renewable energy, and green bonds

Model	Beta	Intercept	R2
GHG = f(RES)	-82.385	5202.532	0.869
RES = f(GreenBonds)	1.021	20.225	0.833

Source: own processing, Eurostat, [7].

The models presented in Table 5 clarify the direction and intensity of the links between the three main indicators, allowing for an integrated interpretation of the European climate transition. The relationship between greenhouse gas emissions and the proportion of renewable energy in the energy mix shows that increased use of clean energy sources is associated with decreased emissions. This demonstrates the important role of renewable energy in reducing the carbon intensity of the economy. The negative coefficient shows that as the energy structure shifts toward lower-emission sources, the EU-27's climate profile improves, making its energy systems more ecologically efficient. The high level of explanatory power demonstrates the stable and coherent relationship between the two indicators over time.

The second model focuses on the relationship between green bonds and the growth of renewable energy. The positive coefficient confirms green bonds' critical role in financing investments in clean infrastructure and technologies. As the number of these instruments grows, European governments have more resources available for sustainable energy initiatives. This is evident in the rising share of renewable energy sources. The high explanatory power suggests that financing through green bonds is not marginal, but rather, is consistently integrated into the architecture of the European energy transition. Overall, the two regression models confirm the existence of a logical chain of the transition: larger green investments favor the expansion of renewable energies, and the expansion of these energies contributes to reducing GHG emissions.

CONCLUSIONS

Analyzing the relationship between greenhouse gas (GHG) emissions, renewable energy, and green bonds is essential to understanding the internal dynamics of the climate transition in the European Union. In a context where climate objectives are becoming increasingly ambitious and the global pressure

to reduce emissions is growing, identifying the mechanisms that support this transformation is becoming strategically relevant. These three indicators measure progress and reveal the interconnection between energy policies, financial instruments, and climate results. Understanding these connections enables the development of coherent, efficient, and adaptable national strategies.

The analysis's importance is amplified by the EU's central role in promoting global sustainability leadership. The European Green Deal, the Fit-for-55 legislative package, the REPowerEU initiative, and the intensification of regulatory pressures in capital markets transform the green transition into a process involving the economy, finance, and public policies simultaneously. Therefore, analyzing the relationship between green investments, energy transformation, and climate results is essential for evaluating the efficiency of current policies and projecting sustainable trajectories in the coming years.

The results of the analysis reflect a coherent European path towards climate objectives, in which sustainable financing, structural transformation of the energy mix, and GHG emissions reduction function as elements of the same transition process. The identified relationships between indicators show that climate progress does not depend only on the implementation of clean technologies, but also on the capacity of states to mobilize adequate financial resources and reconfigure energy infrastructure in a sustainable manner. The green transition is not developing uniformly among states, but the general direction is convergent.

We believe that a mechanism is needed to increase the volume of green bonds, consolidate the expansion of renewable energies, and contribute to reducing GHG emissions. The results demonstrate that the European climate transition is driven by both innovative financial instruments and the energy transition itself. The study emphasizes the need to maintain the pace of green investments, accelerate convergence between member states, and consolidate policies that can transform these trends into long-term sustainable progress.

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THE IMPACT OF GREEN POLICIES ON THE SUSTAINABILITY OF CONSUMPTION AND PRODUCTION IN THE EUROPEAN UNION

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Abstract

The research analyses the impact of green policies on the sustainability of consumption and production in the EU Member States, using a panel data set for the period 2015–2023. The main aim of the study is to assess how instruments such as green financing, environmental taxes, economic performance and energy progress contribute to the progress made by EU countries in achieving the objectives associated with SDG 12. In this regard, specific objectives were set, namely: building a composite index of green policies by analyzing the principal components, examining the relationships between variables using modern statistical methods and estimating their effects on sustainability using panel econometric models. The methodology was based on combining a set of relevant European indicators, subsequently integrated into a synthetic index that would capture the coherence of green policies. The analysis used fixed and random effects models, with the selection of the appropriate model being carried out using the Hausman test. The results obtained highlighted that energy progress and the intensity of green policies have the most consistent contribution to improving sustainability performance, while green financing and environmental taxes, although they have positive effects, are less pronounced. The fixed-effects model provided estimates that showed that structural differences between countries significantly influence the dynamics of the green transition. The study's conclusions show that accelerating sustainability in the EU depends on the integrated strengthening of green policies, the intensification of clean energy investments and a more efficient coordination of fiscal and financial instruments. The results obtained provide useful solutions for formulating recommendations aimed at improving the performance of Member States in the context of European climate objectives.

Key words: *green policies, sustainability, green financing, renewable energy, panel models*

INTRODUCTION

The transition to a sustainable economy represents one of the most complex transformations of contemporary economies, amid pressures generated by climate change, depletion of natural resources and intensified international commitments to reduce emissions [5]. Recent literature highlights that green policies have become a major determinant of development strategy in advanced economies, especially in the EU, where climate objectives are integrated into economic and energy policies [2, 14]. Green finance plays a central role in this transition, facilitating the channeling of capital towards projects with a positive impact on the environment, in particular through instruments such as green bonds, sustainable loans and ESG investments [24]. Studies show that financial markets react favorably to the expansion of green finance, and these instruments contribute to reducing the cost of capital for sustainable projects [13]. A significant body of research assesses the role of green bonds in both the energy transition and the reduction of carbon emissions, showing that their expansion produces measurable effects on investments in green infrastructure [16]. Furthermore, cross-country analysis shows that climate performance is correlated with the development of green bond markets, especially in emerging economies and European countries with ambitious decarbonization goals [20]. In parallel, fiscal instruments, such as environmental taxes, are recognized as effective mechanisms for

reducing negative externalities and accelerating the transition to low-emission production models [18]. Research confirms that environmental taxes, when applied consistently, stimulate the adoption of clean technologies and improve the energy performance of economies [4, 7].

Another analytical pillar is renewable energy, whose effects on economic sustainability and competitiveness are intensively documented. The specialized literature shows that investments in clean energy determine both emission reductions and increases in productivity and technological innovation [19]. Also, the strong correlation between the expansion of renewable capacities and the improvement of environmental indicators is confirmed in numerous panel studies applied to advanced economies [25]. Economic performance - SDG 8 - is, in turn, closely linked to the green transition, both through the impact on employment and through the structural transformations associated with the circular economy [6].

Methodologically, the literature provides research using panel models to analyze the relationships between green policies, economic growth and sustainability [1]. Fixed and random effects models are commonly used to assess variation over time and across countries, while comparative studies recommend rigorous selection of the appropriate model through the Hausman test [15]. In parallel, there is a strong trend towards integrating composite indicators in the analysis of green policies, as they better capture the complexity of the ecological transition and reduce collinearity problems [22]. Principal component analysis – PCA – is used extensively in the construction of synthetic indices that aggregate financial, fiscal and energy variables into a single integrated measure of the intensity of green policies [21].

At the same time, the relationship between sustainability - SDG 12 - and climate policies is widely documented, with emphasis on the importance of integrated approaches, combining green finance, fiscal regulations and technological innovation [23]. Recent studies show that the sustainability of consumption and production depends directly on the quality of institutions, the coherence of green policies and the pace of structural reforms [17]. In the European context, these mechanisms are amplified by binding climate policies and the strategic framework of the European Green Deal, which gives Member States a convergent but heterogeneous dynamic in terms of implementing transition measures [3].

Given these theoretical directions and case studies, this research falls into the category of those that evaluate the effects of green policies on economic and environmental sustainability, contributing by building a composite index of green policies and by applying panel econometric models that allow for an in-depth examination of the relationships between green investments, economic dynamics and energy transition.

In this context, the objectives of this research are: analyzing the evolution of green policies and the sustainability of consumption and production in EU countries during the period 2015–2023; building a composite index of green policies, in order to capture the coherence and intensity of public measures; empirically assessing the impact of this index on sustainability, through panel econometric models; comparing methodological specifications for selecting the appropriate model; formulating policy recommendations for strengthening the ecological transition in a European context.

MATERIALS AND METHODS

The research uses a panel data set for the EU Member States, for the period 2015–2023, including variables relevant for the assessment of green policies and their effects on sustainable consumption and production - SDG 12.

The analysis combines descriptive methods, the construction of a composite index and panel econometric models, so as to capture both developments over time and structural differences between countries. The approach starts from the hypothesis that green policies produce cumulative and interdependent

effects, difficult to capture through isolated indicators; consequently, a synthetic index is constructed through the analysis of principal components, which aggregates in a single measure the intensity and coherence of green policies.

The dependent variable is SDG 12, and the explanatory variables include the composite index of green policies - PC1, economic performance - SDG 8, environmental taxes, green finance and energy progress - SDG 7. The PC1 index is obtained by applying principal components analysis to the standardized variables, resulting in a linear combination of the form:

$$PC1 = \alpha_1 z_1 + \alpha_2 z_2 + \alpha_3 z_3, \quad (1)$$

where:

-z_1, z_2 and z_3 - are the variables of the composite index

-coefficients α_i - maximize the variance of the principal component.

This composite indicator captures the common structure of green policies and eliminates collinearity between variables.

The impact of green policies on sustainability is analyzed through a linear panel model:

$$SDG12_{it} = \beta_0 + \beta_1 PC1_{it} + \beta_2 SDG8_{it} + \beta_3 Taxes_{it} + \beta_4 GBonds_{it} + \beta_5 SDG7_{it} + u_{it} \quad (2)$$

where:

-ß$_0$..... ß$_5$ are regression coefficients

- u_{it} includes country-specific effects and idiosyncratic variation.

To control for unmeasured structural differences across countries, the fixed-effects model was applied:

$$SDG12_{it} = \beta X_{it} + \mu_i + \varepsilon_{it}, \quad (3)$$

which eliminates fixed effects by de-mean transformation.

In parallel, the random effects model was estimated, using quasi-demeaning transformation, to assess the consistency of the estimates in the scenario where country characteristics are uncorrelated with the explanatory variables. The choice between models was made using the Hausman test:

$$H = (b_{FE} - b_{RE})'[Var(b_{FE}) - Var(b_{RE})]^{-1} \cdot (b_{FE} - b_{RE}) \quad (4)$$

b_{FE} - vector of estimated coefficients in the fixed effects model;

b_{RE} - vector of coefficients of the random effects model;

$Var(b_{FE})$ - the variance–covariance matrix of the FE coefficients, which reflects the uncertainty of the FE estimates;

$Var(b_{RE})$ - variance–covariance matrix of RE coefficients;

$(b_{FE} - b_{RE})$ - the difference between the estimates of the two models;

$[Var(b_{FE}) - Var(b_{RE})]^{-1}$ - inverse of the difference of variance–covariance matrices.

RESULTS AND DISCUSSIONS

The analysis carried out in this research is based on a case study applied to the EU Member States, for the period 2015–2023, which tracks how green policies are reflected in progress on sustainable consumption and production. The dataset used includes representative indicators for green finance, fiscal instruments, energy performance and economic dynamics, integrated in a common analytical framework. By constructing a composite index of green policies and applying panel econometric models, the analysis highlights that sustainability depends not only on the intensity of individual measures, but also on the coherence with which they evolve over time. The main results are presented below, structured to highlight both the variations between countries and the relationships identified between the components of green policies and sustainability performance. Their interpretation allows for a clearer understanding of how the EU is progressing towards the ecological transition and the factors influencing the pace of these transformations.

Table 1. E.U. green and sustainability policy indicators in 2015

Country	**Green Bonds** (Million EUR)	**Environmental Taxes** (Million EUR)	**Renewable energy** (SDG7) (%)	**Economic performance** (SDG8 score)	**Sustainable production and consumption** (SDG12 score)
Austria	0	9,035.19	9.19	0.3	11.2
Belgium	0	10,594.1	6.46	0.9	18
Bulgaria	0	2,643.75	2.18	4.7	3.1
Croatia	0	1,930.16	5.36	3.4	4.6
Cyprus	0	603.29	7.04	3.2	2.4
Czechia	0	94,858	4.11	4.9	6.9
Denmark	0.359	80,900.8	14.34	1.4	8.3
Estonia	8.065	629.38	3.43	2	11.4
Finland	0	6,118	5.7	0.1	5.2
France	1.918	47,101	8.04	0.6	19.1
Germany	0.246	80,837	8.87	0.9	11.7
Greece	0	7,401	7.02	0.4	1.8
Hungary	0	864,209	4.38	4	5.7
Iceland	*	49,289.72	2.02	*	*
Ireland	0	4,977.25	16.48	23.5	2.1
Italy	0	59,533	9.92	1	16.7
Latvia	6.835	863.72	4.54	4.7	5.3
Liechtenstein	*	39.32	*	*	*
Lithuania	0	708.87	4.7	3.8	4.1
Luxembourg	0	954.44	11.29	0.3	9.6
Malta	0	266.33	3.94	7	4.6
Netherlands	1.333	25,555	7.6	1.7	27.4
Norway	*	73,111	13.27	*	*
Poland	0	47,706	4.39	4.5	11.9
Portugal	0	4,331.22	7.09	2	2.1
Romania	0	17,424.9	4.61	3.6	1.7
Slovakia	0	1,997.56	4.62	5.1	5
Slovenia	0	1,694.15	5.6	2.3	8.6
Spain	0	20,868	8.3	4.2	7.6
Sweden	0.731	91,638	8.46	3.3	6.7
Switzerland	*	9,060.16	*	*	*

Source: own processing, Eurostat [8, 9, 10, 11,12].

The analysis used annual data for the period 2015–2023, covering indicators that refer to green policies and sustainability performance in the Member States of the European Union. Table 1 and Table 2 present the values of the indicators for the years 2015 and 2023, which mark the beginning and, respectively, the end of the analyzed interval and which allow highlighting the positioning of the Member States in two benchmark years.

The data on green bonds reflect the intensification of financial instruments intended to finance the ecological transition, capturing both the maturation of the capital market oriented towards the environment and the increasing involvement of European governments and institutions in the mobilization of green resources. In a complementary way, environmental taxes capture the fiscal components of climate

policies, highlighting how Member States use taxation to discourage polluting activities and generate resources for sustainable investments. The associated indicator SDG 7 captures progress in the energy transition by measuring the share of renewable energy and energy efficiency. It reflects technological and structural changes in the energy mix at EU level, being a key element of decarbonisation. In turn, the SDG 8 indicator integrates the economic dimension, capturing labor market performance and economic activity dynamics, aspects that influence the ability of states to support consistent investments in green transition measures.

Table 2. E.U. green and sustainability policy indicators in 2023

Country	**Green Bonds** (Million EUR)	**Environmental Taxes** (Million EUR)	**Renewable energy (SDG7)** (%)	**Sustainable production and consumption** (SDG12 score)
Austria	15.087	9,533.28	10.93	14.2
Belgium	7.741	13,820.15	7.84	21.8
Bulgaria	0	6,212.14	2.94	4.9
Croatia	5.86	2,575.87	6.68	6.1
Cyprus	0	661.05	9.48	5.4
Czechia	0	118,998	5.23	13.6
Denmark	16.627	57,496.1	18.81	9.3
Estonia	0	995.14	4.64	20.5
Finland	16.047	6,182	6.1	2.6
France	3.739	49,859	10.23	16.9
Germany	6.472	71,407	11.84	14.5
Greece	0	9,257	8.94	5.2
Hungary	7.372	1,622.8	5.69	6.8
Iceland	*	78,098.04	*	*
Ireland	13.138	4,909.09	26.16	2.1
Italy	6.248	54,224	11.8	21.1
Latvia	2.075	949.88	5.66	6
Lithuania	0	1,188.66	6.02	4.1
Luxembourg	0.713	1,016.39	15.08	10.1
Malta	0.683	315.55	4.52	19.5
Netherlands	14.281	29,983	10.46	32
Norway	*	74,494	*	*
Poland	6.176	87,121	5.69	7.8
Portugal	13.189	5,378.36	8.98	3
Romania	2.943	36,082	6.35	1.5
Slovakia	5.435	2,456.04	5.48	10.6
Slovenia	11.601	1,791.44	7.72	9.9
Spain	5.145	24,640	9.94	8.2
Sweden	16.172	124,617	10.07	10.1
Switzerland	*	9,554.77	*	*

Source: own processing, Eurostat, [8, 9, 10, 11, 12].

Economic indicators - SDG 8 - demonstrate that economic performance plays an ambivalent role in the green transition. On the one hand, strong economies have the resources to invest heavily in sustainable infrastructure; on the other hand, high consumption rates can amplify environmental pressures. The data show that some developed economies have

progressed, but not always in proportion to their economic capacity, which indicates the critical role of well-targeted public policies.

Although SDG 12 most accurately expresses the performance of green policies, the indicator is reported biannually, so the latest data available based on Eurostat are those for 2022. During the period under review, there was an increase in performance in most EU countries, indicating an improvement in resource circularity, industrial process efficiency and consumer behaviour. However, the differences remain considerable. Northern EU villages consistently rank at the top of the distribution, while those in south-eastern Europe register lower values, reflecting differences in the level of environmental education, infrastructure, administrative capacity and the availability of support policies.

It is thus found that the EU has registered a moderate convergence in terms of green policies, but not in sustainability performance. Although financial policies, especially green bonds, and fiscal instruments have produced positive effects, these tend to manifest themselves with different intensity depending on the level of economic development of the states. The aggregate impact of green policies is visible in the increase in SDG12 values, but the uneven evolution shows that the sustainable transition remains an uneven process, conditioned by institutional factors and the level of maturity of European economies.

Table 3. Statistical characteristics of the indicators analyzed in the period 2015–2023

	Green Bonds (Million EUR)	**Environmental Taxes** (Million EUR)	**Renewable energy** (SDG7) (%)	**Economic performance** (SDG8 score)	**Sustainable production and consumption** (SDG12 score)
Count	270	277	258	189	270
Mean	3.242222	62042.92	7.738721	2.627513	9.502222
Std	5.249662	195412.6	4.165107	4.217187	6.687924
min	0	37.96	2.02	-11.4	1.3
25%	0	1819.75	4.81	1	4.625
50%	0.4325	9469.47	6.86	2.7	7.85
75%	5.11475	57496.1	9.415	4.8	12.075
max	32.423	1622822	27.19	23.5	32.7

Source: own processing, Eurostat, [8, 9, 10, 11, 12]

The data in Table 3 highlight significant differences between the indicators used, reflecting the diversity of mechanisms through which the Member States of the European Union implement green policies in the period 2015–2023. The distribution of green bonds indicates a relatively concentrated market, characterized by low values in most countries and very high levels in a few advanced economies, a dispersion that demonstrates the existence of unequal financial and institutional capacities, as well as different paces of integration of green finance into national strategies. Environmental taxes also show high variability, reflecting structural differences between European economies in terms of the size of tax bases and the architecture of tax systems. The relatively low central levels indicate that, in many countries, environmental taxation is not yet used to its potential as a tool to guide consumption and production behaviors.

The SDG 7 indicator demonstrates a gradual evolution of the energy transition at EU level, its distribution highlighting constant progress in the adoption of renewable energies and in improving energy efficiency, even if the pace remains different from one country to another. In contrast, the associated SDG 8 indicator, which has a significant dispersion, includes situations of economic contraction, highlighting the period of economic volatility

experienced by some countries with implications for labor market performance. For SDG 12, the distribution of values shows considerable differences between countries in terms of sustainable consumption and production, confirming that the transition to sustainable models depends largely on the institutional capacity, the level of economic development and the maturity of public policies in each Member State.

Table 4. Correlation matrix between green policy indicators and sustainability

	Green Bonds	Environmental Taxes	Renewable energy (SDG7)	Economic performance (SDG8)	Sustainable consumption and production (SDG12)
Green bonds	1	0.0851	0.2294	0.0207	0.1391
Environmental taxes	0.0851	1	-0.0975	0.0287	-0.0647
Renewable energy (SDG7)	0.2294	-0.0975	1	0.0266	0.0254
Economic performance (SDG8)	0.0207	0.0287	0.0266	1	-0.2054
Sustainable consumption and production (SDG12)	0.1391	-0.0647	0.0254	-0.2054	1

Source: own processing, Eurostat, [8, 9, 10, 11, 12].

The low level of correlations between green bonds and other variables shows that green finance evolves relatively independently of fiscal instruments and economic dynamics, which confirms its emerging nature and the different degree of adoption among Member States. The slightly negative correlation between environmental taxes and other indicators demonstrates that the intensification of green taxation is not directly associated with superior energy or sustainability performance, reflecting the complex nature of these instruments, which generate long-term effects and can have a differentiated impact depending on the economic structure of each state.

The indicator related to SDG 7 has weak relationships with the other indicators, which indicates that progress in the energy transition is influenced to a greater extent by structural factors and dedicated policies, more than by green finance or green taxation. Also, the negative relationship between SDG 8 and SDG 12 shows that economic developments do not automatically translate into increased sustainability of consumption and production, confirming the existence of a conflict between economic dynamics and environmental performance (Table 4).

The weak and heterogeneous relationships between the analyzed indicators show that each of them captures different dimensions of green policies and sustainability, without directly reflecting a common structure. In this context, we proposed the use of a composite indicator that we considered necessary to measure the overall intensity of green policies at the level of the Member States. By applying a principal components analysis, we believe that we can synthesize the information contained in the financial, fiscal and energy variables into a single index, which will subsequently be used in econometric models to assess the impact of green policies on the sustainability of consumption and production in the E.U.

The principal component extracted through PCA measures the common structure of the three indicators used to measure the intensity of green policies — green finance, environmental taxes and energy progress - SDG 7.

The principal component extracted through PCA highlights the structural link between the different green policy mechanisms used in the European Union.

Table 5. Principal component structure for green policy indicators

Indicator	Value
Green bonds	0.689
Environmental taxes	-0.077
SDG 7 – Renewable energy	0.721
Energy efficiency	0.41

Source: own processing, Eurostat, [8, 9, 10, 11, 12].

The associated weights indicate that green finance and energy progress are the dominant forces shaping this component, showing that investments oriented towards the ecological transition and the expansion of renewable energies are the main drivers of the dynamics of green policies in the analyzed period.

The reduced contribution of environmental taxes shows that these fiscal instruments, although conceptually important, have evolved at a less synchronized pace with the investment and technological dimension of the green transition.

From a causal perspective, the structure of the component demonstrates that countries that issue more green bonds and advance in the energy transition tend to exhibit more robust green policies overall.

The combined effect of these two dimensions generates a coherent profile of policies oriented towards sustainability, while variations in environmental taxation do not contribute significantly to this common direction (Table 5).

The distribution of average scores of the Green Policy Index highlights the existence of distinct profiles among EU Member States. Countries such as Sweden, Denmark, Finland, Germany and the Netherlands consistently rank among the countries with high index values, reflecting the fact that they have effectively combined green financial instruments with technological advancement and rapid progress in the energy transition, as a result of the existence of solid administrative capacity, institutional stability, developed financial markets and the consistent prioritization of the ecological transition in public policies.

At the opposite end, countries such as Romania, Bulgaria, Croatia, Slovakia and Hungary are in the group with low scores, due to the slower pace of adoption and implementation of green policies, which are the consequence of structural constraints such as greater dependence on conventional energy sources, variable administrative capacity, low level of green investments or a weaker integration of financial mechanisms dedicated to the climate transition. (Table 6).

Table 6. Average score of the Green Policy Index - PC1 in the period 2015–2023, by country

Country	PC1 2015-2023
Austria	0.4597
Belgium	0.3388
Bulgaria	-1.3547
Croatia	-0.6507
Cyprus	-0.3557
Czechia	-1.0210
Denmark	1.8644
Estonia	-0.9924
Finland	-0.0061
France	0.3896
Germany	0.5336
Greece	-0.2224
Hungary	-0.7480
Ireland	2.4652
Italy	0.3839
Latvia	-0.4560
Lithuania	-0.2036
Luxembourg	0.6778
Malta	-1.0597
Netherlands	0.6074
Poland	-0.5015
Portugal	0.3328
Romania	-0.7612
Slovakia	-0.4820
Slovenia	-0.4449
Spain	0.2311
Sweden	0.9754

Source: own processing, Eurostat, [8, 9, 10, 11, 12].

The cumulative effect is the persistence of gaps between the countries in north-west Europe and those in south-east or the centre of the continent, gaps that may affect the coherence of the European effort as a whole. This heterogeneity generates direct implications for European public policy. Without additional support instruments, the differences in pace risk deepening, diminishing the EU's ability to

advance uniformly towards climate objectives, the consequences including disproportionate pressure on high-performing countries and difficulties in implementing common frameworks. In this context, it is necessary to intensify funding programs directed at low-scoring countries, expand technology transfer mechanisms and create instruments for minimal harmonisation of green policies at European level. This can facilitate the reduction of discrepancies and the consolidation of more balanced progress among Member States.

The index obtained through the PCA thus becomes not only a descriptive tool, but also a strategic benchmark, highlighting both convergences and structural vulnerabilities, providing the necessary basis for formulating differentiated policies, adapted to the needs of each European economy.

After highlighting the variations between countries, we considered that the next step should be to assess how this index influences performance in sustainable consumption and production. Integrating the index into panel econometric models allows the investigation of a dynamic and controlled relationship between green policies and the results obtained in the field of sustainability, providing a more precise estimate of the structural effects of the policies implemented.

Table 7. Relationship between variables in the fixed effects model regarding the impact of green policies on sustainability

	Coef.	Std. Err.	t	P>|t|	[0.025	0.975]
Const	0.00000	0.10791	0.00000	1.00000	-0.21284	0.21284
PC1	0.05342	0.02734	1.95374	0.05219	-0.00051	0.10736
Economic Performance (SDG8)	-0.01534	0.02879	-0.53269	0.59487	-0.07212	0.04145
Environmental Taxes	-0.00001	0.00001	-0.85440	0.39395	-0.00002	0.00001
Green bonds	0.01455	0.03034	0.47965	0.63202	-0.04529	0.07440
Renewable energy (SDG7)	0.25712	0.14132	1.81939	0.07042	-0.02163	0.53587

Source: own processing, Eurostat, [8, 9, 10, 11, 12].

The results of the fixed-effects model in Table 7 show that the green policy index, synthesized through PCA, has a positive influence on the sustainability of consumption and production, which shows that the intensification of green financing measures and technological progress in the energy transition contribute to improving performance in terms of resource efficiency and reducing environmental impact. Although the estimated effect is moderate, its direction confirms that the strategic orientation of green policies produces tangible results at the level of SDG 12.

Individual variables such as green financing, environmental taxes and economic dynamics do not have significant effects when analyzed simultaneously with the synthetic index, which shows that their influence on sustainability is diffuse and dependent on complex interactions, which are not strongly manifested when isolated.

Energy progress has a positive, albeit small, effect on sustainable consumption and production performance, confirming that investments in clean energy and energy efficiency lead to structural improvements in sustainability. However, the impact of this indicator becomes particularly visible in combination with other green policy mechanisms, which reinforces the idea that the sustainable transition is an integrated process that requires complementary actions.

The model highlights the fact that it is not individual instruments that produce major changes, but the coherence and overall intensity of green policies. Thus, it results that fragmented efforts, focused on isolated measures, tend to have limited impact, while integrated policy packages - financial, fiscal and technological - generate effects on sustainability. Therefore, strengthening the institutional framework and coordinating public policies become essential conditions for

accelerating progress towards SDG 12 objectives in the E.U.

Table 8. Relationship between variables in the random effects model regarding green policies on sustainability

	Coef.	Std.Err.	t	P>|t|	[0.025	0.975]
Const	0.35311	0.12081	2.92278	0.00389	0.11481	0.59141
PC1	0.02537	0.03158	0.80357	0.42264	-0.03691	0.08765
Economic Performance (SDG8)	-0.01631	0.02932	-0.55634	0.57863	-0.07413	0.04151
Environmental Taxes	0.00000	0.00001	-0.75512	0.45111	-0.00002	0.00001
Green bonds	0.01868	0.03096	0.60328	0.54704	-0.04239	0.07975
Renewable energy (SDG7)	0.24917	0.13959	1.78498	0.07585	-0.02617	0.52450

Source: own processing, Eurostat, [8, 9, 10, 11, 12].

The results of the random effects model show that the relationships between green policies, economic dynamics and sustainability are largely influenced by structural variations between EU Member States (Table 8). The coefficients demonstrate that none of the analyzed indicators exerts a major statistical effect on the performance regarding sustainable consumption and production when the variation between countries is integrated into the model. This situation reflects the fact that the differences in context - institutional, economic, energy - remain dominant and attenuate the direct influence of green policies on sustainability at the aggregate level.

The green policies index - PC1 - shows a positive, but insignificant effect, as a result of the fact that the intensity of green policies, although oriented towards the ecological transition, does not generate uniform effects across countries when their structural characteristics are taken into account. Similarly, green finance, environmental taxes and economic performance do not distinguish major effects, due to the different level of development, energy structure and strategic priorities of the Member States. The only indicator with a visibly positive trend is the progress in renewable energy, which approaches statistical significance and demonstrates that investments in clean energy can contribute to sustainability, but this effect is not uniform across all the countries analyzed. Thus, we find that the variations between countries are strong enough to dilute the direct effects of green policies on sustainability, the consequence being that green policies, in order to produce tangible results, require adaptation to the particularities of each economy and a closer integration with national economic and energy strategies. This leads to the need for differentiated interventions and a flexible European framework, capable of supporting convergence towards sustainability objectives, despite the structural diversity of the Member States.

The Hausman test was then applied, in order to determine the appropriate econometric model for the analysis of panel data. The test could not generate a valid statistic, since the differences between the coefficients of the two models are extremely small, which leads to almost identical variance-covariance matrices and makes it impossible to calculate the Hausman statistic stably. As a result, the fixed-effects model was selected as the main model of the analysis.

Thus, the analysis carried out highlights the fact that the intensification of green policies contributes to the consolidation of the sustainability of consumption and production in the Member States of the European Union, but this effect becomes visible only when the policies are viewed in an integrated structure. The results of the fixed-effects model show that the internal developments of each country largely explain the variation in sustainability, which confirms that institutional, financial and energy transformations must be analyzed in their temporal dynamics, not in a static comparison between countries. In this framework, the green policy index represents an analytical tool superior to individual variables, capturing the coherence and

continuity of public measures, essential elements for the advance towards a sustainable economic model. The persistent heterogeneity between countries demonstrates that the ecological transition does not evolve uniformly in the European space, and green policies generate differentiated effects depending on the economic capacity, energy structure and the stability of the institutional framework. This results in the need for interventions adapted to the profile of each country, as well as the importance of maintaining a constant pace of green investments and institutional reforms to accelerate progress towards the sustainability objectives.

CONCLUSIONS

The research highlighted that the transition towards sustainability in the European Union depends on the coherence and continuity of green policies, as well as on the capacity of states to integrate financial, fiscal and energy instruments into a unified strategic framework. The quantitative analysis showed that the internal dynamics of each economy are essential for progress in sustainable consumption and production, confirming that developments over time are more relevant than structural differences between countries, underlining that the ecological transition is not determined by isolated measures, but by the set of policy directions and the way in which they are supported by stable institutions and adequate financial mechanisms.

Thus, the need to strengthen an integrated approach is observed, in which green policies are seen as part of a profound economic transformation. Although the pace of the transition differs across Member States, the general direction is clear: economies that simultaneously develop green investments, modern energy infrastructure and advanced administrative capacity increase their resilience and move faster towards sustainability. The results obtained demonstrate that the ecological transition cannot be decoupled from the economic and institutional context, but must be supported by reforms that strengthen the capacity of states to absorb and implement complex policies.

As a result of the results obtained, we consider that:

Member States need financial mechanisms adapted to their level of development, which facilitate access to capital for projects with an impact on sustainability. The expansion of green bonds, the creation of joint investment platforms and the development of public-private partnerships can accelerate the economic transformation;

The transition to renewable sources must be accompanied by the modernization of infrastructure, the diversification of the energy mix and the improvement of the efficiency in the use of resources. These actions generate positive effects on both the environment and economic competitiveness;

The structural heterogeneity of the Member States requires differentiated solutions. A uniform approach cannot reduce the existing gaps. It is necessary to make European instruments more flexible and to orient them towards the real needs of the states with a slower pace of transition;

The effective implementation of green policies depends on the stability and professionalization of public institutions. Investments in administrative skills, digitalization and planning capacity become essential for long-term success;

Green policies must be part of macroeconomic decisions, not stand-alone measures. Linking sustainability to competitiveness, employment and innovation provides a solid basis for the transition to a circular economy;

The results obtained underline the importance of composite indicators, such as the Green Policy Index, that capture the integrated dynamics of the ecological transition. The expansion of these instruments can support a more accurate assessment of progress over time;

This research confirms that the transition to sustainability is a structural process that goes beyond the logic of one-off interventions and depends on the quality of governance, the mobilisation of capital and the consistency of public policies. Although the challenges differ

between countries, the common direction is clear: only through integrated green policies, adapted to the national context and supported by strong institutions, can the E.U. move towards a sustainable, balanced and resilient development model.

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ANALYSIS OF THE SUSTAINABLE DEVELOPMENT OF THE PIG SECTOR IN ROMANIA AND THE EUROPEAN UNION BASED ON STRUCTURAL AND ENVIRONMENTAL INDICATORS

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Abstract

This research analyzes the evolution and level of sustainability of the pig sector in Romania compared to the European Union, by integrating the structural and ecological dimensions of the livestock activity. The research is based on a descriptive-comparative statistical approach, using official data from Eurostat sources for the period 2016–2024. The total pig population and the main animal categories were analyzed, along with ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) emissions, considered essential indicators for assessing the ecological pressure of production. Based on this information, derived indicators were calculated – the rate of variation of the population, the intensity of emissions related to the population and the ratio between greenhouse gas emissions and ammonia – in order to capture the dynamics of structural and environmental sustainability. The results show a clear difference between Romania and the European Union average in terms of the pace of adaptation to sustainability objectives. The European Union has recorded a moderate but controlled reduction in livestock numbers, accompanied by a steady decrease in specific emissions, which indicates a technological and ecological efficiency of production. In contrast, Romania has experienced a sharp decline in livestock numbers, accompanied by a higher emission intensity, caused by the predominance of traditional farms and the slow adoption of modern manure management technologies. The climate report confirms that, in Romania, local pollution continues to dominate the contribution to the greenhouse effect, while the European Union is moving towards a balance between local and global impacts. The analysis highlights that the transition to sustainability in the pig sector does not depend exclusively on reducing livestock numbers, but on the capacity for technological modernization and integration of circular economy principles. Romania is on a convergent trajectory with European trends, but maintaining this direction requires strategically oriented investments, the consolidation of commercial farms and the development of ecological infrastructure. Research demonstrates that the sustainability of the pig sector can only be achieved by balancing economic, social and environmental dimensions, within an agricultural policy that favors innovation and ecological responsibility.

Key words: *sustainable development; swine; performance; integration; European Union, Romania*

INTRODUCTION

Contemporary agriculture is undergoing a profound structural transformation, driven by the combined pressure of food security requirements, the need to protect the environment and the objectives of reducing greenhouse gas emissions. In this context, the sustainable development of European agriculture requires reconciling the three fundamental dimensions – economic, social and ecological – by adopting practices capable of ensuring stable production, fair incomes for farmers and a minimal impact on natural resources [13]. The pig sector occupies a central place in this process, being one of the most important branches of European livestock, with a significant contribution to total meat production and to the balance of the agri-food balance [13, 17]. At the same time, it is responsible for a considerable part of agricultural ammonia and methane emissions, and the sustainable management of this sector is one of the strategic priorities of the European

Union within the framework of the European Green Deal and the "Farm to Fork" Strategy [4].

Recent research highlights that pig production is in a precarious balance between economic performance and environmental impact [7, 12, 18]. The European Environment Agency report shows that agriculture is the main source of ammonia emissions and one of the major sources of methane at European level, and pig farms contribute significantly to these values [14]. Also, the specialized literature highlights that the main environmental "hot-spots" of the production chain are feed production and manure management [15, 21]. Thus, measuring and monitoring emissions become essential tools for understanding and controlling the environmental impact of farms [2, 16]. At the same time, Eurostat reports and studies on the sustainability of pig farms confirm that the transition to sustainable practices cannot be achieved without a solid and comparable statistical basis between Member States [1, 5, 20].

At the European level, the Common Agricultural Policy encourages the integration of sustainability objectives in all branches of agricultural production. For the pig sector, this direction involves increasing the efficiency of resource use, reducing emissions, technological modernization of farms and adapting to animal welfare standards. Western countries, such as Denmark, the Netherlands or Spain, are considered models of successful transition to high-performance and sustainable pig farms, capable of combining high economic yields with compliance with environmental standards. On the other hand, other Member States are facing slower restructuring processes, driven by economic, structural or health factors. Romania falls into this category, with a significant tradition in pig farming, but also persistent challenges: fragmentation of holdings, high share of family farms, impact of epizootics and adaptation to European requirements [22]. Beyond these difficulties, the development potential of the pig sector remains high, and the analysis of its dynamics is a necessary step to substantiate the directions of modernization and sustainability [3, 19].

The need for this research stems from the strategic importance of the pig sector and the need to assess, on an objective basis, the degree of Romania's alignment with European sustainable development trends. Beyond perceptions of decline or stagnation in production, a rigorous assessment of structural and environmental indicators provides a realistic picture of the directions of evolution. At the same time, statistical analysis allows identifying the relationship between the evolution of livestock and the level of emissions, an essential relationship for defining environmental and agricultural policies. In the specialized literature, the concept of "sustainable agriculture" involves maintaining the balance between economic performance and ecological responsibility [11]. Applied to the pig sector, this concept translates into the efficiency of resource use, the reduction of nitrogen and carbon losses and the implementation of technologies for the valorization of manure in a circular system [6, 23]. In a Europe increasingly attentive to the impact of agri-food on the environment, such an analysis has both scientific and applied value: it can guide investments, agricultural policy priorities and farmers' adaptation strategies.

The general aim of this research is to analyze the sustainable development of the pig sector in Romania, in comparison with developments in the European Union, using structural indicators (animal numbers) and environmental indicators (ammonia emissions – NH_3, methane – CH_4 and nitrous oxide – N_2O). The research aims to highlight to what extent the transformations in the period 2016–2024 reflect Romania's convergence towards European standards and trends of agricultural sustainability.

The specific objectives are: analysis of the evolution of the total pig population and the main animal categories in Romania and the European Union; comparison of trends in Romania with the average and with the EU reference states, in order to identify structural differences and the degree of convergence;

evaluation of ammonia emissions (NH_3) as an indicator of local pollution generated by the management of pig manure; analysis of methane emissions (CH_4) and nitrous oxide (N_2O) as indicators of the sector's global climate impact; formulating conclusions regarding Romania's position in relation to the sustainability objectives established at EU level and identifying directions for improving the ecological performance of farms.

The proposed approach combines the structural perspective – which follows the dynamics of the livestock – with the ecological one – focused on specific emissions. The results obtained will provide an objective basis for interpreting recent trends in the pig sector and for assessing its sustainability. In the context of the European green transition, such analyses become indispensable tools for monitoring progress and guiding public policies.

MATERIALS AND METHODS

The methodology of this research aims to build a coherent framework for statistical analysis of the sustainable development of the pig sector in Romania, in the context of the European Union, by correlating the structural and ecological dimensions of agricultural activity. The study has a quantitative, descriptive and comparative nature, based exclusively on official statistical data provided by Eurostat, which represents the main harmonized and comparable source at European level. The period analyzed is 2016–2024, an interval for which the data series are complete and relevant in relation to the sustainability objectives assumed by the Common Agricultural Policy and the European Green Deal.

The analysis uses two main categories of indicators. The first category, structural indicators, describes the size and dynamics of the pig sector through: total livestock, piglet populations under 20 kg, breeding sows, pregnant sows and sows in sows. These indicators highlight the productive capacity, the degree of specialization and trends in concentration or reduction of livestock. The second category, ecological indicators, captures the impact on the environment through: ammonia emissions (NH_3), considered a local air pollutant, and methane (CH_4) and nitrous oxide (N_2O) emissions, reported in CO_2 equivalent and classified as greenhouse gases. The correlation of the two dimensions allows the assessment of the level of structural-ecological sustainability of the pig sector.

To interpret the developments, a series of derived indicators were calculated, intended to express the dynamics and ecological efficiency of the activity.

a) The rate of change in the number of animals (RVE_t) indicates the annual rate of increase or decrease in the total number of animals, according to the relationship:

$$RVE_t = \frac{E_t - E_{t-1}}{E_{t-1}} \times 100$$

where:

E_tr - total pig population in year *t*

E_{t-1}- the previous year's headcount.

Positive values indicate expansion, and negative values indicate decrease, providing a picture of the medium-term structural evolution.

b) The intensity of emissions per livestock (IE) reflects the ecological pressure of the sector, expressing the amount of gas emitted per unit of livestock:

$$IE = \frac{Gas_{emissions}}{Total_{livestock}} \times 1000$$

where:

IE- specific emission (tons of gas/ 1,000 pigs)

$Gas_{emissions}$- total emissions of the analyzed gas (NH_4, CH_3, or N_2O);

$Total_{livestock}$ - total number of pigs

The indicator allows for the comparison of ecological efficiency between countries and over time, illustrating how structural changes influence the level of emissions.

3) The ratio of greenhouse gas emissions to ammonia ($R_{climatic}$) provides an integrated perspective on the ecological impact:

$$R_{climatic} = \frac{CH_4 + N_2O}{NH_3}$$

where:

CH_4 and N_2O - methane and nitrous oxide emissions; NH_3 - ammonia emissions

The report shows the proportion of the contribution to global warming compared to

local pollution, illustrating the balance between the two dimensions of environmental impact.

The analysis uses annual values and rates of variation for each country and for the EU-27 average. Romania is analyzed in comparison with the Union average and with the main producing countries (Spain, Germany, Poland, Denmark and France). The methodological approach is a descriptive-comparative one, based on the calculation and interpretation of indicators in chronological series. The results will be presented synthetically in tables and graphs, and the interpretation will aim to identify the relationship between structural transformations and the ecological pressure of the sector. The methodology has the role of providing an integrated picture of the sustainability of the pig sector, based on objective and comparable statistical indicators at European level.

RESULTS AND DISCUSSIONS

Based on the methodology presented, the statistical data collected from Eurostat sources are analyzed, organized in the eight tables that capture the evolution of livestock and emissions related to the pig sector. The analysis aims to identify the structural dynamics of livestock, as well as trends regarding the ecological impact of the activity, through the calculated indicators.

Table 1. Evolution of total pig population in the European Union and Romania, 2016–2024 (Thousands heads)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
E.U. 27 countries (from 2020)	142,649.62	145,543.55	143,518.56	143,146.16	145,918.60	141,681.38	134,410.04	132,845.67	132,135.52
Belgium	6,176.58	6,108.08	6,209.13	6,085.10	6,218.27	6,042.15	5,751.18	5,380.02	5,375.20
Austria	2,792.80	2,820.08	2,776.57	2,773.23	2,806.46	2,785.59	2,650.15	2,516.46	2,534.44
Bulgaria	616.43	593.15	654.55	491.81	592.10	694.66	601.70	724.75	700.78
Croatia	1,163.00	1,121.00	1,049.00	1,022.00	1,033.00	972.00	945.00	853.00	873.00
Cyprus	352.61	350.16	362.05	351.76	359.06	360.59	330.87	309.76	309.79
Czechia	1,479.28	1,531.69	1,507.58	1,508.91	1,546.02	1,493.44	1,328.82	1,362.28	1,421.82
Denmark	12,281.00	12,832.00	12,642.00	12,728.00	13,391.00	13,152.00	11,541.00	11,368.00	11,583.00
Estonia	265.90	289.10	290.40	301.60	316.60	308.00	269.38	274.96	283.55
Finland	1,196.70	1,108.40	1,041.20	1,062.20	1,103.90	1,093.70	997.67	984.34	974.13
France	12,791.00	13,353.00	13,713.00	13,510.00	13,393.00	12,941.00	12,182.59	11,794.05	11,714.94
Germany	27,376.06	27,577.57	26,445.40	26,053.40	26,069.90	23,762.30	21,366.30	21,223.70	21,292.30
Greece	743.00	744.00	721.00	733.00	743.00	758.90	741.60	771.50	786.20
Hungary	2,907.00	2,870.00	2,872.00	2,634.00	2,850.00	2,725.90	2,558.10	2,607.70	2,802.40
Ireland	1,527.83	1,616.36	1,572.15	1,613.27	1,678.57	1,713.59	1,570.39	1,407.61	1,473.75
Italy	8,477.93	8,570.75	8,492.23	8,510.27	8,543.03	8,407.97	8,739.00	9,171.00	7,820.49
Latvia	336.39	320.56	304.90	314.20	306.82	327.02	307.95	289.98	300.06
Lithuania	663.90	611.90	572.00	550.80	580.40	573.80	517.42	497.09	496.79
Luxembourg	95.48	90.94	82.59	84.04	82.13	78.33	66.41	65.20	64.81
Malta	40.60	34.01	36.29	35.48	40.09	40.05	29.55	35.79	37.21
Netherlands	11,881.00	12,296.00	11,909.00	11,921.00	11,541.00	10,872.00	10,706.00	10,375.00	10,192.00
Poland	11,106.70	11,908.20	11,027.70	11,215.50	11,727.40	10,242.40	9,624.25	9,769.70	9,078.25
Portugal	2,151.16	2,165.31	2,205.05	2,255.87	2,259.18	2,221.02	2,183.32	2,181.04	2,192.68
Romania	4,707.70	4,406.00	3,925.30	3,834.10	3,784.50	3,619.60	3,328.70	3,154.10	3,257.50
Slovakia	585.84	614.38	627.02	589.23	538.31	453.08	380.90	403.04	412.31
Slovenia	265.74	257.24	259.13	240.14	229.48	215.71	202.15	196.14	232.35
Spain	29,231.60	29,971.36	30,804.10	31,246.04	32,796.07	34,454.09	34,073.38	33,803.04	34,565.28
Sweden	1,436.40	1,382.30	1,417.20	1,481.20	1,389.30	1,372.50	1,416.27	1,326.44	1,360.46
United Kingdom	4,538.00	4,713.00	4,648.00	4,741.00	:	:	:	:	:

Source: own processing, Eurostat, [8].

The analysis of the total pig herds in the European Union and Romania highlights the profound transformations that the European livestock sector is going through. The negative

dynamics of the herds is the result of a combination of economic, health, technological and environmental factors. At the European level, the decrease correlates with the increasingly strict application of animal welfare standards, with the pressures generated by production costs and with the reorientation of agricultural policies towards sustainability and emission reduction. Also, the liberalization of markets, the volatility of feed prices and health crises, such as African swine fever, have determined a concentration of production in large farms and a gradual reduction of small and medium-sized holdings. The structure of the sector has changed visibly, with large agricultural economies, such as Spain, Germany and Denmark, consolidating their leading positions through investments in modern technologies and rapid adaptation to European ecological standards. In these countries, productivity per head of animal has increased, partially offsetting the numerical decline in herds. The countries of Central and Eastern Europe, including Romania, have experienced a different dynamic, characterized by an accelerated process of herd reduction, caused by the restructuring of traditional farms, the fragmentation of agricultural land and the lack of capital for modernization. In the case of Romania, the decline is also the consequence of the difficulties of integration into European value chains, the high dependence on family farms and the severe impact of epizootics on pig populations.

Table 2. Evolution of piglet herds under 20 kg in the European Union and Romania, 2016–2024 (Thousands heads)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
E.U. 27 countries (from 2020)	39,982.44	41,262.55	40,308.04	41,508.88	41,914.37	41,608.30	39,511.94	40,567.58	39,994.85
Belgium	1,577.09	1,563.80	1,596.52	1,584.68	1,649.78	1,622.81	1,592.62	1,485.00	1,504.08
Austria	660.56	667.80	652.75	650.93	664.11	655.05	635.85	605.34	614.53
Bulgaria	121.16	133.23	152.47	91.86	131.01	155.15	125.02	163.92	176.14
Croatia	309.00	259.00	274.00	265.00	273.00	272.00	231.00	228.00	252.00
Cyprus	123.55	124.38	127.94	123.16	129.14	128.20	115.66	111.60	114.45
Czechia	414.94	476.96	465.71	483.39	481.93	468.31	417.18	376.74	398.64
Denmark	4,337.00	4,582.00	4,543.00	4,563.00	4,674.00	4,608.00	4,118.00	4,141.67	4,269.00
Estonia	85.00	98.40	104.70	111.40	103.40	104.10	92.89	98.37	93.44
Finland	342.30	312.40	273.30	272.40	299.70	338.50	301.65	303.56	299.20
France	3,122.00	3,259.00	3,350.00	4,982.00	4,933.00	4,731.00	4,417.27	4,331.65	4,316.45
Germany	7,998.23	8,071.20	7,671.60	7,673.80	7,708.80	6,991.10	6,368.00	6,410.70	6,326.30
Greece	195.00	204.00	204.00	196.00	224.30	192.30	186.20	183.80	202.20
Hungary	668.00	654.00	690.00	656.00	717.00	703.10	661.20	693.20	731.90
Ireland	426.24	449.92	436.87	451.63	426.93	482.59	418.75	363.02	386.25
Italy	1,375.03	1,385.18	1,407.23	1,411.60	1,424.32	1,384.06	1,688.00	1,680.00	1,879.34
Latvia	75.61	62.91	57.56	58.61	55.61	59.25	56.94	52.82	57.59
Lithuania	124.40	117.20	113.40	103.50	111.80	116.40	97.60	98.03	99.38
Luxembourg	11.54	18.41	17.20	16.77	16.78	12.08	9.38	9.12	7.77
Malta	10.00	8.30	8.59	7.38	10.00	9.88	7.06	9.02	9.46
Netherlands	4,986.00	5,522.00	5,287.00	5,002.00	4,872.00	4,773.00	4,444.00	4,498.00	4,600.00
Poland	2,789.80	2,723.20	2,278.90	2,288.20	2,376.80	2,145.20	1,891.41	2,006.74	1,780.29
Portugal	709.09	743.42	763.00	806.96	820.80	817.32	796.86	834.05	811.90
Romania	785.70	836.70	698.40	735.90	710.40	609.10	522.10	609.50	568.60
Slovakia	170.63	186.45	169.87	202.33	202.98	178.23	144.81	166.32	179.40
Slovenia	57.53	58.66	58.01	51.33	50.45	41.85	46.94	42.62	48.26
Spain	8,100.46	8,364.93	8,550.74	8,341.14	8,484.05	9,638.93	9,760.32	10,730.77	9,914.45
Sweden	406.60	379.10	355.30	377.90	362.30	370.80	365.24	334.04	353.84
United Kingdom	1,184.00	1,244.00	1,216.00	1,233.00	:	:	:	:	:

Source: own processing, Eurostat, [8].

The effects of these transformations are multiple. On the one hand, the reduction in herds has led to a decrease in direct pressure on the environment, but, on the other hand, it has affected the productive potential and competitiveness of the Romanian pig sector. Overall, the European picture indicates a transition from an extensive, volume-based

model to an intensive and technological one, oriented towards efficiency, traceability and reducing the ecological impact. Romania, although following the general trend of adaptation to sustainability objectives, remains in a stage of structural adjustment, with a slower pace of modernization. The analysis thus highlights that, during the analyzed period, the structural performance of the European pig sector has been qualitatively consolidated, while the quantitative dimension has been subject to a controlled contraction, a sign of its reconfiguration towards sustainability and economic efficiency.

The evolution of piglet herds under 20 kg faithfully reflects the structural transformations of the pig sector and its capacity for reproduction and regeneration. This category of animals constitutes the basis of the production cycle, and the variations recorded over time signal changes in the level of profitability, in the technological adaptation of farms and in the intensity of the reproductive processes. At the level of the European Union, the trends indicate a slight decrease in the medium term, associated with the process of restructuring and concentration of production in high-capacity units, oriented towards economic and ecological efficiency. In Western countries, piglet production has stabilized, thanks to the adoption of modern reproductive technologies, genetic control and improved welfare conditions, which has allowed for an increase in productivity per sow, even in the context of a reduction in total herds. On the other hand, in Central and Eastern European countries, including Romania, the evolution of piglets reflects an oscillating dynamic and a reduced regeneration potential. This trend is influenced by the structural fragmentation of farms, the lack of investment in reproductive technology, the difficulties related to ensuring high-performance genetic material and the increased sanitary-veterinary vulnerability. In Romania, the constant decline in the number of piglets is a signal of the limitation of the reproductive capacity at the level of small farms and the difficulty of reconstituting mature herds.

The lack of modern multiplication units and the dependence on piglet imports for fattening accentuate the structural imbalance and undermine the autonomy of the sector.

At the European level, the analysis indicates an increasingly clear polarization between countries with integrated systems, characterized by stability and efficiency in reproduction, and those in which the sector remains vulnerable.

The reduction of piglet herds does not necessarily imply a decrease in final production, but an increase in unit productivity through technology and genetic optimization.

There is a transition towards a more concentrated growth model, based on large and high-performance farms, with the role of family farms in ensuring the breeding base diminishing.

Romania, despite its resources and tradition, continues to face the challenge of stabilizing its young herds, an essential condition for the sustainable relaunch of the pig sector.

The evolution of breeding sow herds highlights a constant downward trend, which reflects the profound reconfiguration of the genetic and technological base of the pig sector.

The decrease in the number of animals intended for breeding does not mean a proportional decrease in the productive potential, but rather a paradigm shift, in which the emphasis has shifted from numerical to qualitative growth.

European farms have focused on genetic improvement, increasing reproductive efficiency and the use of biotechnology in the reproduction process, which has allowed piglet production to be maintained at stable levels, despite the reduction in sow herds.

This dynamic is influenced by the consolidation of large, vertically integrated farms, which have access to high-performance genetic material and reproductive management technologies.

In countries with developed animal husbandry – such as Spain, Denmark, the Netherlands or France – there has been clear progress in quality control and the standardization of breeding lots, while countries in Central and Eastern Europe continue to show structural

vulnerability, determined by the lack of resources and the delay in modernization processes.

In Romania, the reduction of breeding sows has complex causes: the loss of breeding farms, insufficient investment in genetic and technological infrastructure, as well as the direct impact of specific diseases, which led to massive culling and the reduction of the selection base.

The European trend shows a convergence towards a more efficient and sustainable model, in which the reproductive performance per sow compensates for the numerical decrease.

Smaller, but more productive, herds generate a more efficient use of resources and a decrease in the intensity of emissions reported to the production obtained.

For Romania, maintaining a performing nucleus of breeding sows is an essential condition for the recovery of the sector, by stabilizing the genetic base, increasing productivity and integrating into European sustainable production chains.

In conclusion, the data indicate a transition from extensive to selective, concentrated and technological reproduction, which redefines the balance between economic performance and environmental responsibility of the pig sector.

Table 3. Evolution of breeding sow herds in the European Union and Romania, 2016–2024 (Thousands heads)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
E.U. 27 countries (from 2020)	11,703.28	11,850.37	11,446.28	11,473.09	11,416.08	11,035.18	10,537.03	10,646.49	10,341.46
Belgium	423.43	416.04	406.35	399.20	398.98	389.42	367.77	353.59	344.77
Austria	240.76	243.69	232.71	234.19	230.58	228.00	211.99	207.00	204.57
Bulgaria	65.59	63.16	71.11	51.61	66.70	67.60	60.67	80.33	71.02
Croatia	123.00	128.00	125.00	128.00	113.00	107.00	87.00	87.00	92.00
Cyprus	32.92	33.64	34.25	33.19	32.82	31.45	27.18	26.66	25.53
Czechia	135.33	138.12	135.11	132.27	135.79	127.94	117.40	121.02	125.92
Denmark	1,247.00	1,270.00	1,254.00	1,254.00	1,286.00	1,245.00	1,128.00	1,142.00	1,169.00
Estonia	25.90	26.50	24.90	26.10	27.50	26.00	22.72	24.35	23.61
Finland	109.70	100.50	96.60	93.50	89.80	94.00	85.44	84.94	83.59
France	994.00	1,007.00	1,026.00	992.00	979.00	941.00	880.01	859.66	843.54
Germany	1,933.35	1,929.60	1,854.90	1,806.40	1,714.30	1,602.40	1,415.60	1,414.90	1,420.60
Greece	114.00	107.00	96.00	99.00	92.20	110.30	101.40	90.90	101.70
Hungary	258.00	254.00	261.00	234.00	246.00	243.00	230.00	233.50	250.50
Ireland	146.63	150.17	142.99	144.96	147.85	145.88	127.47	126.76	122.24
Italy	586.74	590.66	579.91	579.45	591.01	573.27	717.00	673.00	614.99
Latvia	38.39	36.24	33.06	34.89	35.18	40.12	36.41	36.65	37.22
Lithuania	49.50	49.70	45.60	42.90	45.70	44.70	39.81	39.92	39.84
Luxembourg	6.72	6.64	5.48	4.79	4.31	3.16	2.53	3.27	3.21
Malta	3.87	3.67	3.85	3.74	4.63	3.77	3.64	2.67	2.47
Netherlands	1,025.00	1,075.00	974.00	1,052.00	928.00	918.00	892.00	917.00	806.00
Poland	875.90	925.10	758.30	771.10	829.70	665.30	602.52	674.39	610.02
Portugal	238.12	241.43	241.12	242.49	235.92	234.47	229.74	225.02	226.46
Romania	367.30	356.40	316.60	315.50	323.60	306.30	289.10	276.90	319.20
Slovakia	51.42	58.05	54.08	54.60	51.19	37.84	37.38	35.60	40.31
Slovenia	20.13	21.31	19.35	17.30	16.35	14.69	13.85	13.44	15.72
Spain	2,448.40	2,485.75	2,529.42	2,603.82	2,666.49	2,712.47	2,690.31	2,789.75	2,636.58
Sweden	142.20	133.00	124.60	122.10	123.50	122.10	120.10	106.29	110.88
United Kingdom	505.00	503.00	502.00	502.00	:	:	:	:	:

Source: own processing, Eurostat, [8].

The evolution of pregnant sow herds reflects the complex adjustment processes that pig breeding is undergoing towards modernization and alignment with the principles of sustainability. The decreasing dynamics of the number of pregnant sows expresses a structural reconfiguration, determined by the efficiency of reproductive processes and the gradual transition to high-performance technological systems, in which productivity per animal

becomes a priority objective. At the level of the European Union, the reduction of pregnant sow herds did not generate a proportional decrease in piglet production, a sign that technological and genetic performance compensated for the decrease in the numerical base. In Western countries, continuous investments in genetics, nutrition and reproductive management led to an increase in fertility indices and piglet survival rates, which allowed maintaining stable production in a more restricted and controlled framework.

Table 4. Evolution of pregnant sow herds in the European Union and Romania, 2016–2024 (Thousands heads)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
E.U.27 countries (from 2020)	11,532.17	11,675.55	11,294.61	11,328.36	11,253.37	10,883.00	10,399.50	10,517.90	10,213.67
Belgium	419.56	413.25	403.35	396.49	395.31	386.34	364.87	349.66	342.17
Austria	236.36	239.21	228.71	230.22	226.84	224.08	208.32	203.54	201.37
Bulgaria	64.51	62.16	69.99	50.86	65.77	65.75	59.85	79.58	70.36
Croatia	120.00	125.00	122.00	125.00	110.00	104.00	85.00	85.00	90.00
Cyprus	32.61	33.16	33.81	32.73	32.40	31.02	26.93	26.28	25.22
Czechia	133.58	136.05	133.26	130.68	134.10	126.36	116.15	119.91	124.51
Denmark	1,236.00	1,260.00	1,243.00	1,244.00	1,273.00	1,235.00	1,118.00	1,133.00	1,159.00
Estonia	25.40	26.00	24.40	25.80	27.30	25.70	22.50	24.10	23.37
Finland	108.10	99.10	95.20	92.20	88.70	93.00	84.62	84.18	82.83
France	986.00	998.00	1,018.00	984.00	965.00	928.00	869.27	851.99	836.33
Germany	1,908.36	1,905.36	1,837.00	1,787.90	1,694.70	1,583.00	1,401.10	1,399.90	1,398.20
Greece	106.00	100.00	91.00	94.00	85.50	103.90	97.70	87.10	99.20
Hungary	255.00	250.00	258.00	231.00	243.00	240.70	227.30	231.60	248.30
Ireland	145.41	148.95	141.78	143.97	146.90	144.84	126.62	125.82	121.43
Italy	558.07	561.64	556.81	556.01	568.55	550.99	693.00	649.00	596.99
Latvia	37.76	35.49	32.64	34.45	34.74	39.69	36.04	36.31	36.91
Lithuania	48.80	49.10	45.10	42.50	45.30	44.30	39.37	39.54	39.53
Luxembourg	6.65	6.57	5.39	4.72	4.25	3.11	2.48	3.22	3.16
Malta	3.66	3.46	3.64	3.56	4.42	3.66	3.53	2.57	2.37
Netherlands	1,022.00	1,066.00	967.00	1,047.00	923.00	910.00	888.00	910.00	801.00
Poland	859.00	908.10	744.60	756.80	815.00	654.10	592.63	663.34	599.71
Portugal	233.25	235.64	236.06	237.28	230.91	229.58	224.81	220.61	221.50
Romania	361.20	349.90	308.80	309.00	315.70	298.90	284.50	272.60	314.50
Slovakia	50.71	57.14	52.80	53.86	49.99	37.20	35.60	35.13	39.90
Slovenia	19.23	20.47	18.65	16.55	15.65	14.18	13.36	13.03	15.20
Spain	2,415.17	2,454.33	2,500.52	2,576.99	2,635.25	2,684.91	2,659.39	2,766.09	2,611.25
Sweden	139.80	131.50	123.10	120.80	122.10	120.70	118.58	104.78	109.39
United Kingdom	490.00	490.00	490.00	490.00	:	:	:	:	:

Source: own processing, Eurostat, [8].

At the same time, European regulations on animal welfare and the minimum space allocated to pregnant sows have directly influenced the structure of the herds, leading to a reduction in density and an increase in production costs. In Central and Eastern European countries, the herds of pregnant sows have experienced wider fluctuations, amid economic and health vulnerabilities. Romania illustrates this oscillating evolution, marked by difficulties in rebuilding herds and a limited capacity to adapt to technological and biosecurity standards imposed at European level. The moderate decrease in the herds of pregnant sows can also be interpreted as a consequence of the transition to a controlled reproduction model, which emphasizes quality, not volume. This change favors the reduction of the ecological impact and the increase of the efficiency of resource use, integrating economic and environmental objectives. In the case of Romania, the consolidation of the reproductive segment remains an essential condition for the stability and restoration of the national pig potential. The general evolution thus indicates a stage of herd rationalization, in which the European pig sector optimizes its reproductive structure to ensure long-term sustainability, while Romania is still in the process of adjusting

towards a competitive and ecologically balanced model.

Table 5. Evolution of covered sow herds in the European Union and Romania, 2016–2024 (Thousands heads)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
E.U.27 countries (from 2020)	7,928.08	7,939.64	7,715.28	7,743.65	7,675.87	7,337.83	7,067.38	7,085.99	6,924.90
Belgium	345.58	340.15	331.17	328.08	325.58	314.42	299.80	287.08	278.87
Austria	167.94	170.48	161.29	161.73	162.27	157.97	146.53	144.53	139.67
Bulgaria	39.74	38.72	42.98	26.62	36.02	39.35	39.17	45.18	35.83
Croatia	39.00	39.00	39.00	44.00	47.00	38.00	33.00	37.00	38.00
Cyprus	27.90	28.56	28.22	27.54	27.27	26.42	22.78	22.89	22.62
Czechia	83.12	85.43	83.95	84.06	87.26	79.81	72.91	74.37	76.45
Denmark	765.00	786.00	775.00	785.00	787.00	777.00	698.00	704.00	719.00
Estonia	19.60	19.80	18.90	19.80	18.20	21.20	18.31	17.87	18.13
Finland	77.50	70.10	71.50	65.60	65.70	68.10	61.79	61.45	60.34
France	698.00	702.00	718.00	694.00	692.00	647.00	605.54	595.67	580.62
Germany	1,383.42	1,368.66	1,314.40	1,291.70	1,223.50	1,129.50	1,008.70	1,004.60	1,006.00
Greece	58.00	53.00	51.00	51.00	52.50	57.60	49.20	48.30	50.00
Hungary	169.00	163.00	166.00	148.00	166.00	155.90	151.00	158.40	167.80
Ireland	97.69	105.26	97.18	99.40	102.10	100.84	88.19	80.58	80.64
Italy	463.98	465.41	464.26	462.60	473.67	463.62	571.00	536.00	486.55
Latvia	16.95	15.32	15.47	14.82	16.26	15.19	14.01	13.83	13.69
Lithuania	40.60	38.50	35.90	34.80	36.50	35.50	30.76	31.47	31.18
Luxembourg	4.84	4.39	3.69	3.53	3.16	2.29	1.73	2.20	2.18
Malta	3.28	3.05	3.12	3.21	3.79	3.18	3.06	2.24	2.06
Netherlands	664.00	690.00	640.00	661.00	580.00	567.00	561.00	563.00	501.00
Poland	581.70	617.10	501.60	519.50	546.70	433.90	404.76	456.48	411.39
Portugal	161.81	160.92	163.37	164.06	157.55	157.37	152.31	148.70	149.71
Romania	223.10	219.50	188.00	198.80	197.80	183.00	173.70	169.00	178.80
Slovakia	19.81	29.47	32.65	31.35	33.29	16.89	20.11	19.65	20.44
Slovenia	11.07	12.17	10.60	9.34	9.36	8.06	8.02	7.87	9.38
Spain	1,667.24	1,623.26	1,676.73	1,732.01	1,740.09	1,758.63	1,752.73	1,782.61	1,770.18
Sweden	98.20	90.40	81.30	82.10	85.30	80.10	79.27	71.04	74.39
United Kingdom	346.00	346.00	340.00	345.00	:	:	:	:	:

Source: own processing, Eurostat, [8].

The evolution of sow herds confirms the process of structural optimization of the reproductive segment, specific to the transition to a sustainable zootechnical model. The gradual reduction of herds in most Member States does not reflect a decrease in reproductive capacity, but the streamlining of biological and technological processes. In Western countries, investments in genetics, reproductive management and welfare conditions have allowed piglet production to be maintained, while the number of sows has decreased. European regulations on housing space and comfort standards have contributed to the reduction of traditional farms and the concentration of production in large, technologically advanced units. At the same time, the use of high-quality semen and precise control of reproductive cycles have increased biological efficiency, reducing losses and unproductive growth. In Central and Eastern Europe, including Romania, structural adjustment has been more difficult, against the backdrop of investment deficit, high costs and epidemiological risks. In Romania, the decline in the number of sows in sow herds reflects the vulnerability of the breeding base, the lack of modern breeding centers and the dependence on imported genetic material.

The dynamics highlight a transition towards controlled breeding, oriented towards performance and sustainability. The decrease in the number of sows correlates with an increase in productivity and a reduction in ecological pressure, especially in countries that have integrated ecological resource management into the production strategy. For Romania, the restoration of the breeding segment by modernizing farms and improving genetic material remains an essential condition for the consolidation of the pig sector. At the European level, the general trend indicates the maturation of the breeding system, based on biological efficiency and ecological responsibility, defining elements of contemporary sustainable agriculture.

Table 6. Rate of variation of total pig herds in Romania and the European Union, during 2016–2024 (%)

Indicator	2016	2017	2018	2019	2020	2021	2022	2023	2024
UE-27 (%)	0	2.03	-1.39	-0.26	1.94	-2.9	-5.13	-1.17	-0.53
Romania (%)	0	-6.41	-10.9	-2.32	-1.3	-4.36	-8.04	-5.24	3.28

Source: own processing.

The evolution of the rate of change of pig herds indicates significant structural differences between Romania and the European Union average. While the EU-27 recorded a gradual but controlled reduction of herds, Romania went through a period of sharp contraction, followed by a slight recovery in the last year analyzed. The European dynamics reflect a strategic adjustment of the pig sector, based on the modernization of farms, the consolidation of high-performance farms and the application of environmental policies that limit extensive growth. In this context, the moderate decreases at the Union level are associated with an increase in productivity per unit of herd and a reduction in the ecological impact. In Romania, however, the persistent negative values of the rate of change betray a deeper structural vulnerability. The determining factors include the loss of small farms, epizootics, the low level of capitalization and the fragmentation of the production system. The absence of sustained investments in zootechnical infrastructure and in high-performance genetic material has limited the sector's capacity to recover. However, the slight increase in 2024 can be interpreted as a sign of stabilization, resulting from the consolidation of commercial farms and partial alignment with European trends. Thus, the RVE indicator shows that Romania remains in a stage of structural reconstruction, while the European Union has already entered a phase of sustainable optimization of pig production.

Table 7. Evolution of ammonia (NH_4) emissions from pig manure management in the EU and Romania, 2016–2023 (Tons)

Country	2016	2017	2018	2019	2020	2021	2022	2023
E.U. 27 countries (from 2020)	371,820	367,940	363,720	353,840	351,670	343,640	320,840	311,140
Belgium	14,360	14,020	13,710	13,330	13,310	12,950	11,540	10,480
Austria	6,460	6,480	6,410	6,420	6,520	6,550	6,260	6,010
Bulgaria	2,340	2,330	2,390	2,210	2,060	2,400	2,390	2,540
Croatia	5,140	5,000	4,680	4,720	4,290	4,020	3,830	3,480
Cyprus	1,120	1,100	1,130	1,080	1,110	1,100	1,000	940
Czechia	5,280	4,880	5,060	4,990	4,830	4,960	4,830	4,530
Denmark	14,700	14,690	14,940	14,080	14,530	13,920	12,640	10,560
Estonia	610	650	640	640	680	660	570	590
Finland	2,700	2,350	2,200	1,990	2,280	1,900	1,680	1,640
France	37,490	37,120	37,360	36,820	36,500	36,370	34,780	33,270
Germany	85,790	85,330	81,270	78,450	77,660	71,700	62,650	62,120
Greece	2,810	2,800	2,900	2,840	2,820	2,680	2,730	2,690
Hungary	8,480	7,890	7,890	7,600	7,600	7,520	7,030	6,660
Ireland	4,580	4,680	4,680	4,700	4,800	4,970	4,720	4,570
Italy	37,160	37,610	36,920	36,890	36,950	36,320	37,110	38,890
Latvia	980	920	860	900	860	920	850	800
Lithuania	2,410	2,260	2,100	1,980	1,990	2,040	1,930	1,790
Luxembourg	260	280	260	230	230	230	200	190
Malta	200	170	180	170	200	190	150	170
Netherlands	17,190	16,770	15,360	14,050	13,410	12,880	12,800	11,060
Norway	1,400	1,350	1,370	1,270	1,190	1,150	1,110	1,100
Poland	28,500	29,800	30,920	27,700	28,920	27,620	23,970	23,320
Portugal	6,060	6,090	6,040	6,060	6,100	6,050	6,000	5,900
Romania	19,640	18,340	16,530	16,420	16,210	15,970	14,650	13,690
Slovakia	730	760	800	780	670	560	610	490
Slovenia	990	960	950	880	830	800	730	710
Spain	63,040	61,820	64,740	65,070	63,440	65,490	62,270	61,320
Sweden	2,650	2,690	2,670	2,690	2,740	2,740	2,780	2,590

Source: own processing, Eurostat, [9].

The evolution of ammonia emissions from pig manure management shows a generally downward trend, specific to the transition towards a more environmentally responsible agricultural production model. The reduction in emissions during the period under review

reflects the combined efforts of Member States to implement measures to reduce air pollution and to comply with the objectives set by the European directives on air quality and sustainable use of nitrogen. The decrease in values at European Union level is the result of the modernization of manure management technologies, the use of closed storage systems, the covering of fermentation tanks and the introduction of low-emission organic fertilizer application techniques. In addition, the intensification of environmental controls and the conditioning of agricultural subsidies on compliance with ammonia emission standards have contributed to accelerating the adaptation process. Thus, countries with a developed livestock sector, such as Germany, Denmark and the Netherlands, have achieved the most visible reductions due to the early adoption of ecological technologies. In these countries, modern manure management is integrated into the circular economy, through the valorization of biogas and organic fertilizers, which has reduced the environmental impact and generated economic added value. On the other hand, in the countries of Central and Eastern Europe, the pace of emission reduction has been slower, influenced by the low level of investments and the limited technological infrastructure. In the case of Romania, the decreasing trend of ammonia emissions indicates a slow but steady progress, determined rather by the reduction of livestock numbers than by the improvement of manure management technologies. Industrial farms have started to adopt systems of storage and controlled application of fertilizers, but at the level of small and medium-sized farms, traditional practices remain predominant. This gap explains the persistent differences between Romania and the European Union average. Thus, the evolution of ammonia emissions confirms the general direction of convergence towards sustainability objectives, but also reveals the continued need for investments in clean technologies and for strengthening support mechanisms to reduce the environmental impact of the pig sector.

Table 8. Evolution of methane (CH_3) emissions from pig manure management in the European Union and Romania, 2016–2023 (million tonnes CO_2 equivalent)

Country	2016	2017	2018	2019	2020	2021	2022	2023
E.U.27 countries (from 2020)	6.75	6.73	6.76	6.56	6.59	6.39	5.95	5.71
Belgium	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.13
Austria	0.22	0.22	0.22	0.22	0.23	0.23	0.22	0.21
Bulgaria	**	**	**	**	**	**	**	0.01
Croatia	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cyprus	**	**	**	**	**	**	**	**
Czechia	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06
Denmark	0.81	0.8	0.84	0.78	0.77	0.74	0.67	0.54
Estonia	**	**	**	**	**	**	**	**
Finland	0.06	0.05	0.05	0.04	0.05	0.04	0.04	0.04
France	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
Germany	1.54	1.52	1.44	1.37	1.35	1.23	1.07	1.06
Greece	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07
Hungary	0.18	0.16	0.16	0.15	0.15	0.16	0.14	0.12
Ireland	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Italy	0.8	0.81	0.79	0.79	0.79	0.78	0.8	0.83
Latvia	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Lithuania	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0
Luxembourg	**	**	**	**	**	**	**	**
Malta	**	**	**	**	**	**	**	**
Netherlands	0.33	0.33	0.34	0.34	0.33	0.31	0.3	0.28
Norway	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Poland	0.8	0.87	0.95	0.9	0.96	0.93	0.81	0.79
Portugal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Romania	0.48	0.44	0.4	0.39	0.38	0.37	0.34	0.32
Slovakia	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03
Slovenia	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Spain	0.86	0.85	0.9	0.91	0.91	0.95	0.93	0.92
Sweden	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.09

Source: own processing, Eurostat, [10].

The evolution of methane emissions from pig manure management reflects a generally downward trend, specific to the process of adaptation to the requirements of the European Green Deal and the Union's climate strategies. The decrease in emissions during the analyzed period indicates an improvement in the efficiency of manure management systems, as a result of the modernization of storage infrastructure, the introduction of biogas capture technologies and the expansion of manure energy recovery practices. States with a developed livestock sector, such as Germany, Denmark and Spain, have recorded significant reductions due to the early implementation of these technologies and investments in integrated agricultural waste management systems. In these countries, methane emitted in anaerobic fermentation processes is increasingly recovered and used as an energy resource, which contributes both to reducing emissions and to diversifying renewable energy sources.

The general trend of decreasing methane emissions correlates with the reduction of pig herds, but also with the increase in conversion efficiency and productivity in industrial farms. At the same time, new reporting and monitoring requirements for emissions, introduced by European climate policies, have led to a better quantification and management of methane sources from agriculture.

Central and Eastern European countries, including Romania, still show modest reduction values, influenced by the predominance of small-sized farms and the partial application of ecological technologies.

In Romania, the decrease in methane emissions is explained more by the contraction of herds and the gradual extension of biosecurity standards, than by ecological valorization technologies.

The sector is at an early stage of adaptation to European circular economy standards, which leaves significant potential for further emission reductions through investments in biogas infrastructure.

Table 9. Evolution of nitrous oxide (N_2O) emissions from pig manure management in the European Union and Romania, 2016–2023 (million tonnes CO_2 equivalent)

Country	2016	2017	2018	2019	2020	2021	2022	2023
E.U. 27 countries (from 2020)	0.00675	0.00673	0.00676	0.00656	0.00659	0.00639	0.00595	0.00571
Belgium	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00014	0.00013
Austria	0.00022	0.00022	0.00022	0.00022	0.00023	0.00023	0.00022	0.00021
Bulgaria	**	**	**	**	**	**	**	0.00001
Croatia	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
Cyprus	**	**	**	**	**	**	**	**
Czechia	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00006	0.00006
Denmark	0.00081	0.0008	0.00084	0.00078	0.00077	0.00074	0.00067	0.00054
Estonia	**	**	**	**	**	**	**	**
Finland	0.00006	0.00005	0.00005	0.00004	0.00005	0.00004	0.00004	0.00004
France	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00011
Germany	0.00154	0.00152	0.00144	0.00137	0.00135	0.00123	0.00107	0.00106
Greece	0.00007	0.00007	0.00008	0.00007	0.00007	0.00007	0.00007	0.00007
Hungary	0.00018	0.00016	0.00016	0.00015	0.00015	0.00016	0.00014	0.00012
Ireland	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004
Italy	0.0008	0.00081	0.00079	0.00079	0.00079	0.00078	0.0008	0.00083
Latvia	0.00002	0.00002	0.00002	0.00001	0.00001	0.00001	0.00001	0.00001
Lithuania	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0
Luxembourg	**	**	**	**	**	**	**	**
Malta	**	**	**	**	**	**	**	**
Netherlands	0.00033	0.00033	0.00034	0.00034	0.00033	0.00031	0.0003	0.00028
Norway	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
Poland	0.0008	0.00087	0.00095	0.0009	0.00096	0.00093	0.00081	0.00079
Portugal	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
Romania	0.00048	0.00044	0.0004	0.00039	0.00038	0.00037	0.00034	0.00032
Slovakia	0.00004	0.00004	0.00004	0.00004	0.00004	0.00003	0.00003	0.00003
Slovenia	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
Spain	0.00086	0.00085	0.0009	0.00091	0.00091	0.00095	0.00093	0.00092
Sweden	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.00009

Source: own processing, Eurostat, [10].

Overall, the evolution indicates a slow but steady convergence of Romania with the general trend of the European Union, confirming a transition towards a more energy-efficient and climate-sustainable production system.

The evolution of nitrous oxide emissions from pig manure management shows a slightly decreasing trend, specific to the process of adapting European agriculture to greenhouse gas reduction objectives. Although emission levels are relatively low compared to other agricultural sources, N_2O has a global warming potential almost 300 times higher than carbon dioxide, which gives it a strategic importance in climate policies. The slow decrease in emissions at European Union level reflects the implementation of integrated nutrient management measures, improved manure application practices and the expansion of storage systems that reduce nitrogen losses through volatilization and biological conversion.

In Western countries, progress has been more consistent, thanks to the application of strict nitrogen balance rules and the optimization of organic fertilizer dosage. Countries such as Germany, Denmark or the Netherlands have recorded clear reductions in N_2O emissions by adopting advanced monitoring technologies and by transforming livestock waste into an energy resource, simultaneously reducing the risk of soil and water pollution. In contrast, Central and Eastern European countries, including Romania, are at an intermediate stage of compliance. The slightly decreasing emission levels in Romania can be attributed mainly to the decrease in livestock numbers and the partial application of environmental standards, less to the modernization of manure management infrastructure.

Although the contribution of the pig sector to total N_2O emissions from agriculture is small, the evolution of this indicator is essential for assessing the effectiveness of climate impact reduction measures. In Romania, improving manure storage and application practices, introducing treatment facilities and increasing farmer training can accelerate convergence with the European average. Thus, the dynamics of nitrous oxide emissions confirm that the transition to low-emission agriculture is underway, but requires additional investments and a stronger application of environmental policies to achieve the European Union's climate neutrality objectives.

Table 10. Intensity of ammonia (NH_4), methane (CH_3) and nitrous oxide (N_2O) emissions related to pig herds in Romania and the European Union, 2016–2023 (tons/1,000 heads)

Indicator	NH_3		CH_4		N_2O	
	2016	2023	2016	2023	2016	2023
UE-27 (tons/1,000 heads)	2.61	2.34	0.047	0.043	0.000047	0.000043
Romania (tons/1,000 heads)	4.17	4.34	0.102	0.102	0.000102	0.000102

Source: own processing.

Emission intensity per head is an indicator of the environmental efficiency of pig production. The results show a steady decrease in values in the European Union, a sign of technological modernization and adaptation to air quality and climate regulations. Member States have implemented low-emission manure management technologies, invested in storage infrastructure and applied controlled fertilization systems, thus reducing nitrogen and methane losses. This efficiency is reflected in lower NH_4 and CH_3emissions per 1,000 heads, which indicates a more judicious use of resources and better compatibility with environmental objectives. In contrast, Romania presents values almost double the European average, confirming a lower environmental efficiency and a higher pollution intensity. The lack of advanced storage technologies, the traditional application of manure and the absence of biogas capture systems maintain a high level of emissions. Despite the reduction in numbers, emissions intensity has not decreased proportionally, indicating that improving environmental performance depends not only on volume but also on the quality of the technologies used. Thus, the European Union is on a clear greening trajectory, while Romania needs to accelerate its modernization

to reduce the ecological gap and align its performance with European standards.

Table 11. The ratio between greenhouse gas emissions (CH_3 + N_2O) and ammonia emissions (NH_4) in Romania and the European Union, 2016–2023

Indicator	2016	2017	2018	2019	2020	2021	2022	2023
UE-27	0.000018	0.000018	0.000019	0.000019	0.000019	0.000019	0.000019	0.000019
Romania	0.000025	0.000024	0.000024	0.000024	0.000024	0.000024	0.000024	0.000024

Source: own processing.

The climate ratio, which compares greenhouse gas emissions with ammonia emissions, provides a synthetic picture of the balance between the global and local impacts of livestock activities. During the period under review, the values for the European Union remain relatively constant and very low, indicating a balanced management of the environmental footprint. This stability reflects the effect of coordinated policies to reduce local pollution and GHG emissions, carried out simultaneously within the framework of European climate and sustainable agriculture strategies. In Romania, the climate ratio is slightly higher, but the difference does not indicate a significant contribution to global warming, but rather a relatively higher share of local pollution in the total emissions structure. The low values of the ratio are explained by a higher level of ammonia emissions, resulting from inefficient manure management, compared to the low amounts of GHG generated. While the European Union has managed to balance the ratio between these components, Romania remains at a stage where local pollution prevails. Reducing the gap requires investments in methane recovery technologies, in the modernization of storage systems and in the promotion of low-emission agricultural practices. Thus, the convergence of the climate ratio would signify a real transition towards integrated sustainability of the pig sector.

CONCLUSIONS

The analysis of the pig sector in Romania and the European Union reveals a complex transition towards a sustainable production model, in which economic performance is inseparable from ecological efficiency. At the European level, restructuring has occurred gradually, through the reduction of livestock numbers and the increase in unit productivity, which has allowed adaptation to environmental requirements without compromising competitiveness. Countries that have adopted green technologies, integrated manure management systems and circular economy strategies early on have become reference models, demonstrating that modernization and environmental protection can be complementary.

Romania is still in a stage of structural adjustment, marked by imbalances between high-performing commercial farms and vulnerable family farms. The major challenge is to transform this restructuring into a sustainable development process that capitalizes on domestic resources and integrates the principles of climate neutrality.

Consolidating farms, professionalizing management and investing in modern livestock infrastructure are essential conditions for aligning with European standards. At the same time, increasing traceability, biosecurity and digitalization will strengthen Romania's position in agri-food value chains.

The ecological transition is becoming a real opportunity for qualitative growth and innovation. Reducing emissions and energy recovery from waste should not be seen as simple obligations, but as solutions for increasing efficiency and economic diversification. In this sense, Romania has the potential to become an example of agricultural modernization in Eastern Europe, by implementing integrated biogas projects, reusing resources and promoting smart farms.

In the long term, the sustainability of the pig sector will depend on the balance between profitability and environmental protection, but

also on the coherence of agricultural and climate policies. An integrated approach, based on innovation, responsibility and ecological education, can transform this sector into a pillar of sustainable European agriculture and a strategic tool for Romania's rural development.

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ENERGY TRANSITION AND CLIMATE PERFORMANCE IN THE EUROPEAN UNION FROM AN ECONOMIC PERSPECTIVE

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Abstract

This study analyses the relationship between the European Union's climate performance and its energy transition. More specifically, it analyses the state of evolution of greenhouse gas emissions, the share of renewable energy, and the financial mechanisms associated with the green transition. The main objective of this analysis was to assess the impact of structural changes in the energy sector on emission reduction and to measure the disparities in decarbonisation processes between Member States. This study combines time series analysis with specific statistical tools, such as linear regression to estimate the relationship between greenhouse gases and renewable energy sources, logarithmic transformations to determine elasticities, and a β convergence test to examine the tendency of Member States to converge in terms of emission levels.The obtained results identify a negative correlation between renewable energy expansion and emission reductions. This suggests that accelerating the energy transition directly impacts carbon intensity reduction. Regression models confirm that an increase in the share of renewable energy sources is associated with consistent emission reductions. Meanwhile, the convergence test highlights a moderate trend of reducing disparities between countries, which are strongly influenced by economic structures and national energy system characteristics. Overall, the conclusions show that although the EU is on a clear decarbonization trajectory, persistent differences between countries require better-calibrated policies to support high-needs economies. The energy transition has significant economic ramifications, affecting competitiveness, investment, and industrial resilience. Deeper coordination of energy, fiscal, and industrial policies is essential to accelerating climate convergence and achieving Europe's long-term objectives.

Key words: *energy, climate, emissions, renewable, convergence, economic*

INTRODUCTION

In recent decades, the climate problem has led to a significant overhaul of the global energy model. For the European Union, the energy transition is becoming not only an ecological need but also a structural opportunity: reshaping economies, lowering energy vulnerability, promoting innovation and sustainable growth [9; 17]. Renewable energy and lowering greenhouse gas emissions are at the center of the European agenda, with the goal of becoming climate neutral by 2050 through the European Green Deal and the interim targets for 2030 [11]. The European energy transition is occurring in an atmosphere where regional and global environmental issues are growing more urgent [8, 23]. Increases in gas concentrations that have a negative impact on the environment, the intensification of catastrophic climate phenomena, and the degradation of natural capital constitute a threat to modern economies [17, 18, 26]. Fighting climate change is a strategic and ecological necessity for the European Union to maintain the long-term viability of its economic model. Deteriorating infrastructure, rising energy costs, disrupted supply chains, and lower productivity have all been linked to a deterioration in economic competitiveness, according to studies conducted in recent decades [2, 10, 16]. Thus, investing more in green innovation and renewable energy makes the energy transition an integrated response to climate threats and offers the chance for faster technological modernization [5, 25]. Significant geopolitical, ecological, and economic effects result from this change. Reducing emissions and reliance on fossil fuels while preserving economic stability and industrial competitiveness is one of the most difficult problems facing Europe in

the twenty-first century. Because of geopolitical tensions and the instability of global oil and gas markets, recent energy crises have brought attention to the fragility of import-dependent energy systems and accelerated the development of low-emission technology [19, 22]. Strategic security measures, rather than climate change, will propel the development of renewable energy sources and infrastructure as well as the diversification of energy mixes [6]. Energy transfers could therefore be used by the EU as a geopolitical instrument to strengthen economic independence and lessen external vulnerability. [18]. As a result, the shift turns into a structural reconfiguration that links security, the economy, and the environment inside a cohesive framework of governmental policies.These assessments are important because they cover a wide range of topics, including competitiveness, energy security, social sustainability, and regional cooperation, in addition to ecological and economic ones [4, 24]. Recent research highlights this connection. For example, a 2025 research for EU nations shows that moving to renewable energy dramatically reduces CO2 emissions without slowing economic growth. Other studies highlight how renewable energy can improve energy security and lessen reliance on fossil fuels, a strategic goal made more difficult by geopolitical and energy crises [7]. On the other hand, the literature shows the variability of this process: the transition has varied rhythms between nations, depending on the economic structure, the initial energy mix, the investment capacity and national policies [3, 20]. Consequently, the issue arises whether the EU is emerging as a unified unit, with climatic and economic convergence, or as a mosaic of diverse trajectories.

The analysis takes three factors into account: economic dynamics, the percentage of renewable energy, and greenhouse gas emissions. The goal is to determine if the growth of renewable energy sources reduces emissions and if EU nations are moving toward similar economic and climate outcomes [1, 21].

This study is important because it shows how the green energy mix actually affects emissions and highlights national variations, indicating the need for financial instruments, coordination, and institutional cohesion [15, 22]. Energy transfers are also a component of efforts to adapt and re-establish the fundamental changes in energy, technology, and media to European economies in the context of global economic competitiveness. Energy transition and climate performance from an economic standpoint are very relevant topics. These include media, economics, and geopolitics, as well as interdisciplinarity. Lucrarea of the methods it is put forth or made a substantial contribution to the discussion, such as the supply of an integrated viewpoint on decarbonization and climate convergence in the EU, statistical modeling, economic interpretation, and intricate empirical analysis [9].

MATERIALS AND METHODS

The strategy emphasizes how the EU's energy transition reduces greenhouse gas emissions. It makes use of a multidimensional econometric approach and a single set of variables. The approach uses three categories of data to capture essential links between energy structure and climatic performance: The percentage of final energy consumption that comes from renewable energy; net greenhouse gas emissions, measured in megatons of carbon dioxide equivalent; and economic indicators of the transition, like environmental taxes and Environmental Goods and Service Sector - EGSS, which demonstrate Member States' capacity to support green investments. The analysis period, 2015–2024, makes it possible to examine recent developments brought about by European climate efforts, such as the Fit for 55 packages and the Green Deal.

The study employs a traditional linear regression to evaluate the direct effect of renewable energy on Greenhouse Gas -GHG emissions, whereby variations in the fraction of renewables account for the annual variation in emissions. The shape of the calculated model is:

$GHG_t = \alpha + \beta \cdot RES_t + \varepsilon_t$,.....(1)

where:

GHGt represents the net emissions of the EU-27 in year t,
RESt - share of renewable energy
α - intercept
β - marginal effect of renewables growth on emissions.
A negative β coefficient verifies the notion that increasing renewable energy capacity reduces emissions by replacing fossil fuels.
The strength of the relationship is indicated by R^2, which quantifies the extent to which the model explains the variation in greenhouse gases.However, in order to capture the proportional relationship between the two indicators and the elasticity of emissions towards renewables, the model is also calculated in logarithmic form. The log–log transformation allows the coefficient to be viewed as elasticity, so:

$\ln(GHG_t) = \alpha + \beta \ln(RES_t) + \varepsilon_t$.....(2)

The percentage change in emissions that results from a percentage change in the share of renewable energy is expressed in this formulation by the β coefficient. This technique is ideal for energy transition systems, characterized by nonlinear developments and scale effects.
The methodology also incorporates the analysis of β convergence to evaluate inter-state dynamics. Whether states with high initial emissions reduce emissions more quickly than those with low initial emissions is tested via β convergence. The formula that is employed is:

$\ln(GHG_{i,2024}/GHG_{i,2015}) = \alpha + \beta\ln(GHG_{i,2015}) + \varepsilon_i$, ...(3)

where:

GHGi,2015 and GHGi,2024 represent the emissions of country i at the beginning and end of the analyzed period, respectively.

A coefficient $\beta < 0$ indicates the existence of convergence, which means that emission reductions are more accelerated in the most polluting economies at the beginning of the period.
The processing data were extracted from Eurostat and processed by logarithmic transformations, calculation of compound growth rates, construction of trend series and estimation of OLS models. The methodology enables a thorough evaluation of the structural linkages between renewable energy, greenhouse gas emissions, and the general dynamics of European decarbonization by integrating simple regression, elasticity model, and β convergence.
The logarithmic adjustment performed to the variables allows for a more adequate study of the economic factors behind the climatic transition. In this case, logarithmization stabilizes dispersion, smoothes the amplitude of changes, and creates comparability across processes evolving on different scales. More significantly, this transformation makes it possible to interpret the findings in terms of elasticities, showing how a percentage change in emissions corresponds to a proportionate change in renewable capacity. In addition to being a technical tool, logarithmization is a means of capturing the marginal effects of the energy transition, making it easier to pinpoint the times when increased investments in clean sources either accelerate climate responses or, conversely, dampen them due to structural factors.
Regression models thus emerge as the primary instrument for measuring the links found both conceptually and experimentally. They make it possible to evaluate the strength and direction of the relationships between variables, differentiating between the short-term consequences of the rise in the proportion of renewable energy sources and the long-term advancements brought about by the reorganization of the energy system. Furthermore, the regressions show how much green bonds accelerate the shift through their function as an investment facilitator rather than as a direct factor in the reduction in emissions. These models offer a synthetic representation

of the intricate processes underlying the European energy transformation. They confirm that the dynamics of greenhouse gases (GHGs), renewable energy sources (RES), and green finance do not operate in isolation but rather form a coordinated system. This system can be rigorously analyzed and predicted based on statistical behavior.

RESULTS AND DISCUSSIONS

This analysis attempts to illustrate the influence of the energy transition on climate performance at the European Union level. It studies the structural links between greenhouse gas (GHG) emission reductions, renewable energy dynamics, and economic indicators of the green transition. By combining statistical and econometric findings, we are able to track the processes that lead to climate convergence and help the EU achieve its decarbonization goals.

Table 1. Evolution of the share of renewable energy in the EU-27 and the Member States in the period 2015–2024

Year	GHG (Mt CO_2eq)	RES (%)
2015	3,494.766	17.82
2016	3,492.159	17.98
2017	3,565.184	18.41
2018	3,546.756	19.10
2019	3,395.486	19.89
2020	3,103.023	22.04
2021	3,268.593	21.90
2022	3,192.218	23.03
2023	2,907.204	24.63

Source: own processing, Eurostat[12, 13, 14].

In the past ten years, the energy system in Europe has changed a lot, shown by how green house gas emissions have changed and by the increasing use of renewable energy across the 27 countries in the EU. Renewable energy is growing more and more, showing that production is getting bigger, clean technologies are becoming more reliable, and more money is being spent on building eco-friendly infrastructure.This shows that energy transition methods are working well and that climate goals are strongly included in the Union's economic and energy plans. At the same time, green house gas emissions have been clearly decreasing, probably because of improved energy systems, better technology efficiency, and more investment in cleaner, low-carbon options.The path is n't perfectly straight, but it shows that economic growth is becoming less connected to environmental stress. This shows that European countries are starting to rely less on fossil fuels in industries that produce a lot of emissions. The two measurements are closely connected in the opposite way: when more renewable energy is used, greenhouse gas emissions go down. This supports the idea that switching from fossil fuels to renewable energy sources has a direct impact on how the climate performs. Using a lot of renewable energy helps reduce harm to the environment and makes energy less risky, which is the main reason for moving away from carbon emissions. In this way, the development of renewable energy and the changes in greenhouse gas levels show that policies supporting renewable energy are the ones that greatly cut down emissions and help move forward the energy revolution across European countries.

Table 2. Statistical characteristics of GHG, RES and green bonds variables

Year	GHG	RES	ln(GHG)	ln(RES)
2015	3494766	17.820	15.067	2.880
2016	3492159	17.978	15.066	2.889
2017	3565184	18.411	15.087	2.913
2018	3546756	19.096	15.082	2.949
2019	3395486	19.887	15.038	2.990
2020	3103023	22.038	14.948	3.093
2021	3268593	21.897	15.000	3.086
2022	3192218	23.030	14.976	3.137
2023	2907204	24.631	14.883	3.204

Source: own processing, Eurostat[12, 13, 14].

The simultaneous rise in greenhouse gas emissions and the amount of renewable energy characterizes the energy transition process, in which the European Union's energy consumption structure is gradually shifting (Table 2). Emissions remain high and nearly steady at the start of the period under review,

while the growth of renewable energy is slow and has no discernible impact on the GHG trajectory. This early stage portrays a scenario in which technical and investment revolutions in the energy sector do not yet significantly influence the functioning of the European energy system.Subsequently, the two series continue to evolve in independent directions. Emissions begin to drop, but the share of renewable energy increases at a more evident pace. This separation shows that the integration of renewable technologies is manifesting at the structural level by reducing dependence on fossil fuels and strengthening decarbonization policies. This transition is becoming more pronounced as European economies implement robust clean energy measures, resulting in a visible change in the region's energy balance.

Recently, the relationship between the two variables has become clearer. The percentage of renewable energy is still growing, while emissions are stabilizing at lower levels than previously observed. This trend implies that the implemented modifications are part of a larger shift in the energy system, where clean energy sources are becoming increasingly important, rather than being transient.

The two series' logarithmic transformations offer further information on how their relationship evolves. The logarithm of emissions indicates the progressive decrease of climate pressure, whereas the logarithm of renewables demonstrates a slow expansion process, which is constantly happening during the entire period. The two transformations' combined history demonstrates that structural changes in the energy mix are linked to the drop in emissions, which is crucial for econometric approaches and the evaluation of elasticities between the two domains. The dynamics of greenhouse gas emissions, but also of renewable energy, are those elements that demonstrate the role of the application of the deep mechanisms that regulate the European energy transition and that extend beyond the increase in the consumption of each element in particular. It is found that the increasing share of renewable energy sources not only replaces fossil fuels, but it also has a high impact on energy market operations, on investment behavior and on energy demand structures. Renewable production promotes innovation, digitization, and the creation of flexible capacities, all of which reduce the need for carbon-intensive technology because of its wider geographic reach and reliance on contemporary infrastructure. However, the decrease in emissions is the result of a systemic adjustment process wherein carbon taxes, industrial modernization, climate laws, and changes in consumer behavior all work together. It is not only a mechanical consequence of the increase in RES. Through intermediary channels like higher final consumption, lower technological losses, and enhanced energy efficiency, this interdependence shows a direct and indirect relationship between greenhouse gas emissions and renewable energy sources. It is observed that a constant decrease in emissions results from the increase in renewable energy sources, but also from the change in the energy landscape, because these clean technologies integrate not only the institutional sector, but also the industrial and commercial ones. Thus, the construction and analysis of statistical models contribute to presenting the complexity of the relationship established between greenhouse gas emissions and the proportion of renewable energy. Since the aforementioned factors, namely the institutional, technical and behavioral ones, are the ones that contribute to the modification of this relationship, it is concluded that these models are the ones that must take into account both the immediate effects of changes in the energy mix, as well as the way in which the economy reacts to these models.

Table 3. Evolution of greenhouse gas emissions in the EU-27 states in the period 2015–2024

Country	GHG_2015	GHG_2024
Belgium	117.82	98.65
Bulgaria	52.85	35.43
Czechia	117.9	92.55
Denmark	50.54	36.75
Germany	907.56	700.35
Estonia	18.62	12.56
Greece	92.6	65.07
Spain	280.26	218.51
France	420.44	331.77

Croatia	19.07	18.84
Italy	401.57	319.54
Cyprus	8.03	8.58
Latvia	11.04	12.72
Lithuania	12.24	13.98
Luxembourg	9.88	6.99
Hungary	56.75	48.2
Malta	2.15	2.18
Netherlands	199.93	145.61
Austria	75.27	74.47
Poland	348.11	298.81
Portugal	64.99	51.49
Romania	68.39	68.51
Slovenia	17.43	11.28
Slovakia	35.22	27.96
Finland	43.75	52.35
Sweden	-2.03	16.25

Source: own processing, Eurostat [12, 13, 14].

This structure necessitates the employment of methods capable of capturing nonlinear dependencies, slope fluctuations over time and probable gaps between the timing of investments and their climate impact. Therefore, the modeling aims to recreate a causal link in which energy policy, technical advancement, and the rearrangement of the industrial system function together, rather of merely focusing on the numerical correlation between two time series.

The trajectory of greenhouse gas emissions at the level of the European Union countries was assessed both at the beginning and at the end of the period (Table 3), illustrating a series of structural changes that reflect distinct paces of the climatic transition. In most nations, a declining trend in emissions is observed, connected with the consolidation of decarbonisation policies, the modernisation of energy infrastructure and the escalation of investments in less polluting technology.

This decline is not consistent; some nations report notable changes, indicating a quickening pace of economic and energy restructuring, while others exhibit gradual changes or oscillations, indicating ongoing challenges in lowering reliance on conventional energy sources or modernizing specific industrial sectors.

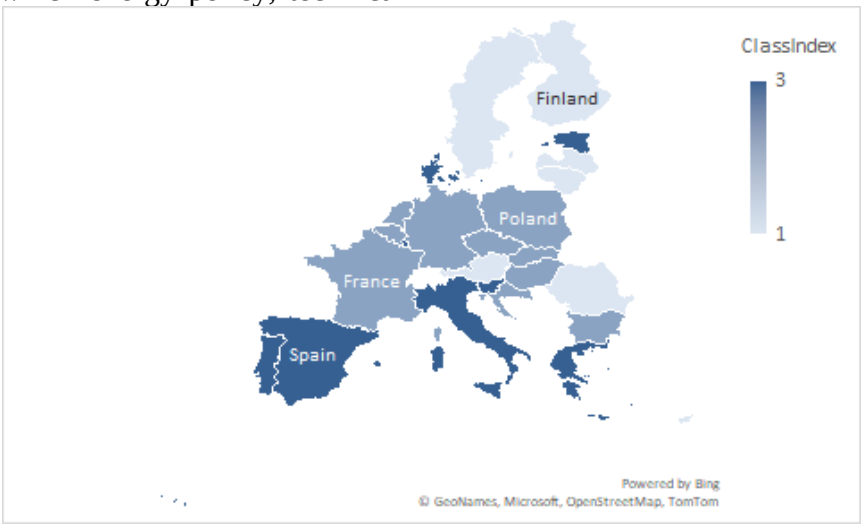


Fig. 1. Classification of EU-27 Countries by GHG Reduction Performance (2015–2024)
Source: own processing, Eurostat [12, 13, 14].

Differences between countries thus become relevant for configuring a typology of climate performance. Based on the observed developments, three categories are distinguished: countries with pronounced emission reductions, which can be considered performers in the transition to neutrality; countries with moderate progress, located in an intermediate stage; and countries where emission dynamics suggest persistent structural challenges.

Figure 1 shows the spatial configuration, highlighting regional clusters of performance. Northern and western Europe tend to concentrate countries with accelerated progress, while parts of central and southern Europe show slower adjustment rates.

This geographical variation suggests that the climate transition is not evolving uniformly

within the EU and is influenced by economic structure, historical dependence on fossil fuels, and the pace at which national decarbonization policies are implemented. At the same time, the performance differences highlighted on the map are relevant for formulating differentiated European policies that would provide more intensive support to regions undergoing difficult structural adjustments and capitalize on the experience of those that have accelerated the transition.

Table 4. Estimation of the impact of renewable energy on GHG emissions

Model	Intercept	Beta	R^2
GHG = f(RES)	5131924	-87786.7	0.896

Source: own processing, Eurostat[12, 13, 14].

The regression model (Table 4) intended to discover the extent to which the expansion of the percentage of renewable energy effects the evolution of GHG emissions in the EU-27 in the medium term. The study confirms that higher production from renewable sources is associated with lower climatic pressure by showing a consistent negative association between the two variables. The negative coefficient linked with renewable energy suggests a structural substitution effect: as renewables grow more dominant in the energy mix, overall emissions fall.
The substantial explanatory power of the model implies that annual variations in the share of renewable energy are a major factor affecting changes in emissions at the European level. This persistent association illustrates that policies aiming at boosting renewable energy sources contribute not only to a more diversified energy mix, but also to demonstrable climate effects. These policies directly contribute to convergence towards European decarbonization objectives. As a result, the model validates the critical role that the green energy transition plays in lowering emissions and the need of ongoing investments in renewable infrastructure to hasten climate progress.

Table 5. Assessment of the convergence trend of GHG emissions in the European Union in the period 2015–2024

Model	Intercept	Beta	R^2
Logarithmic growth of GHG (2024/2015)	0.005753	-0.04347	0.121233

Source: own processing, Eurostat[12, 13, 14].

The results of the β convergence test indicate that the European Union has shown a moderate trend of reducing disparities among its member states in terms of greenhouse gas emissions over the period under review, a process with direct economic implications. The negative convergence coefficient indicates that economies with high initial emission levels tend to reduce carbon intensity more quickly. This dynamic reflects the growing economic pressure on energy-intensive sectors, particularly in regard to the costs associated with the EU ETS program, mandatory investments in efficient technologies, and restrictions on polluting infrastructure (Table 5).
However, the relatively slow convergence suggests that Member States' divergent economic structures — including their respective shares of heavy industry, energy dependence, and capacity for technological innovation — continue to significantly influence national decarbonization trajectories. Highly industrialized or fossil fuel-dependent economies require much more expensive investments to achieve comparable reduction rates to those of early adopters of renewable energy. Thus, the results indicate an ongoing economic adjustment process characterized by structural asymmetries.
The uneven distribution of economic effects generated by the energy transition is also evident in the partial convergence of emissions. The benefits, such as reduced vulnerability to price shocks, increased efficiency, and attracting green investment,

materialize faster in countries with advanced infrastructure. In contrast, the costs of the transition are higher in economies with technological gaps or a rigid energy mix.

The results suggest that the EU is on a climate convergence trajectory, though this trajectory is heavily influenced by the economic fundamentals of each member state. Thus, convergence is not only a climate phenomenon, but also an expression of the gradual alignment of economic models toward efficiency and sustainability standards that are compatible with European decarbonization objectives.

CONCLUSIONS

The findings show a clear connection between climate performance, energy transitions, and EU economic dynamics. Research on the history of renewable energy, greenhouse gas emissions, and green financing approaches demonstrates that decarbonization involves not just technological processes but also the structural restructuring of European economies. Adoption of clean technology is consistently correlated with decreased carbon intensity, and an increase in renewable energy is accompanied with quantifiable reductions in emissions, according to statistical models. This link implies that investments in green infrastructure, innovation and energy efficiency have good climate consequences, while boosting the competitiveness of European economies.

The partial convergence observed in emission levels suggests that countries with high initial emissions are reducing them. However, the pace of this reduction is significantly influenced by economic structure, energy dependence, and innovation capacity. The persistence of these differences shows that the energy transition is occurring within a framework marked by economic asymmetries, wherein the costs and benefits of decarbonization are distributed unevenly. Therefore, climate performance is inextricably linked to the economic fundamentals — industrialization, technological investment, and flexible energy systems — that determine each country's ability to swiftly adopt and implement clean solutions.

Integrating these results into political discussions highlights the need to strengthen European mechanisms aimed at climate and economic cohesion.While current European initiatives like the EU ETS, Social Climate Fund, and Just Transition Mechanism are important, further convergence necessitates more focused resource allocation to economies with structural vulnerabilities. From a strategic perspective, the energy transition should not be considered simply as a climate target, but as a process of industrial modernisation, boosting economic resilience and lowering dependence on fossil fuels. In order to prevent the creation of new kinds of divergence between Member States, it becomes crucial to harmonize energy, fiscal, and industrial policies.

The study's findings demonstrate that the EU is clearly on a decarbonization trajectory, but the capacity to synchronize the institutional, financial, and economic tools of the transition will determine how quickly and coherently this transformation proceeds. Boosting green investments, speeding up technological advances, and increasing cooperation among member countries are key steps to meet climate goals, while keeping the Union competitive on the world stage and ensuring economic stability.

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SUSTAINABLE FINANCE AND GREEN LABOR MARKET DYNAMICS IN THE EUROPEAN UNION

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Abstract

By examining the development of the environmental goods and services sector (EGSS) from 2015 to 2023, this study examines how sustainable finance affects the dynamics of the green labor market in the European Union. The study's objective is to evaluate the impact of ecological transition-related investments on employment, productivity, and economic performance at the Member State level. The main objectives aimed at examining the evolution of the workforce in the EGSS, measuring disparities between economies, assessing the relationship between employment and value added, as well as exploring the role of complementary factors — environmental taxation and renewable energy — in the structure of the European green economy. The methodology used exclusively Eurostat data, processed to obtain descriptive indicators, growth rates, aggregations per employee and a matrix of correlations between key variables. The statistical analysis included calculations of central tendencies, dispersion, annual dynamics and structural relationships, complemented by graphical representations and Romania–EU comparisons. The indicators have been harmonised for comparability, and all results reflect the gross values reported by Member States. The results highlight a consistent growth of employment in EGSS at European level and a strong correlation between the size of the workforce and the value added generated by the sector. However, the contribution of renewable energies and the level of environmental taxes prove to be weakly correlated with economic performance, indicating a fragmented evolution of green policies. The analysis reveals considerable differences between mature economies and emerging countries, but also clear convergence trends, accelerated after 2020 by the intensification of sustainable financing. The conclusions underline that the efficiency of green investments depends on the industrial structure, technological capacity and national public policies. Romania follows the European trajectory of green sector expansion, but lags behind in productivity and integration of sustainable investments in high value-added activities. The study confirms that the green transition is becoming a structural component of the European economy, with direct implications for the labor market and future competitiveness.

Key words: *sustainable finance, green economy, EGSS, labor market, European Union*

INTRODUCTION

One of the EU's core strategic goals is the shift to a green economy, which is expressed in the EU taxonomy, the European Green Deal, and the sustainable finance legislation [8]. With the environmental goods and services sector playing a key role, this collection of policies seeks to restructure the European economy in a way that is compatible with climate, energy efficiency, and circular economy objectives [2, 7]. The EGSS is seen as a pertinent measure of the extent of the green shift and includes industrial operations and services focused on resource management, eco-innovation, and environmental protection.

The literature highlights that green jobs tend to expand with increased investment in clean technologies, renewable infrastructure and energy-efficient industrial processes [1, 3, 5]. The standard definition of green jobs, formulated by the International Labour Organization, highlights the transversal nature of these activities and their relevance for sustainable development [4, 13]. Recent empirical studies show that green employment is concentrated in industries that combine complex technological processes with a high demand for new skills – such as energy efficiency, digitalization of industrial processes, resource management and the circular economy [22]. From this perspective,

the dynamics of the green labor market depend on the capacity of national economies to absorb innovation, the level of public and private investment, but also on vocational training policies that support the development of green skills [15].

In parallel, sustainable finance is the investment framework that directs capital towards activities compatible with environmental objectives, playing a key role in the structural transformation of the economy [17, 18]. The EU taxonomy, the SFDR Regulation and the recovery plans financed by NextGenerationEU align financial markets with sustainability principles, setting clear criteria for classifying green assets and reporting non-financial impacts. The literature shows that climate-oriented investments act as a catalyst for change, having direct effects on productivity, innovation and employment, especially in industries with high decarbonisation potential [6, 16]. In addition, sustainable finance stimulates the relocation and modernisation of value chains, creating space for low-emission technologies and new business models [20].

However, the pace of transformation varies considerably across EU Member States. Structural disparities are driven by differences in industrial capacity, technological maturity, environmental tax structure and the share of renewables in the energy mix [14]. In particular, Central and Eastern European countries show divergent adaptation patterns, with rapid increases in green activities, but starting from a low initial level, indicating an ongoing convergence process [19]. Romania falls into this category, characterized by high expansion potential, but also by constraints related to labor productivity, investment in innovation and the fiscal structure, aspects that require in-depth empirical investigations. Another aspect highlighted by recent literature is the lack of integrated studies that simultaneously analyze the relationship between sustainable financing, the economic performance of the EGSS sector and labor market developments. Most research focuses either on climate finance or green employment, without correlating the mechanisms through which investments generate structural effects on the economy [21]. Also, cross-country comparisons are often incomplete, and contributions regarding Eastern Europe remain limited, with little emphasis on the analysis of harmonized statistical indicators from official sources.

In this context, the present study aims to contribute to the specialized literature through a complex quantitative analysis, based on Eurostat data, which tracks the evolution of employment, productivity, environmental taxes and renewable energy in relation to the dynamics of sustainable finance. The main goal is to evaluate how the labor market and economic performance are affected by the changes brought about by the green transition, both in Romania and at the EU level. Using derived indicators, growth rates, and variable correlations, the analysis presents a comprehensive picture of the mechanisms via which the European economy is reconfiguring itself towards sustainability, boosting the scientific relevance of the research.

MATERIALS AND METHODS

The applied methodology sought to determine how sustainable financing affects the dynamics of the EU's green labor market by analyzing the expansion of the environmental goods and services sector as well as the links between employment, value added, environmental taxation, and the share of renewable energy. Eurostat provided the figures for 2015 to 2023. The datasets contained indicators on employment in the EGSS, value added, exports, environmental taxes, and renewable energy, from which more relevant variables were constructed, such as value added per employee, environmental taxes per employee, and yearly growth rates. The processing involved the harmonisation of intervals, cleaning of missing values, cross-country comparability and standardisation of the series. The statistical methods applied included descriptive analysis (mean, median, quartiles, standard deviations), calculation of growth rates based on the formula:

$$Growth_t = \frac{X_t - X_{t-1}}{X_{t-1}} \times 100, \quad \text{.....(1)}$$

as well as the construction of indicators derived by relating economic values to the number of employees. The structural relationships between variables were examined with the Pearson correlation coefficient:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}. \quad \text{.....(2)}$$

The comparative analysis Romania–EU used the country's position in the European distribution, deviations from the averages and relative dynamics. The graphical representations were generated to highlight temporal developments and inter-state differences, without interpolations or artificial adjustments. The methodology reflects an integrated approach to official Eurostat data, using fundamental statistical tools to capture the structural trends of the European green economy and the specific profile of Romania in this process.

RESULTS AND DISCUSSIONS

We began by examining the development of the environmental goods and services sector in the European Union between 2015 and 2023 to analyze the effect of sustainable finance on the green labor market. The 4 tables in the research include Eurostat data on employment, value added, exports, environmental taxes, and the share of renewable energy. The structuring of the results allows highlighting the dynamics of the sector, the differences between Member States and the relationships between the main components of the green transition.

Table 1. Statistical distribution of employment in the environmental goods and services sector in the period 2015-2023 (persons employed)

Year	Count	Mean	Std	Min	Q1=25%	Q2=50%	Q3=75%	Max
2015	23	133,873.5	159926.8	3,334	33492	73265	145158	585,359
2016	24	155,290.6	180553.3	3,736	35776	87137.5	151727.8	588,075
2017	25	156,603.6	183402.7	4,242	38313	79549	151618	605,168
2018	27	154,759.2	191544.1	3,716	36561	80695	158232.5	638,759
2019	27	161,782.5	200181	3,769	37722	82418	166556.5	670,636
2020	27	164,990.9	201083.7	3,757	41675.5	81999	178023	682,063
2021	27	184,588.3	237127.5	3,618	41838	86157	182322.5	848,497
2022	27	211,252.6	287923.9	3,577	44888	89878	205550	1,153,508
2023	1	577,746		577,746	577746	577746	577746	577,746

Source: own processing, Eurostat [9, 10, 11, 12].

Descriptive data (Table 1) show a steady increase in employment in the environmental goods and services sector in the European Union throughout the period under review. The average expansion of the green workforce is accompanied by a diversification of economic structures, reflected by a gradual increase in the variation between Member States, a pattern that becomes clearer when indicators are grouped into quartiles. Quartiles segment the distribution of values into four equal parts - Q1–Q43, allowing differences in performance to be observed more accurately and highlighting the widening gap between countries that advance rapidly in the green transition and those facing structural constraints**.**

This increase in heterogeneity shows that the adoption of green technologies and services has not been uniform, and that economies with high investment capacity have accelerated the transition process faster than those with limited resources..

The employment distribution shows a distinct difference between the group of nations with less established markets, where green activities are still minimal, and the group of economies with integrated industrial ecosystems, which house the majority of the EGSS workforce. Over time, the intermediate thresholds of the

distribution are moving upwards, signaling the consolidation of a critical mass of green activities in an increasing number of Member States. At the same time, the upper extreme values indicate accelerated growth in large economies, where sustainable financing policies and investments in clean technologies have generated oversized expansions of the labor force. The general trend increases until the end of the period, suggesting the progressive maturation of the European green economy and the integration of circular-economic activities, renewable energies and efficient technologies in more and more sectors. The data obtained confirm the gradual consolidation of the green labor market in the EU and highlight relevant structural differences between countries, which will be detailed in the following subsections.

Table 2. Evolution of annual employment growth rates in EGSS by EU member state (%)

Country	2016	2017	2018	2019	2020	2021	2022
Belgium	4.26	4.31	6.88	4.34	-0.51	5.07	3.67
Bulgaria	13.08	7.91	8.78	-0.61	3.89	4.53	6.34
Czechia	-0.55	-0.10	3.45	2.04	11.93	3.36	2.83
Denmark	3.33	5.08	1.90	-0.23	1.19	5.01	4.57
Germany	-1.50	4.43	8.13	4.85	1.37	6.40	19.17
Estonia	6.37	-4.53	-4.19	6.27	-1.09	6.60	6.97
Ireland	34.56	17.13	10.26	2.05	-0.87	-4.75	7.18
Greece	-8.47	15.62	18.46	8.90	-6.45	11.46	38.51
Spain	4.00	1.87	13.16	1.11	6.57	10.23	7.13
France	0.46	2.91	5.55	4.99	1.70	10.06	3.60
Croatia	-0.02	2.07	6.32	2.36	-0.63	7.41	5.78
Italy	*	2.85	2.27	3.99	-4.54	40.51	35.95
Cyprus	*	*	*	6.37	-15.02	18.26	6.45
Latvia	-3.75	1.65	-10.00	1.61	10.32	-1.68	9.46
Lithuania	4.05	10.37	-1.05	12.34	-3.84	16.94	-0.14
Luxembourg	13.12	13.44	13.01	16.38	14.91	18.98	7.98
Hungary	*	*	-6.18	5.12	-0.22	-8.14	8.82
Malta	12.06	13.54	-12.40	1.43	-0.32	-3.70	-1.13
Netherlands	5.94	5.94	5.71	7.30	14.06	0.94	5.32
Austria	1.12	3.60	7.11	2.68	1.14	4.10	3.94
Poland	12.07	4.95	10.43	14.51	2.58	5.97	13.92
Portugal	5.27	5.16	3.16	1.69	6.79	43.52	21.55
Romania	-6.60	0.86	6.81	3.17	-0.77	2.53	15.23
Slovenia	5.15	11.17	4.63	-2.10	-0.60	0.56	4.21
Slovakia	*	*	*	4.16	33.25	7.24	-0.12
Finland	4.03	0.82	-15.89	6.70	0.79	-4.32	14.24
Sweden	6.93	5.95	6.19	1.73	0.75	5.12	4.45

Source: own processing, Eurostat [9, 10, 11, 12].

The evolution of annual employment growth rates in the EGSS sector highlights a dynamic pattern, strongly influenced by the European economic context and the intensity of sustainable financing policies. In the first part of the period under review, growth rates are moderate and relatively balanced across Member States, signaling a gradual expansion of green activities in line with the implementation of European ecological transition strategies. As the pandemic approaches, annual variations become more pronounced. In advanced economies, investments aimed at modernizing energy

infrastructure and adopting low-emission technologies have sustained above-average growth. In contrast, emerging market countries experience wider fluctuations, due both to dependence on investment cycles and the institutional adjustments necessary to align with European environmental standards.

The period 2020–2021 marks a significant change in the growth rate. Despite economic restrictions, European economies continued to invest in green projects, supported by recovery funds and the reorientation of fiscal policies towards sustainability. This is reflected in a visible acceleration in employment in the EGSS sector, indicating that environmental activities have demonstrated greater resilience than traditional sectors.

Towards the end of the period, growth rates generally become higher and more convergent across countries. This evolution suggests a progressive consolidation of the sector, increasing demand for green skills and the widespread adoption of sustainable financing mechanisms. At the same time, differences between countries persist, reflecting both the uneven level of investment and the particular structure of national labor markets. Thus, the dynamics of growth rates confirm that green jobs have expanded at an accelerated and adaptive pace, directly influenced by the European policy framework and global decarbonization trends.

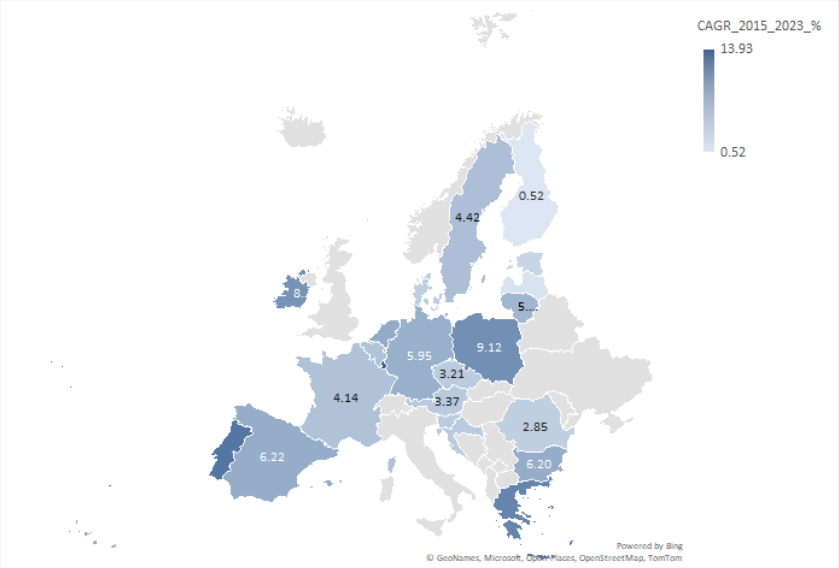


Fig. 1. Evolution of annual employment growth rates in the EGSS sector for the period 2015–2023 (%)
Source: own processing, Eurostat [9, 10, 11, 12].

A varying evolution of yearly job growth rates in the EGSS sector is depicted in Figure 1, which reflects both the dynamics of green investment and structural variations among EU member states. In the first years of the analysed period, the growth rates are moderate and relatively consistent, suggesting a gradual expansion of green activities with the implementation of the European directives on the circular economy and energy efficiency. Later, the variations become more pronounced, which indicates the different ways in which European economies have absorbed sustainable financing and adopted clean technologies. In some countries, the accelerated growth reflects the expansion of green industrial capacities and the intensification of investment policies, while the negative fluctuations in other countries can be associated with labour market restructuring or the postponement of investments in periods of economic instability.

The impact of the pandemic is visible in the form of atypical dynamics, but the EGSS sector demonstrates a higher resilience than other economic branches, quickly returning to a positive growth rate with the targeting of European recovery funds to projects with

climate impact. The graph's acceleration and convergence patterns in the later half of the examined period imply that the green transition is starting to become a structural feature of the European labor market.

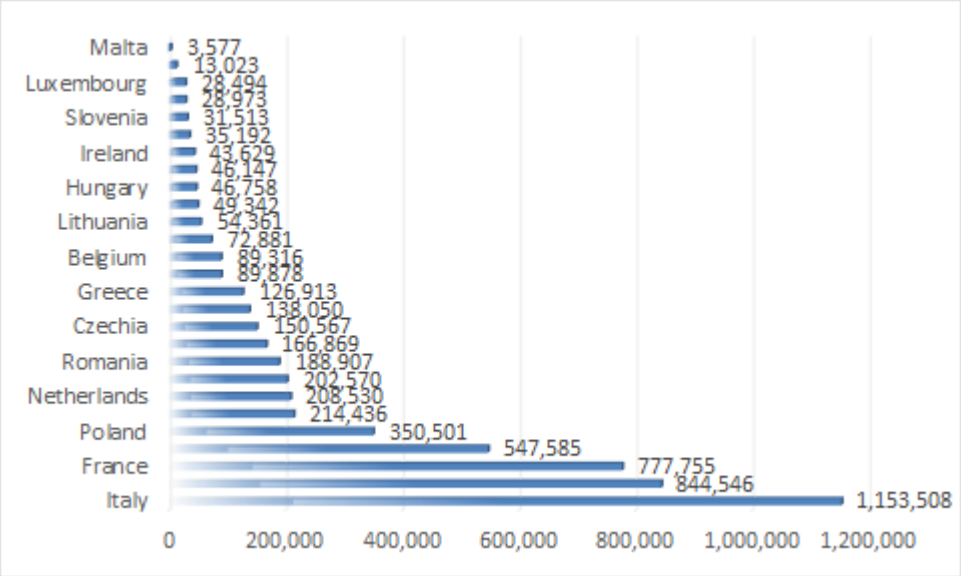


Fig. 2. Structure of employment in EGSS at the European Union level in 2023 (persons)
Source: own processing, Eurostat [9, 10,11, 12].

The environmental goods and services sector's workforce structure reveals a significant concentration in major economies, where industrial capacity, technological foundation, and green transition-oriented public policies are more developed (Figure 2). Given the scale of the local market and the maturity of the industries related to resource management, energy efficiency, and environmental technology, Italy, France, and Germany undoubtedly dominate the distribution. These economies produce productive industrial ecosystems with long value chains and steady uptake of sustainable finance, which results in high employment levels. Conversely, employment levels in the Baltic region and Central and Eastern Europe are moderate, but they are growing at a faster rate, suggesting a stage of structural convergence. Targeted European investments, the growth of environmental infrastructure, and the emergence of new industries like recycling, waste management, and industrial energy efficiency all help these markets.

Small economies at the bottom of the ranking have a minimal representation of the EGSS sector due to their restricted economic structure and low market capacity. Nonetheless, there are growth patterns even in these situations, indicating that the demands of aligning with European policies provide a continuous push to increase employment in an industry that is still undergoing consolidation.

An intricate picture of the performance of the EGSS sector in the EU's member states is painted by the examination of value added per employee, the proportion of renewable energy, and the level of environmental taxation (Table 3). The countries with the highest level of value added per employee are distinguished by consolidated industrial ecosystems, capable of transforming green investments into consistent economic results. These economies are characterized by advanced technological specialization, the capacity to produce high-value equipment and services and a strong integration into European and global value chains of environmental goods.

The percentage of renewable energy also illustrates the disparities in the rates of energy transition among nations. Given that certain countries with high productivity in the green sector may not have an equally high share of renewable energy, there may be a disparity between the economic performance of EGSS activities and the transformation of national

energy systems. Other economies, particularly those in northern and eastern Europe, combine high levels of renewable energy with balanced productivity, illustrating transition models in which climate policies and investments in advanced energy infrastructure develop in parallel.

Table 3. Economic and energy indicators of the environmental goods and services sector in EU Member States in 2023

Country	Value added/employee (Euro/employee)	Share of renewable energy (%)	Relative employee productivity in the EGSS sector (index)	Environmental taxes/employee (Euro/employee)
Austria	21,680.05	34.06	0.10	0.04
Belgium	10,757.06	13.82	0.12	0.14
Bulgaria	2,278.51	19.08	0.03	0.11
Croatia	1,113.06	28.09	0.02	0.05
Cyprus	512.73	19.43	0.04	0.05
Czechia	7,875.44	18.12	0.05	0.67
Denmark	12,044.81	41.37	0.13	0.75
Estonia	1,719.76	38.54	0.05	0.03
Finland	16,473	47.74	0.12	0.05
France	62,830.21	20.33	0.08	0.07
Germany	105,746.2	20.81	0.13	0.09
Greece	6,156.09	22.67	0.05	0.09
Hungary	867.95	15.13	0.02	26.10
Ireland	4,402.68	13.02	0.10	0.10
Italy	79,859.73	19.13	0.07	0.04
Latvia	1,329.9	43.72	0.05	0.03
Lithuania	2,325.43	29.60	0.04	0.02
Luxembourg	2,600.62	14.29	0.09	0.03
Malta	150.36	14.04	0.04	0.08
Netherlands	35,418.83	15.29	0.17	0.14
Poland	13,110.02	16.64	0.04	0.24
Portugal	8,186.52	34.68	0.04	0.02
Romania	8,727.57	24.23	0.05	0.26
Slovakia	1,846.03	17.48	0.04	0.05
Slovenia	760.08	25.00	0.02	0.05
Spain	40,803.94	21.84	0.07	0.04
Sweden	21,256.85	66.29	0.13	0.68

Source: own processing, Eurostat [9, 10, 11, 12].

Relative productivity indicators and environmental taxes per employee add additional insight into the architecture of the green sector. Countries with high relative productivity and moderate environmental taxation suggest a stable model, where technological capacity and sustainable financing mechanisms work in synergy. In contrast, in economies with low productivity and low environmental taxation, the impact of green investments on economic value remains limited, reflecting structural difficulties in upgrading environmental activities and adopting clean technologies. The existence of extreme values of taxation indicates either methodological peculiarities or dependence on atypical economic structures.

Thus, the analysis of the four indicators shows that the performance of the EGSS sector is the result of the interaction between industrial

capacity, energy progress and the design of fiscal policies. Countries that manage to coherently integrate these three dimensions benefit from a more robust, competitive and efficient green economy. In contrast, economies in which these components evolve asynchronously reflect difficulties in transforming sustainable financing into tangible economic advantages. This integrated perspective thus highlights both the existing disparities between Member States and the strategic directions needed to consolidate the ecological transition at European level.

Table 4. Matrix of correlations between economic, fiscal and energy indicators of the EGSS sector in the European Union in 2023

	EGSS Employment 2023	EGSS VA 2023	Env Taxes 2023	Renewables 2023
EGSS Employment 2023	1	0.929765	-0.05164	-0.13171
EGSS VA 2023	0.929765	1	-0.06135	-0.07473
Env Taxes 2023	-0.05164	-0.06135	1	-0.13308
Renewables 2023	-0.13171	-0.07473	-0.13308	1

Source: own processing, Eurostat [9, 10,11, 12].

Employment in the EGSS sector and the value added produced are consistently correlated, according to the correlation matrix (Table 4), indicating that EU Member States with a sizable workforce in environmental goods and services are typically also those where the sector generates the highest economic value. This link highlights the role of industrial capacity and strengthened economic ecosystems in supporting the performance of the green sector, indicating that investments in human capital and technological infrastructure are directly reflected in economic efficiency.

The share of renewable energy and employment or value added, on the other hand, show poor correlations, demonstrating that Europe's green transition is taking different courses. In instance, the rise of renewable energy sources and the EGSS business do not always occur together. While some nations attain large proportions of renewable energy without having an equally productive EGSS sector, others thrive in high-value-added industrial sectors but take longer to restructure their energy infrastructures. The structural, institutional, and regional variations in the application of climate policies are reflected in this lack of synchronization.

Weak connections between environmental taxes and other metrics imply that employment or economic performance in the EGSS sector are not directly influenced by the amount of environmental taxes. This could suggest that environmental levies are primarily employed as a means of deterring polluting activities rather than directly affecting productivity or the composition of the green sector. Simultaneously, notable variations among nations demonstrate the variety of fiscal approaches, legal systems, and administrative capabilities to execute successful carbon pricing regulations

As a result, the correlation matrix presents a nuanced view of the EU's green transition. While the weak correlations with taxation and renewable energy highlight the fact that climate, fiscal, and economic policies frequently evolve on different trajectories, the strong correlation between employment and value added emphasizes the significance of human capital and industrial capacity in the development of the EGSS sector. Some economies can quickly transform sustainable finance into great economic achievements, but others move more slowly or in different directions. This is explained by the diverse structure of the green transition.

Insisting on Romania's positioning in relation to the European Union Member States, an EGSS sector in full development is highlighted, but characterized by important disparities compared to the advanced economies of the EU. The level of employment in the environmental goods and services sector places Romania in the middle of the European distribution, reflecting both the gradual expansion of green activities and the structural limitations of the labor market. Although the

EGSS labor force has expanded in recent years, the growth rate remains dependent on European investments and national programs for the modernization of environmental infrastructure. Value added per employee and relative productivity indicators show that Romania is below the EU average, which confirms that green activities are predominantly concentrated in segments with modest economic value, such as waste management or operational services. The lack of a critical mass of advanced green industries and the persistent reliance on low-technology activities limit Romania's ability to transform sustainable financing into robust economic growth. Thus, the gap with Western European economies reflects both technological gaps and institutional constraints of the national industrial ecosystem. In terms of the share of renewable energy, Romania ranks above some Western European countries, which shows substantial progress in the energy transition, supported by favorable natural resources and investments in wind and hydropower. Nevertheless, structural constraints and the sluggish rate of grid modernization continue to have an impact on the integration of clean sources into the energy system, and the dynamics of renewable technology adoption are still unequal. The low level of EGSS productivity, which implies that the energy transition is not yet accompanied by a proportionate industrial development in the field of green technology, must be linked to this energy advance.
Romania is at the top of the European distribution when it comes to environmental taxes, demonstrating the use of fiscal tools to address activities that have an impact on the environment. However, the sector's productivity and value added do not immediately reflect the high tax rate, indicating that fiscal policies have not yet been successfully integrated with industrial plans and sustainable financing structures. Romania still has issues with effectively allocating the funds raised by environmental levies and directing them toward ventures with significant potential for innovation and competitiveness. Romania's overall profile is mixed, with notable advancements in the energy transition and job growth, but low productivity, little value addition, and a restricted ability to incorporate sustainable financing in high-potential industrial sectors. In order to boost economic performance in the EGSS sector, policies focused on technological modernization, bolstering green industrial ecosystems, and making effective use of fiscal and financial tools are necessary, as indicated by this structural gap with advanced economies.

CONCLUSIONS

Sustainable finance has emerged as a key component of economic change and the expansion of the green labor market, according to an analysis of the EU's environmental goods and services industry. The growth of investments in clean technology, green infrastructure, and climate transition initiatives supports the steady development of the green economy, as seen by the evolution of employment and economic value produced by EGSS. Differences between Member States remain visible, but the general trend points to a gradual convergence, especially in the context of the acceleration of European green finance programmes.
The high economic performance of advanced economies suggests that the results of sustainable investments depend directly on the industrial structure, technological capacity and the integration of value chains associated with environmental activities. At the same time, energy progress and fiscal instruments specific to the ecological transition often evolve separately from economic dynamics, which reflects the complexity of the process of adapting to European climate policies. This gap highlights the need for more integrated approaches between industrial, fiscal and energy strategies at national level.
Romania's positioning is part of the general trend of consolidating the European green sector, but significant gaps remain in terms of productivity and the capacity to capitalize on sustainable financing. The expansion of employment and the advance in the field of

renewable energies confirm Romania's progress in the ecological transition, but the transformation of these developments into high economic performance requires technological modernization, industrial specialization and the strengthening of institutional mechanisms.

Thus, the results obtained indicate that sustainable financing produces its effects to the extent that it is supported by solid industrial infrastructure, qualified human capital and coherent public policies. The states capable of integrating these dimensions into a unitary strategic framework are the ones that will benefit the most quickly from the potential of the green transition. Therefore, strengthening administrative capacity, stimulating innovation and accelerating investments oriented towards clean technologies remain essential conditions for consolidating the green economy at European level.

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SUSTAINABLE MOBILITY AND RURAL TOURISM DEVELOPMENT IN ROMANIA AND THE EUROPEAN UNION

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Abstract

This research analyzes the dynamics and structure of tourism demand in the European Union and Romania. It focuses on rural tourism developments and the role of sustainable mobility in transforming this sector. The analysis aimed to evaluate the influence of post-pandemic changes, visitor preferences, and territorial capacity on the development of tourism in urban, peri-urban, and rural areas. The main objectives were: identifying trends in the evolution of accommodation capacity; analyzing changes in the distribution of tourism demand by type of space; measuring the growth rate and resilience of the sector in the period 2015–2024; comparing Romania's performance with that of the EU. The research methodology was based on the analysis of statistical series provided by Eurostat, using quantitative indicators such as the annual growth rate, the share of rural areas in total accommodation nights and the resilience index, calculated as the ratio between the values in 2024 and the pre-pandemic levels. Descriptive and comparative methods, as well as standardized formulas for measuring dynamics, were also integrated, which allowed us to interpret developments in a coherent and replicable manner. The results obtained highlight a structural increase in tourism capacity in the EU and Romania, with a higher CAGR in Romania. Tourism demand shows an intensification of orientation towards rural areas, a phenomenon especially visible in Romania, where the share of rural areas rises to 27%. Although both systems have strongly felt the decline in 2020, their resilience is high: the EU returns to around 96% of the pre-pandemic level, and Romania to around 89%, confirming a general trend of accelerated recovery. The conclusions formulated support the strategic importance of rural tourism as a vector of sustainable mobility and diversification of the offer. The analysis demonstrates the convergence of the adjustment processes between the EU and Romania and highlights the need for coherent policies regarding infrastructure, sustainability and the valorization of rural resources, in a context in which demand is reoriented towards spaces with low density and high development potential.

Key words: *resilience, sustainable mobility, demand for travel, rural tourism, regional development*

INTRODUCTION

Tourism is one of the most dynamic sectors of the global economy. It makes major contributions to economic growth, employment, and infrastructure development in many countries. At the European Union level, the tourism sector plays a strategic role in regional competitiveness and in promoting balanced territorial development, being perceived not only as an income-generating industry, but also as a catalyst for socio-economic transformations [7]. Given the recent difficulties brought on by the COVID-19 epidemic, which has resulted in demand swings and altered how people travel and select tourist places, the significance of tourism has become even more apparent [4, 13, 16].

In the last decade, rural tourism has gained particular relevance in the debates on sustainable development and territorial cohesion. The Organization for Economic Cooperation and Development emphasizes that rural regions face challenges such as depopulation, population aging and the gradual elimination of public services, but at the same time they have valuable resources that can generate economic opportunities through diversified tourism activities [20, 21]. Rural tourism is thus considered an important tool for

revitalizing communities, consolidating local incomes and reducing disparities between regions [2, 19]. In Romania, this strategic function is highlighted both by the specialized literature and by statistical reports, which show that rural tourism remains one of the forms of tourism with the most significant evolution in the last two decades [24, 25].

At the academic level, rural tourism is analyzed as a multidimensional phenomenon, located at the intersection of economy, culture, environment and public policies. Studies emphasize its role in diversifying local economies, creating jobs and capitalizing on cultural specificity [5, 23]. Further research shows that, beyond the economic impact, rural tourism contributes to the revitalization of community identity and to the consolidation of perceptions of the authenticity of rural space [11, 17]. Also, the concept of "integrated rural tourism" proposed by Cawley and Gillmor highlights the need for an interdisciplinary approach that connects local resources, stakeholders and infrastructure in a coherent way [3]. These contributions reflect the gradual maturation of the field and the recognition of its complexity.

At the same time, recent changes in tourist behaviour have directly influenced the evolution of rural tourism. The European Travel Commission report shows that, after the pandemic, tourists show an increased interest in less crowded destinations, oriented towards nature and authentic experiences [10], a trend also confirmed by specialized studies on the consumption of local products or rural tourism experiences, which show an increased appreciation of identity and natural elements [14]. Moreover, the relationship between mobility and rural tourism is gaining increasing importance, given the excessive dependence on individual car transport, specific to many European rural regions, which results in significant challenges for sustainability and accessibility, aspects that are highlighted in Hall and Page's research on the geography of tourism and tourist mobility [12].

In Romania, the dynamics of rural tourism are influenced by both the rich cultural heritage and the territorial distribution of natural resources, with studies showing that rural areas can become important actors in regional development if supported by investments in transport infrastructure, diversification of services and integration into thematic tourism networks [22]. Other authors show that, although Romania has high potential, development is still uneven and vulnerable to external shocks, depending on the resilience of local systems and the adoption of sustainable development models [1, 18].

Access to coherent and comparable statistical data at European level has been essential for understanding these developments, with Eurostat providing a comprehensive framework for comparative analyses and this allows for an assessment of the dynamics of tourism demand and the relevance of rural areas in the context of contemporary European tourism [6, 7].

In addition to statistical analysis, recent literature also emphasizes the need to align tourism with sustainability objectives and the green transition. The European Commission, through documents such as the Transition Pathway for Tourism, emphasizes the need to reduce emissions, modernize infrastructure, promote sustainable mobility and encourage responsible consumption [8, 9]. Thus, the development of rural tourism must also be analyzed in relation to policies regarding mobility, accessibility and environmental protection, all of which have a decisive role in territorial competitiveness [15].

Given these conceptual, statistical and strategic developments, the present research is part of the direction of studies that investigate the interdependencies between the structure of tourism demand, mobility dynamics and rural development. The comparative analysis between Romania and the European Union aimed to identify the major trends in tourism demand, the transformations that have occurred in rural areas and how these influence the prospects for sustainable development. Thus, the main purpose of the research was to assess the extent to which recent developments support the consolidation of rural tourism as a vector of territorial development and to identify the convergences and differences

between Romania and the EU, with direct implications for future policies in the field of tourism and sustainable mobility.

MATERIALS AND METHODS

The research methodology assumed a mixed methodological design, combining descriptive statistical analysis with comparative methods to examine the evolution of tourism demand in the EU and Romania during the period 2015–2024. We were able to evaluate the sector's resilience and pinpoint structural changes in tourism demand because the investigated interval covered both the pre-pandemic dynamics and the disruptive impact of 2020 as well as the recovery stage.
The capacity of tourist reception buildings, the total number of nights spent in lodging units, and the breakdown of nights spent by territorial categories according to the DEGURBA classification—Cities, Towns and Suburbs, and Rural Areas—were the three primary statistical sets from the official Eurostat database that were used. By allowing us to examine demand in various ways depending on the type of location, these sets assisted us in assessing the specifics of rural tourism and its relationship to sustainable mobility.
Data processing included the calculation of derived statistical indicators frequently used in tourism studies and time series analyses. To assess the long-term trend, the compound annual growth rate – CAGR - was used, calculated as follows:

$$CAGR = (\frac{X_t}{X_0})^{\frac{1}{t}} - 1, \quad \text{.....(1)}$$

where:
X_0 - indicator value in the base year;
X_t - the indicator value in the last year of the interval;
t - number of years in the analyzed interval.
The annual growth rate was computed in order to monitor yearly fluctuations in demand:

$$rate_t = (\frac{X_t - X_{t-1}}{X_{t-1}}) \times 100, \quad \text{.....(2)}$$

where:
X_t - the value of the indicator in the current year;
X_{t-1} - the value of the indicator in the previous year.

By calculating the proportion of nights spent in rural areas, the pattern of visitor demand was investigated:

$$\text{Rural Overnight Share} = \frac{\text{Nights in isolated rural areas}}{\text{Total nights in all accommodation}} \times 100 \text{.....(3)}$$

The resilience index, which is the ratio of demand in 2024 to pre-pandemic demand in 2019, was utilized to evaluate the sector's ability to recover from the pandemic shock:

$$Resilience = \frac{X_{2024}}{X_{2019}}, \quad \text{.....(4)}$$

where:

X_{2019} - the indicator's value prior to the COVID-19 epidemic;
X_{2024} - the value of the indicator after the full resumption of tourist mobility.
The time series' evolutionary analysis, the structural analysis by area type, the comparison between Romania and the EU, and the interpretation of the connections between shifts in visitor demand and the dynamics of sustainable mobility were among the analytical techniques employed. According to Eurostat classifications, the processing was done only based on aggregate numbers.

RESULTS AND DISCUSSIONS

In the framework of the European Green Deal and the 2030 Agenda, one of the main goals of European policy is the shift to sustainable patterns of production and consumption. In this process, green policies—such as fiscal tools, clean energy development, and contemporary finance methods—are crucial in directing the economies of Member States toward greater sustainability standards. The present analysis tracks the combined impact of these policies on sustainability performance - SDG12, using harmonised indicators for the European Union countries. Using an integrated methodology based on modern statistical techniques and multi-annual panel data, the study aims to illustrate the structural relationships between green policies and the growth of sustainable consumption and production.
The data in Figure 1 reflect the evolution of the number of tourist accommodation establishments at EU level during the period

under review. While a moderate increase is observed between 2015 and 2019, corresponding to the gradual expansion of accommodation infrastructure in most Member States, starting in 2020 the number of establishments decreases as a result of the restrictions imposed on the tourism sector in the context of the pandemic. Subsequently, the values show a gradual recovery, and in the years 2022–2024 the levels return to values close to those recorded before the pandemic. The evolution is characterized by relatively uniform annual adjustments, typical of a mature tourism system in which variations are limited by the already consolidated structure of the market.

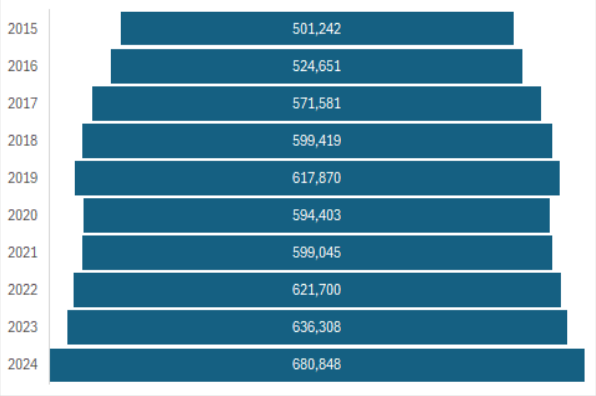


Fig. 1. Evolution of lodging facilities for tourists in the EU between 2015 and 2024 (number)
Source: own processing, Eurostat [6, 7].

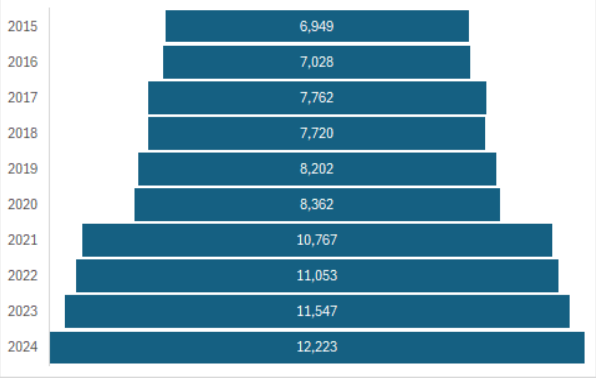


Fig. 2. Evolution of lodging facilities for tourists in the Romania between 2015 and 2024 (number)
Source: own processing, Eurostat [6, 7].

Romania's tourism capacity evolution differs from that of Europe, as Figure 2 illustrates. The Covid-19 epidemic prompted a similar decline in 2020, despite the fact that the growth of guesthouses and hotels in rural areas was more than the EU average between 2015 and 2019. However, it is noted that Romania experienced a sustained growth between 2021 and 2024, surpassing pre-pandemic levels due to an increase in small and medium-sized units focused on alternative forms of tourism. The show demonstrates that Romania's tourism infrastructure is currently expanding.

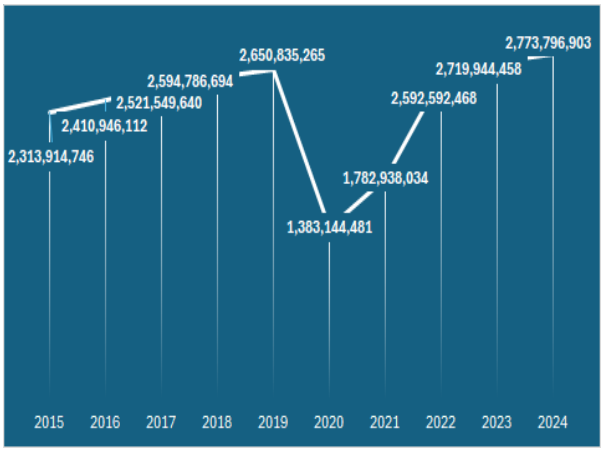


Fig. 3. Evolution of the number of nights that visitors from Europe in the EU-27 spent in lodging establishments between 2015 and 2024 (number nights)
Source: own processing, Eurostat [6, 7].

Different trends in demand and structural development are highlighted by the data on tourism and lodging infrastructure in Romania and the EU (Figures 3 and 4). In Romania and the EU-27, the number of nights spent in tourist lodgings increased gradually between 2015 and 2019, but sharply decreased in 2020 as a result of the pandemic before steadily increasing again. In parallel, the evolution of accommodation establishments indicates a more accelerated expansion in Romania compared to the EU average, reflecting a still-developing lodging market. In contrast, the EU-27 shows relatively stable structural adjustments, characteristic of a mature and consolidated accommodation system. These differences underline the divergent growth trajectories of the two markets, with Romania displaying higher elasticity in response to changes in tourist flows.
Changes in tourism demand, influenced by preferences for less crowded spaces and increased internal mobility in the post-pandemic years, have contributed to the repositioning of some rural areas as relevant

destinations, leading to adjustments in the territorial distribution of nights spent. These changes are more visible in Romania, because newly created or expanded infrastructure was quickly integrated into the tourism circuit, generating more pronounced annual variations and a progressive increase in the importance of extra-urban areas. At EU level, variations are more moderate, due to the existence of a more stable market, in which changes come mainly from external factors and from the redistribution of flows between types of destinations.

These trends require the need to consolidate infrastructure, especially in rural regions, where demand continues to shift constantly, but also the development of complementary services, diversification of the offer and improvement of accessibility through sustainable mobility solutions, which represent directions that can support the exploitation of existing potential, while reducing the pressure on traditional urban destinations.

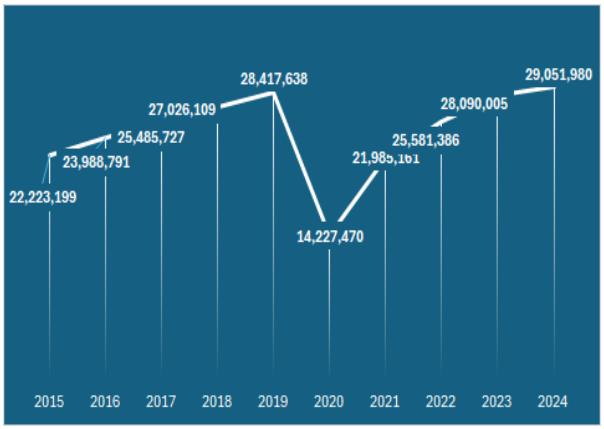


Fig. 4. Evolution of the number of nights that visitors from Europe spent in Romanian lodging businesses between 2015 and 2024 (number of nights)
Source: own processing, Eurostat [6, 7]

Table 1. Evolution of nights spent in accommodation facilities, in the EU and Romania, in the period 2015–2024 (Number of night)

Year	Cities		Towns		Rural	
	E.U.	Romania	E.U.	Romania	E.U.	Romania
2015	802,147,744	10,682,774	763,232,347	7,801,143	920,875,166	4,961,369
2016	826,479,721	11,459,949	796,977,711	8,343,836	962,562,278	5,470,864
2017	900,313,551	12,025,139	933,108,645	8,738,224	885,525,279	6,152,210
2018	939,921,354	12,528,123	954,910,375	9,242,167	916,260,119	6,690,863
2019	971,668,973	12,908,305	968,564,019	9,760,432	934,888,066	7,221,157
2020	382,725,598	5,414,349	465,803,799	5,281,891	573,566,859	3,758,224
2021	516,726,729	8,231,709	637,170,524	8,070,072	679,721,743	6,120,690
2022	906,468,306	11,116,484	922,516,283	8,603,309	925,888,181	6,894,428
2023	988,443,324	12,217,459	996,210,542	9,360,528	958,593,532	7,627,581
2024	1,026,683,680	12,550,760	1,039,730,089	9,678,929	955,349,909	8,001,515

Source: own processing, Eurostat [6, 7].

The distribution of nights spent by type of area highlights structural differences between the EU and Romania (Table 1). At European level, the three territorial categories - urban, suburban and rural - contribute in relatively balanced proportions to the total volume of tourist demand, with adjustments determined mainly by changes in mobility during the pandemic and post-pandemic period, while in Romania, the dynamics are different, with variations between areas. The urban market is more sensitive to changes in domestic and international mobility. For example, while changes in the EU are slow, they are more pronounced in Romania. There are also smaller variations in suburban areas in Romania, due to the intermediary role of these destinations between the urban and rural offer. As for rural areas, the evolution is distinct. At EU level, values remain relatively stable, with moderate adjustments during the pandemic period and a return to levels close to pre-pandemic levels, while in Romania demand for rural areas increases significantly after 2021, as a result of the repositioning of tourist preferences in favor of low-density destinations and a faster

integration of rural infrastructure into the tourist circuit. The differences observed between the two spaces indicate that Romanian rural areas benefit from a growing demand, supported by the expansion of the offer and the diversification of services, while at European level developments are more moderate, characteristic of a stabilized market.

Table 2. Dynamics and structure of tourism demand in the EU and Romania in the period 2015–2024

Indicator	Value
EU CAGR (%)	2.191
RO CAGR (%)	2.865
EU Rural Share (%) min–max	31.6–40.3
RO Rural Share (%) min–max	21.2–27.3
EU Resilience (2022/2019)	0.958
RO Resilience (2022/2019)	0.890

Source: own processing, Eurostat [6, 7].

The developments presented in Table 2 reflect significant differences between the European Union and Romania in terms of the pace and structure of tourism demand. The average annual growth rate indicates a more accelerated growth in Romania, where the long-term dynamics exceed the level recorded at EU level, despite much lower volumes, due to the gradual expansion of reception capacity and diversification of the offer.

The structure of demand has a stable distribution in the EU, where the share of rural areas remains within a narrow range, specific to a mature market, unlike Romania. However, due to the shifting preferences of tourists and the growing value of low-density areas, the percentage of nights spent in rural areas is rising. This evolution contributes to the reconfiguration of the urban-rural ratio and confirms the growing interest in natural spaces and alternative tourism experiences.

The post-pandemic resilience analysis highlights an almost complete recovery in the EU and a substantial return in Romania, although slightly slower. The difference is due to the different structure of the markets, the degree of dependence on international tourism and the pace of reactivation of mobility. The dynamics highlighted by the calculated indicators confirm the emerging nature of the Romanian market and the high degree of adaptability of the rural segment, relevant elements for the orientation of future policies and investments in sustainable tourism.

The developments in the period 2015–2024 reflect structural transformations in tourism demand in the EU and Romania, which go beyond the simple variation in volumes and outline changes in the spatial and functional configuration of tourist mobility. Taken as a whole, this evolution highlights a process of gradual redistribution of demand, in which low-density areas are visibly gaining ground, both as recreational destinations and as alternatives to established urban spaces. This trend does not derive only from conjunctural contexts, but expresses a sustainable reorientation of preferences, observable both in the European space and at national level.

The differences between Romania and the EU are less about the direction of changes and more about their intensity. Romania is registering faster adjustments in the structure of demand, as a result of the greater sensitivity of the market to socio-economic conditions, but also of the increased openness to alternative forms of tourism. The increasingly high level of demand for rural destinations shows that tourist mobility is diversifying, and the duration and typology of stays are acquiring a more pronounced component of local and experiential exploration. At the same time, the EU presents a more uniform evolution, in which the structure of demand is less influenced by cyclical factors.

An essential element that emerges from the analyzed series is the different way in which the two areas absorbed the pandemic shock. Although both returned to levels close to previous ones, the way in which demand was redistributed is distinct. At the European level, the recovery occurred in relatively proportional parameters between areas, which denotes a diversified and well-calibrated tourism system. In Romania, the recovery is associated with a sharp reconfiguration of preferences, in favor of the rural environment and peri-urban destinations, which indicates a recalibration of internal mobility, with structural effects in the medium term. Thus, the relationships between

growth rate, demand structure and post-pandemic resilience indicate that Romania is aligning with European trends, but is following this trajectory at its own pace, more dynamic and more responsive to changes in consumer behavior, this uniqueness offers significant potential for the growth of rural tourism, which is becoming into one of the primary paths of market development rather than only an alternative. However, the EU's internal variety and structural stability serve as helpful benchmarks for assessing upcoming phases of the Romanian market's growth.

CONCLUSIONS

The comparison of Romania's tourism demand with that of the EU reveals that, although the two areas differ significantly in size and maturity, the directions of evolution are convergent. Rural tourism represents a strategic vector of growth for Romania, with the potential to consolidate sustainable mobility and diversify the offer.

The differences in resilience and pace of post-pandemic adjustments highlight a different degree of sensitivity to changes in the external environment, but confirm the capacity of both systems to return to levels close to previous ones. In both cases, emerging trends favor the redistribution of flows towards low-density areas, which opens up prospects for strengthening strategies oriented towards sustainability.

The results of the analysis support the need for coherent public policies and investments oriented towards infrastructure, connectivity, quality of services and protection of rural resources, as the observed developments indicate that rural tourism will continue to be a central element of the transformations in the tourism sector both in Romania and within the EU.

The expansion of interest in rural areas and the diversification of mobility forms associated with them show the need for an integrated approach that capitalizes on the complementarity between rural and urban environments. In this sense, the development of territorial networks that facilitate access to emerging destinations, together with the promotion of forms of transport with low environmental impact, can amplify the role of rural areas in the overall tourism economy. In order to support a growth model that prioritizes territorial balance and the preservation of natural assets, it becomes imperative that local, regional, and European actors expand their collaboration mechanisms. In the future, the competitiveness of rural destinations will depend on their capacity to integrate digital technologies, to highlight cultural identity and to diversify the experiences offered to visitors, and adapting to global trends – such as the increase in interest in green, experiential and responsible tourism – can transform rural areas into a pole of long-term attractiveness. Therefore, future development directions should privilege innovation, sustainability and multilevel cooperation, to ensure the consolidation of the role of rural areas in regional and European tourism dynamics.

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DEGREE OF CONVERGENCE OF THE STATE OF HEALTH INFRASTRUCTURE IN RURAL AREAS OF BULGARIA

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Abstract

This study examines the development of healthcare infrastructure in the rural areas of Bulgaria during the period 2007–2024, with a focus on the degree of convergence relative to the capital based on key indicators – hospital beds, general practitioners, and specialist physicians per 10,000 inhabitants. The analysis reveals significant territorial disparities, with rural areas remaining substantially disadvantaged in terms of access to hospital care and availability of medical personnel. Most municipalities exhibit either a lack of convergence or divergence compared to Sofia, while only a limited number of areas demonstrate positive trends. The findings underscore the importance of implementing context-specific health policy measures, such as coordinated regional planning, strengthening regionally based healthcare facilities, and introducing supportive mechanisms for medical professionals, with the aim of narrowing access gaps and enhancing the overall standard of healthcare provision in rural areas.

Key words**:** *healthcare infrastructure, rural areas, convergence, access to healthcare, territorial inequalities*

INTRODUCTION

Health infrastructure represents a complex and interconnected system of institutions, organizations, structures, and activities aimed at preserving, strengthening, and restoring the population's health. As a key component of social infrastructure, it is a crucial factor for the socio-economic development of individual regions in the country. Its functioning depends on government policy in the sector, as well as on the demographic, economic, and territorial characteristics of the various municipalities.

The priorities for the development of health infrastructure are outlined in the main national strategic documents – [13], [12], and [15]. The fundamental principles of healthcare are legally established in Article 52 of [20], which guarantees citizens the right to health insurance, access to medical care, and free use of medical services under conditions and procedures defined by law.

Despite the clearly defined regulatory framework in the Constitution, a significant portion of the population continues to have limited access to necessary health services. The disparities are particularly pronounced between the capital, urban municipalities, and rural areas. As noted in [14], a major problem in the country's healthcare system is not only the shortage of medical specialists but also their uneven territorial distribution, which restricts access to health services across different regions, limits the implementation of promotion and prevention policies, and leads to an excessive workload for medical professionals in underserved areas. Therefore, the topic of balanced distribution of healthcare services and medical personnel is of critical importance for public health and the population's quality of life in the country.

The observed differences between the capital, rural, and urban municipalities indicate the existence of imbalances in the territorial distribution of health infrastructure, the underestimation of which calls into question the effectiveness of support for rural development under national and European programs [8], [9], [10], etc. Neglecting these structural factors and not conducting sufficient evaluations of their causes and consequences can lead to multiple issues, including lower

patient satisfaction and reduced quality of healthcare services [11]. Mikova (2022) analyzed the trends and patterns of changes in the health and educational infrastructure in rural areas of Bulgaria between 2008 and 2020 using the Regional Factor Shift Analysis (RFSA) [16].

To determine the factors that impact the utilization of health care services, Atanasova and Panayotova, used Andersen's Behavioural Model [1].

In Kyustendil region of Bulgaria, in the emergency cases, the population is facing difficulties to access the medical services [18]. The sustainable development of the rural areas is closely linked to the health status of the population [7].

In this context, the aim of this study is to analyze the processes of convergence and divergence in the development of health infrastructure in Bulgaria and to assess the extent to which rural municipalities are catching up with the capital in key indicators of health coverage during the period 2007–2024. Achieving this goal provides an analytical basis for formulating more effective policies aimed at reducing territorial inequalities in healthcare and improving equitable access to health services, particularly in rural and peripheral areas of the country.

MATERIALS AND METHODS

The present study examines rural municipalities that meet the criteria for rural areas and are explicitly listed in the Strategic Plan for the Development of Agriculture and Rural Areas. The definition of rural areas is based on the administrative division of the country. In Bulgaria, the administrative unit used is the municipality. According to the national definition, 215 municipalities in which there is no settlement with a population exceeding 15,000 inhabitants are classified as rural areas (Map 1). Fifty municipalities are excluded from the scope of rural areas. Data on these municipalities have been used in cases where it is necessary to compare the existing differences between rural and urban municipalities. For the analysis, the following indicators were used: the number of hospital beds per 10,000 inhabitants, the number of general practitioners per 10,000 inhabitants, and the number of specialist physicians per 10,000 inhabitants. The study uses officially published data from the current demographic and social statistics of the NSI for the period 2007–2024. The maps in this study were produced using ArcMap (ArcGIS Pro) software, and the statistical analysis was conducted with Excel (MS Office).

To achieve the stated objective, the convergence method proposed by Ivanov [4], [5], [6] was applied, which assesses the degree of convergence of rural areas in Bulgaria relative to the reference municipality (Sofia) for the period under study. The analysis covers two consecutive sub-periods – 2007–2015 and 2016–2024 – and was carried out by examining the trend of the convergence coefficient (**K_CNV**) for each of the included indicators to determine whether the convergence processes between municipalities are strengthening or weakening over time.

The convergence coefficient used is illustrated as follows:

$$\mathbf{K_{CNV}} = \frac{\frac{\mathbf{IV^{t}_{SubST}}}{\mathbf{IV^{t}_{BscST}}} + \left(\frac{\left(\mathbf{IV^{t}_{SubST}} - \mathbf{IV^{t-1}_{SubST}}\right) - \left(\mathbf{IV^{t}_{SbcST}} - \mathbf{V^{t-1}_{SbcST}}\right)}{\mathbf{IV^{t^{0}}_{BscST}}}\right)}{2} + \mathbf{IV^{t-1}_{BscST}}$$

where:

K_CNV – the convergence coefficient, which measures the extent to which a rural municipality is approaching the level of the reference municipality (Sofia);

IV^{t}_SubST - the value of the indicator for for the rural municipality in the current period t;

IV^{t}_BscST - the value of the indicator for for the reference municipality (Sofia) in the current period t;

IV^{t-1}_ SubST - the value of the indicator for the rural municipality in the previous period t−1;

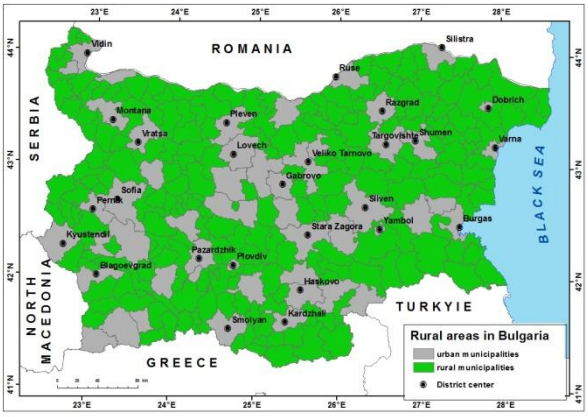
IV^{t-1}_BscST – the value of the indicator for the reference municipality in the previous period t−1.

The values of K_CNV can be interpreted as follows: a coefficient around 1 (K_CNV ≈ 1)

implies minimal change between the two sub-periods (2007–2015 and 2016–2024), suggesting that convergence has not occurred; a value above 1 (K_CNV > 1) indicates that the rural municipality is either catching up with or moving further from the reference municipality depending on the indicator; a value below 1 (K_CNV < 1) reflects a decrease in the coefficient, which may correspond to either convergence toward Sofia or a divergence trend, based on the context of the indicator.

Divergence is said to occur when the coefficient moves away from one, regardless of whether its value increases or decreases relative to it. Convergence is present when the coefficient approaches one, regardless of whether its initial value was lower or higher.

In the analysis of population access to medical care, particular attention was paid to the characteristics related to the territorial distribution of medical services and healthcare. Healthcare facilities do not serve only the population of a single municipality, but often provide services to people from several neighboring municipalities or even from more distant areas. This means that healthcare services are considered as an interconnected system.



Map 1. Rural and urban municipalities in Bulgaria at the LAU 1 level (municipalities) according to the national definition in [16] for the 2023–2027 programming period
Source: [10].

Urban municipalities and the capital are characterized by a concentration of hospitals, specialized clinics, and medical professionals (Map 1).

The attraction of patients from other parts of the country leads to a distortion of statistical data, urban municipalities appear to be better medically provisioned, while in reality, their resources are also utilized by populations from other regions.

A combined approach was used to assess the convergence of urban and rural areas. In addition to quantitative data, such as: the number of hospital beds, general practitioners, and medical specialists—the interconnections between municipalities were also analyzed, showing the extent to which the population actually has access to healthcare services. This allows for a more accurate assessment of whether there is a convergence or divergence in the level of healthcare provision between individual municipalities.

RESULTS AND DISCUSSIONS

The healthcare network developed in the country over several decades has left a mark on its territorial distribution, not only in terms of municipalities and regions but also regarding major regional planning structures. In addition, the changes made in accordance with the Law on Medical Institutions have had a certain impact on the territorial structure of hospital and outpatient care [2]. As a result of these processes, by 2024 there is a clearly differentiated territorial distribution of hospital facilities: 66 institutions operate in the capital, 175 in urban municipalities outside Sofia, and 78 in rural municipalities. This pattern shows that larger urban centers generally have better availability of hospital care, whereas rural municipalities are comparatively underserved, resulting in structural inequalities in healthcare access. Therefore, analyzing how healthcare provision in rural, urban, and capital municipalities aligns over time is essential to evaluate the fairness of access to medical services.

Accordingly, in the present study, the main analytical indicator is the availability of hospital beds, which reflects both the accessibility and the capacity of the healthcare system to provide medical services across different types of municipalities.

The availability of hospital beds is significantly higher in urban municipalities and

the capital (77.6 and 76.8 per 10,000 inhabitants, respectively), exceeding the national average of 73.4 per 10,000 inhabitants (Figure 1).

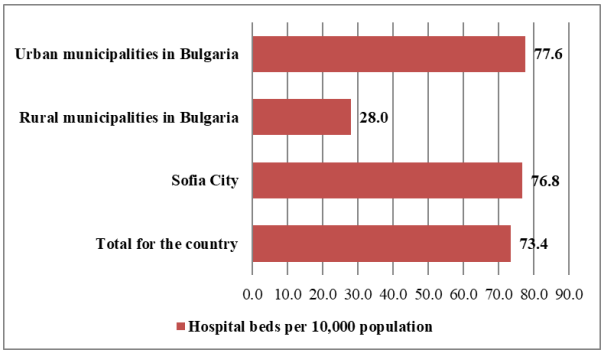


Fig. 1. Availability of hospital beds for the population in the period 2007–2024 (number per 10,000 inhabitants)
Source: based on data and own calculations [17].

Rural municipalities stand out with the lowest provision—only 28 hospital beds per 10,000 inhabitants, representing more than a twofold lag compared to the national average. The data clearly indicate a pronounced urban-rural imbalance in access to hospital infrastructure.

At the regional level, the degree of convergence in healthcare provision among rural municipalities was analyzed in two successive sub-periods—2007–2015 and 2016–2024—by tracking the trend of the convergence coefficient. The coefficient takes values greater than 0, with those approaching 1 indicating a high degree of convergence.

In the period 2007–2024, it was found that in 52 rural municipalities the trend of the convergence coefficient for the indicator availability of hospital beds per 10,000 inhabitants is close to that of Sofia City (**K_CNV ≈ 1**) or has values above one (**K_CNV > 1**). This indicates that in these municipalities, the level of hospital bed availability per 10,000 inhabitants remains stable relative to the capital, and in some cases shows a relatively more favorable trend over time. These municipalities are primarily located in the following districts: **Burgas** (Nessebar, Pomorie, Sredets), **Vratsa** (Kozloduy, Roman, Byala Slatina), **Montana** (Varshets, Berkovitsa), **Pleven** (Nikopol, Cherven Bryag, Gulyantsi, Levski, Belene, Kneja), **Plovdiv** (Parvomay, Sopot, Hisarya, Rodopi, Rakovski, Stamboliyski), **Razgrad** (Isperih and Kubrat), **Silistra** (Dulovo and Tutrakan), **Smolyan** (Zlatograd, Banite, Madan, Rudozem, Devin), **Districts of Sofia** (Etropole, Elin Pelin, Ihtiman, Pirdop, Svoge, Kostenets), **Stara Zagora** (Chirpan, Galabovo, Pavel Banya), and **Targovishte** (Omurtag and Popovo).

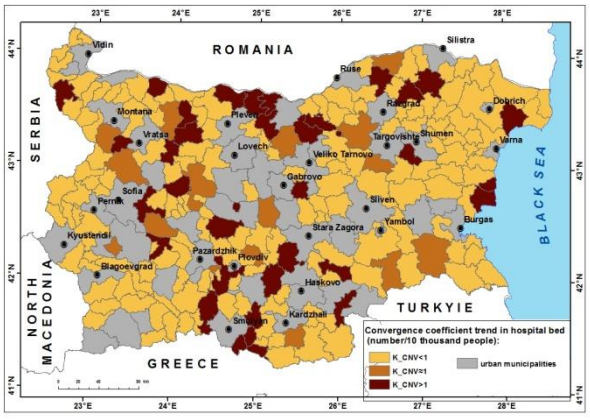
It should be noted, however, that in some of the above-mentioned municipalities (Nesebar, Pomorie, Banite, Devin, Pavel Banya) rehabilitation centers or specialized hospitals have been established, which are used by the population from across the country.

The concentration of medical facilities increases the level of regional healthcare provision and reduces the dependence of these municipalities on the district centers.

A significant share of rural municipalities in the country (70.7%) do not have their own hospital facilities, meaning that the population relies on hospital care located in other municipalities when needed.

This disparity highlights clearly defined regional cores with higher hospital accessibility, surrounded by peripheral areas with limited infrastructure provision.

During the period analyzed, in 163 rural municipalities the trend of the convergence coefficient for the indicator availability of hospital beds per 10,000 inhabitants remained below 1, indicating a lack of convergence toward Sofia City over time.



Map 2. Trend of the convergence coefficient for the indicator number of hospital beds per 10,000 inhabitants in rural areas of Bulgaria, 2016–2024 relative to 2007–2016
Source: own calculations based on the methodology by Ivanov, B. [4], [5], [6].

In 152 of these municipalities, the convergence coefficient remained at zero (K_CNV = 0), demonstrating an absence of positive changes relative to the reference municipality (Map 2).
In several districts, only one rural municipality has its own healthcare facility, as is the case in Vidin (Belogradchik), Gabrovo (Tryavna), Ruse (Byala), Shumen (Veliki Preslav), Sliven (Kotel), Yambol (Elhovo), Blagoevgrad (Razlog), and Kyustendil (Sapareva Banya). In the districts of Pernik and Pazardzhik, there are no rural municipalities with their own hospital facilities.
A similarly unfavorable situation is observed in municipalities such as Mineralni Bani, Tsarevo, Laki, Elena, Kula, Oryahovo, Iskar, Dryanovo, Balchik, General Toshevo, Tervel, Novi Pazar, Malko Tarnovo, Primorsko, Kotel, Maglizh, Gotse Delchev, Bobov Dol, Kocherinovo, Breznik, Radomir, Tran, Godech, Slivnitsa, Rodopi, Ivaylovgrad, and Simeonovgrad, where the closure of hospital facilities further limits the possibilities for timely and adequate access to medical care.
At the same time, in a total of 129 rural municipalities there is a complete absence of a municipal hospital, including Ruzhintsi, Chuprene, Borovan, Krivodol, Mizia, Hayredin, Apriltsi, Letnitsa, Ugarchin, Yablanitsa, Boychinovtsi, Brusartsi, Valchedram, Georgi Damyanovo, Medkovets, Chiprovtsi, Yakimovo, Dolna Mitropoliya, Dolni Dabnik, and other similar municipalities. This places the population in these municipalities in an especially vulnerable position regarding healthcare access.
The current situation clearly reflects a deepening problem with access to healthcare in Bulgarian villages. The closure of municipal hospitals and medical centers leads to the isolation of numerous settlements and to severely limited or entirely absent medical services. As a result, residents, particularly the elderly and chronically ill, are forced to travel significant distances to larger towns, often facing financial, transportation, and physical challenges. The main factors contributing to this situation are insufficient funding for municipal healthcare, demographic decline, shortages of medical personnel, and the ongoing centralization of healthcare services.
In Bulgaria, general practitioners play a central role in primary healthcare and work in independent individual or group practices that have contracts with the National Health Insurance Fund (NHIF) [3]. In 2024, they represent the highest relative share among all medical specialties in the country—12.4%.
The level of provision with general practitioners allows an assessment of how capable rural municipalities are of delivering outpatient medical services.
In the period 2007–2024, rural areas experienced a notable decrease in the number of general practitioners, with 531 fewer doctors, representing a 35.9% reduction. This decline is considerably higher than the national average, which shows a decrease of 23.9%. Consequently, the provision of general practitioners in rural municipalities remains limited, averaging 2,061 inhabitants per physician (Fig. 2).

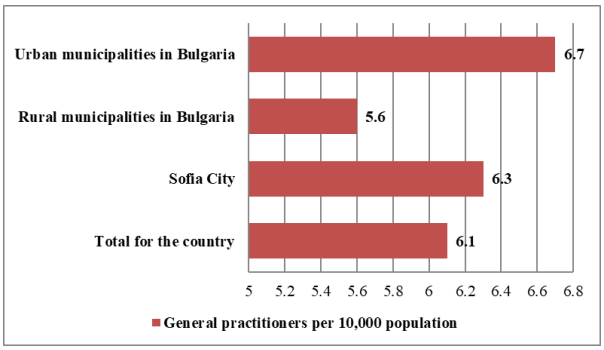
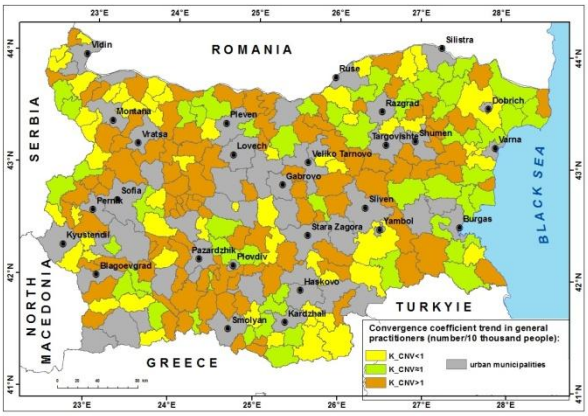


Fig. 2. Availability of general practitioners for the population in the period 2007–2024 (number per 10,000 inhabitants)
Source: based on data and own calculations [17].

A comparative analysis between the capital, urban, and rural municipalities reveals a clear territorial inequality in access to primary healthcare. Rural areas are in a less favorable position, while urban municipalities and the capital demonstrate the highest levels of provision 6.7 and 6.3 general practitioners per 10,000 inhabitants, respectively (Figure 2). This can be explained by the concentration of healthcare infrastructure, medical personnel, and better conditions for professional development.

During the period under review, in 59 rural municipalities there was no convergence toward the level of Sofia City for the indicator availability of general practitioners per 10,000 inhabitants, as the trend of the convergence coefficient in these municipalities is **K_CNV < 1** (Map 3). This indicates an increasing gap over time compared to the baseline municipality. A significant share of these municipalities is concentrated in the following districts: **Vidin** (Gramada, Novo Selo, Dimovo, Boynitsa, Kula), **Varna** (Avren, Beloslav, Devnya, Dolni Chiflik), **Vratsa** (Hayredin, Mizia, Borovan, Kozloduy), **Kyustendil** (Treklyano, Nevestino, Bobov Dol, Boboshevo), **Montana** (Yakimovo, Georgi Damyanovo, Medkovets, Chiprovtsi, Boychinovtsi), **Stara Zagora** (Bratya Daskalovi, Pavel Banya, Opan), and **Haskovo** (Madjarovo, Ivaylovgrad, Simeonovgrad, Topolovgrad, Stambolovo, Mineralni Bani).



Map 3. Trend of the convergence coefficient for the indicator number of general practitioners per 10,000 inhabitants in rural areas of Bulgaria, 2016–2024 relative to 2007–2015

Source: own calculations based on the methodology by Ivanov, B. [4], [5], [6].

The unfavorable trend in the availability of general practitioners in these municipalities is due to pronounced processes of population decline and depopulation, as well as the aging of medical personnel, which is not offset by the entry of a sufficient number of young doctors. Limited opportunities for specialization and professional development lead to a lack of incentives to establish practices in small settlements and result in a persistent outflow of staff to larger towns. Difficult access to complementary services such as pharmacies and laboratories further complicates the work of general practitioners and reduces the attractiveness of practicing in these municipalities.

In the period 2007–2024, in 89 rural municipalities in Bulgaria, the trend of the convergence coefficient for the indicator general practitioners per 10,000 inhabitants is above one (**K_CNV > 1**), indicating an increase in its values over time relative to Sofia City. These municipalities are primarily located in the following districts: **Blagoevgrad** (Strumyani, Satovcha, Simitli, Yakoruda), **Vratsa** (Oryahovo, Krivodol, Roman, Byala Slatina), **Lovech** (Apriltsi, Letnitsa, Teteven, Ugarchin), **Pazardzhik** (Sarnitsa, Bratsigovo, Lesichovo, Batak), **Pleven** (Nikopol, Belene, Cherven Bryag, Levski), **Plovdiv** (Laki, Perushtitsa, Sadovo, Kuklen, Kaloyanovo, Stamboliyski, Rodopi, Parvomay), **Smolyan** (Nedelino, Zlatograd, Dospat, Devin, Chepelare), **Districts of Sofia** (Anton, Chavdar, Pirdop, Zlatitsa, Etropole, Kostenets, Dolna Banya, Chelopech, Koprivshtitsa, Mirkovo, Pravets, Slivnitsa, Svoge), **Stara Zagora** (Chirpan, Nikolaevo, Radnevo, Maglizh), **Shumen** (Kaspichan, Veliki Preslav, Smyadovo, Varbitsa, Kaolinovo), and **Yambol** (Bolyarovo and Straldzha).

At the same time, in 67 rural municipalities in the country, the trend of the convergence coefficient for the indicator availability of general practitioners approaches one (**K_CNV ≈ 1**), indicating that the values over time are close to those of Sofia City (Map 3). These municipalities are located in the following districts: **Blagoevgrad** (Garmen, Razlog, Belitsa), **Burgas** (Sozopol, Ruen, Pomorie, Nessebar, Sungurlare, Kameno, Malko Tarnovo), **Varna** (Vetrino, Aksakovo, Suvorovo, Valchi Dol), **Dobrich** (Balchik, Tervel, Kavarna, General Toshevo), **Kardzhali** (Ardino, Kirkovo, Momchilgrad, Chernoochene), **Pleven** (Iskar, Pordim, Dolna Mitropoliya, Kneja, Gulyantsi), **Plovdiv** (Saedinenie, Maritsa, Rakovski, Krichim, Hisarya, Brezovo), **Ruse** (Dve Mogili, Vetovo, Tsenovo), **Silistra** (Dulovo, Alfatar, Kaynardzha), **Smolyan** (Madan, Borino,

Rudozem), Districts of Sofia (Elin Pelin, Dragoman, Kostinbrod, Bozhurishte), Stara Zagora (Gurkovo and Galabovo), and Shumen (Nikola Kozlevo, Novi Pazar, Venets).

The relatively good provision of general practitioners in these two groups of rural municipalities can be explained by the presence of healthcare facilities that serve not only the local population but also residents of neighboring settlements.

In the period 2007–2024, rural areas of Bulgaria experienced a substantial reduction in the number of medical specialists, with 1,058 fewer professionals, corresponding to a 49.6% decline. This results in an average of 967 inhabitants per specialist in these areas. In contrast, at the national level, the number of medical specialists increased by 13.9% over the same period. Consequently, the provision of medical specialists in rural municipalities amounts to 6.3 per 10,000 inhabitants, which is markedly lower than the national average of 34.9 specialists per 10,000 inhabitants (Figure 3).

These values lag considerably behind urban municipalities and the capital, where provision is 36.9 and 43.8 specialists per 10,000 inhabitants, respectively. The main reason for this territorial imbalance is the concentration of multi-profile and specialized healthcare facilities in the capital and larger cities.

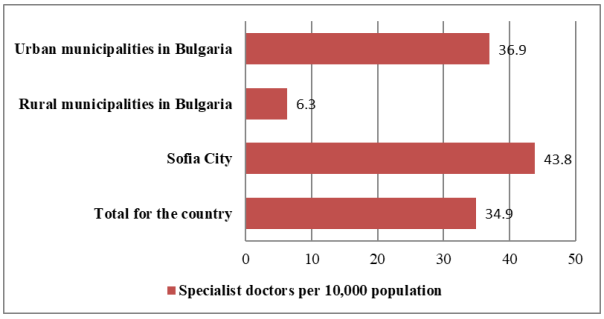


Fig. 3. Availability of medical specialists for the population in the period 2007–2024 (number per 10,000 inhabitants)

Source: based on data and own calculations [17].

In this context, the role of healthcare facilities with a specific profile and institutional affiliation should also be taken into account, as they further influence the spatial distribution of healthcare infrastructure. Facilities with a specialized function and profile include those under the Ministry of Defence, the Ministry of Interior, the Council of Ministers, the Ministry of Justice, and the Ministry of Transport. The same applies to infrastructure associated with the medical universities and their affiliated colleges. These include: the Medical Universities in Sofia, Plovdiv, Varna, and Pleven; the Faculty of Medicine at Trakia University in Stara Zagora; the Faculty of Medicine at Sofia University "St. Kliment Ohridski" in Sofia; and the Medical College at Prof. Dr. Assen Zlatarov University in Burgas [19]. This spatial and institutional concentration further deepens the uneven provision of medical specialists in the capital and provincial centers compared to rural municipalities.

The values of the trend of the convergence coefficient (**K_CNV**) for the period 2007–2024 indicate that in rural areas of Bulgaria, territorial disparities in the distribution of medical specialists are more pronounced compared to those for general practitioners. This reflects a stronger spatial concentration of specialized medical personnel and limited possibilities for their even distribution in less urbanized areas.

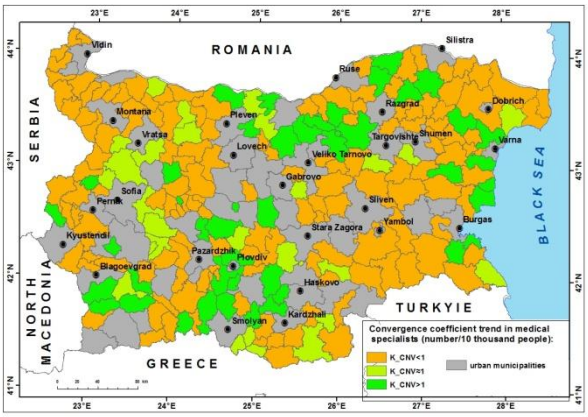
During the period under review, in 25 rural municipalities the trend of the convergence coefficient for the indicator availability of medical specialists per 10,000 inhabitants approaches one (**K_CNV ≈ 1**), reflecting a high degree of similarity in values over time relative to Sofia City (Map 4). These municipalities are primarily located in the following districts: **Pleven** (Levski, Kneja, Nikopol, Cherven Bryag), **Smolyan** (Rudozem, Zlatograd, Madan), **Districts of Sofia** (Dolna Banya, Kostenets, Kostinbrod, Svoge, Ihtiman, Elin Pelin), and **Stara Zagora** (Galabovo and Chirpan).

At the same time, in 42 rural municipalities divergence is observed for this indicator, as the trend of the convergence coefficient exceeds one (**K_CNV > 1**). This group includes rural municipalities in the districts: **Blagoevgrad** (Bansko, Simitli, Kresna, Sandanski), **Burgas** (Nessebar and Sozopol), **Varna** (Dalgopol, Aksakovo, Avren, Valchi Dol), **Pleven** (Belene, Gulyantsi, and Pordim), **Veliko**

Tarnovo (Pavlikeni, Polski Trambesh, Strazhitsa), **Plovdiv** (Parvomay, Maritsa, Hisarya, Sopot, Kuklen, Rodopi), **Smolyan** (Devin, Chepelare, Banite, and Dospat), and Districts of Sofia (Slivnitsa, Pravets, Chelopech) (Map 4).

Better access to specialized medical care in some municipalities is directly linked to the presence of multi-profile and specialized hospitals, as well as diagnostic and consulting centers, which serve as regional healthcare hubs. In most of these municipalities, there is also better transport accessibility, higher economic activity, and functional connectivity with larger urban centers, creating more favorable conditions for retaining and attracting medical specialists.

During the period under review, in small rural municipalities the trend of the convergence coefficient for the indicator availability of medical specialists per 10,000 inhabitants remains below one (**K_CNV < 1**), indicating that no convergence over time is observed relative to Sofia City.



Map 4. Trend of the convergence coefficient for the indicator number of medical specialists per 10,000 inhabitants in rural areas of Bulgaria, 2016–2024 relative to 2007–2015

Source: own calculations based on the methodology of Ivanov, B. [4], [5], [6].

These municipalities are located in the following districts: **Burgas** (Sredets, Pomorie, Kameno, Ruen, Primorsko), **Varna** (Dolni Chiflik, Provadia, Beloslav, Devnya, Vetrino), **Vratsa** (Byala Slatina, Roman, Oryahovo), **Dobrich** (Kavarna, General Toshevo, Tervel), **Kardzhali** (Krumovgrad, Momchilgrad, Ardino), **Pleven** (Dolni Dabnik and Dolna Mitropoliya), **Plovdiv** (Krichim, Rakovski, Stamboliyski, Brezovo), **Districts of Sofia** (Etropole, Pirdop, Bozhurishte, Dragoman, Zlatitsa, Godech), **Haskovo** (Lyubimets, Topolovgrad, Simeonovgrad, Ivaylovgrad), and **Shumen** (Veliki Preslav, Kaspichan, Novi Pazar) (Map 4).

Healthcare facilities in these municipalities are characterized by limited capacity and do not cover all medical specialties, resulting in a systematic redirection of patient flows to provincial hospitals and the capital.

Throughout the entire period 2007–2024, in 92 rural municipalities the trend of the convergence coefficient relative to the baseline municipality remains zero (**K_CNV = 0**), indicating a complete absence of registered medical specialists. These municipalities are located in the following districts: **Blagoevgrad** (Garmen, Satovcha, Strumyani, Hadzhidimovo), **Burgas** (Malko Tarnovo and Sungurlare), **Veliko Tarnovo** (Zlataritsa and Sukhodol), **Vidin** (Boynitsa, Bregovo, Gramada, Kula, Makresh, Novo Selo, Ruzhintsi, Chuprene), **Dobrich** (Dobrich–rural, Krushari, Shabla), **Kardzhali** (Dzhebel and Kirkovo), **Kyustendil** (Boboshevo, Nevestino, Rila), **Lovech** (Apriltsi, Letnitsa, Ugarchin, Yablanitsa), **Montana** (Boychinovtsi, Brusartsi, Valchedram, Georgi Damyanovo, Medkovets, Chiprovtsi, Yakimovo), **Pazardzhik** (Batak, Belovo, Bratsigovo, Lesichovo, Rakitovo, Sarnitsa), **Pernik** (Breznik, Zemen, Kovachevtsi, Tran), **Plovdiv** (Laki, Perushtitsa, Sadovo, Saedinenie), **Razgrad** (Zavet, Loznitza, Samuil, Tsar Kaloyan), **Ruse** (Borovo, Vetovo, Ivanovo, Slivo Pole, Tsenovo), **Silistra** (Alfatar, Glavinitsa, Kaynardzha, Sitovo), **Smolyan** (Borino and Nedelino), **Districts of Sofia** (Anton, Gorna Malina, Koprivshtitsa, Mirkovo, Chavdar), **Stara Zagora** (Bratya Daskalovi, Gurkovo, Nikolaevo, Opan), **Targovishte** (Antonovo and Opaka), **Shumen** (Venets, Varbitsa, Kaolinovo, Nikola Kozlevo, Smyadovo, Hitrino), and **Yambol** (Bolyarovo, Straldzha, Tundzha).

The analysis conducted shows that access to healthcare services in Bulgaria remains uneven, with rural areas being in a more

disadvantaged position compared to urban municipalities.

The lack of sufficient medical facilities and healthcare professionals limits the opportunities for the population in these territories to receive timely and quality medical care.

Health policy should aim to reduce territorial inequalities by expanding the availability of social service facilities and programs, as well as by improving the organization and incentives for healthcare personnel. Strengthening cooperation among municipalities and establishing regional health centers may help ensure fairer access to healthcare and improve the quality of life in rural areas with limited resources.

CONCLUSIONS

The analysis of healthcare infrastructure in its national and regional dimensions allows the following conclusions to be drawn:

-During the period 2007–2024, hospital bed availability per 10,000 inhabitants shows a clear urban-rural gap, with rural areas having limited access to inpatient care;

- In 75.8% of rural municipalities, no convergence in hospital bed availability is observed relative to Sofia, while only 52 municipalities show a positive trend;

-During the period under review, rural areas of Bulgaria experienced a significant decline in the number of general practitioners per 10,000 inhabitants, more pronounced than the national average, resulting in lower provision compared to urban municipalities and the capital;

-In 59 rural municipalities, insufficient provision of general practitioners per 10,000 inhabitants was observed (**K_CNV < 1**), while in 67 municipalities approximately equal levels were recorded (**K_CNV ≈ 1**), and in 89 municipalities a faster-than-average growth trend of the convergence coefficient was observed (**K_CNV > 1**);

-Rural areas of Bulgaria are characterized by a shortage of medical specialists, in the context of increasing provision at the national level, resulting in extremely low availability compared to urban municipalities and the capital;

-Only a limited number of rural municipalities achieve convergence in the indicator availability of medical specialists per 10,000 inhabitants, while in a significant share of them (92 municipalities) such personnel are entirely absent, highlighting the serious shortage of specialists;

The analysis shows that access to healthcare services in Bulgaria remains uneven, with rural areas being at a disadvantage compared to urban municipalities. The lack of sufficient healthcare facilities and medical specialists limits the ability of the population in these areas to receive timely and high-quality medical care.

Therefore, healthcare policy needs to focus on reducing territorial disparities through better planning and the motivation of the workforce in the healthcare sector. Improving coordination between municipalities and developing regional health centers can contribute to more equitable access to healthcare and enhance the quality of life for residents in under-served rural areas.

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COST-EFFECTIVENESS OF RAISING AND FATTENING EARLY-WEANED LIGHTWEIGHT PIGLETS USING A PROTEIN-BASED PORK MEAL ALTERNATIVE DURING THE INITIAL REARING PERIOD

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Abstract

A study on lightweight piglets (22–29 days old) showed that short-term feeding of a Pig Milk Replacer (PMR) significantly accelerated growth and improved economic efficiency. PMR usage led to a 21.1% increase in live weight after the nursery phase (29.8 kg vs. 24.6 kg) and a 6.1% increase at finishing (129.3 kg vs. 121.8 kg). The Average Daily Gain rose by 6.4% (49.7 g), while herd survival remained stable at 93.0%. Despite a 1.9% higher cost share for starter feeds, faster growth resulted in an earlier transition to cheaper rations, driving down overall costs. Total lifetime feed consumption was 1.5% lower (318.8 kg vs. 323.6 kg). The economic impact was substantial: the Feed Conversion Ratio improved from 2.8 to 2.6. Consequently, the feed cost per 1 kg of live weight dropped from 0.90 EUR to 0.85 EUR. Profit per head increased by 10.88 EUR to 44.82 EUR, and profitability soared from 31.0% to 42.9%. Thus, short-term PMR use is an economically sound practice that significantly boosts profitability.

Key words**:** *piglets, pig milk replacer, rearing, fattening, growth rate, feed conversion*

INTRODUCTION

Modern pig breeding focuses on increasing sow prolificacy; however, their physiological capacity for lactation does not increase proportionally to this increase. This results in a higher number of piglets being born than a sow can effectively nurse [4, 30]. Such an imbalance between the number of newborn piglets and the sow's lactational potential leads to a greater proportion of low-birth-weight piglets [15, 27]. As it was noted [8, 10], an increase in litter size decreases the average birth weight of piglets, raises pre-weaning mortality, and necessitates the use of nurse sows. Similar findings were reported by [1, 19, 29], who found that when the average litter size exceeds 20 piglets, the mean birth weight decreases to around 1.2 kg. The incidence of intrauterine growth retardation exceeds 10%.
The phenomenon known as "uterine crowding" limits the nutrient supply to fetuses [23], resulting in greater variability in birth weights and reduced viability of newborns. As a result, such piglets have lower energy reserves, poorer thermoregulation, and a higher risk of

mortality in the first days of life. The birth and weaning weights of piglets are key determinants of their subsequent performance [27, 33]. Research indicates that lighter piglets exhibit slower growth rates, poorer feed conversion, and higher mortality during the rearing phase [34, 36]. Experimental results [39] demonstrated that increasing the average live weight of piglets at the beginning of the rearing phase by just 1 kg can shorten the fattening period by 2–3 days and improve the final live weight by 2–2.5%. Similar trends were identified [3, 16, 35], who confirmed that initial body weight is a crucial factor determining nutrient utilization efficiency and growth rate during the production cycle.

Studies [12, 20] indicated that piglets with lower initial weights can partially compensate for their growth lag when provided with adequate protein nutrition and optimal microclimatic conditions. However, such compensation is usually accompanied by increased feed intake, which negatively affects overall economic efficiency. According to [9] a strong correlation exists between the starting weight of piglets and their survival rate. Piglets with lower weaning weights are more susceptible to stressors, show higher incidences of diarrhea, and exhibit reduced feed intake. As reported by [26, 32, 38], such piglets also face a higher risk of being culled during the early stages of rearing.

According to [28], piglets with higher live weight at weaning not only grow faster but also exhibit better muscle tissue development, leading to improved carcass meat quality at slaughter. Experimental findings [42] confirmed that weaning weight has a strong correlation with final fattening weight. Piglets with lower starting weights tend to adapt more slowly to solid feed and exhibit more pronounced symptoms of post-weaning stress. One of the most effective methods to equalize body weights within litters is cross-fostering–redistributing piglets among sows to reduce competition for milk [23]. In addition, early introduction of supplemental feeding (creep feeding) positively influences digestive system adaptation and increases weaning weight [2, 18, 39].

Low-birth-weight piglets require specialized technological and feeding interventions. The use of liquid or combined starter feeds has proven effective, as these facilitate the transition from milk to solid feed [6]. A positive effect is also observed when nutrient-dense milk replacers are used to compensate for the shortage of maternal milk in large litters. According to [3], such piglets achieve higher weaning weights, and this advantage persists throughout the rearing period. However, [7, 14, 21, 31] point out potential short-term growth delays in piglets fed with milk replacers, which may be related to a partial mismatch between the replacer's composition and the biological properties of sow milk. It was explained [22, 40] that early nutrition plays a crucial role in the development of the intestinal tract and microbiota.

According to [43], bioactive components in sow milk contribute to gut maturation and immune system strengthening, whereas piglets fed milk replacers develop a different microbiome [24, 41]. This may lead to higher incidences of diarrhea [13, 31]. However, modern, improved milk replacer formulas include prebiotics and immunomodulatory components that partially compensate for these differences. Feeding piglets with milk replacers during the suckling and post-weaning periods is economically justified, particularly in farms with hyperprolific sows. It helps equalize litter weights, reduce mortality, and increase average daily gain [2, 6, 15].

In experiment [25], the use of a milk replacer increased piglet body weight by 0.41 kg (7.4%) on day 16 after birth and by 0.3 kg (5.5%) at weaning, while also improving survival rates. Similar results were obtained [37, 42], who reported improvements in growth, intestinal development, and production efficiency. Although the use of milk replacers requires additional costs, the resulting improvements in growth performance, reduced mortality, and shortened fattening periods offset these expenses, enhancing the profitability of pig production [11].

Thus, high sow prolificacy increases the risk of low-birth-weight piglets, and effective

management should integrate genetic selection, husbandry, and feeding strategies. Sow milk replacers represent a promising tool to support growth, health, and economic efficiency in pig production; however, their effectiveness depends on formulation, dosage, and housing conditions [34]. A comprehensive management approach for low-birth-weight piglets ensures optimal performance and production stability within the industry.

Based on the above, it is relevant to investigate the impact of supplementing low-birth-weight piglets with sow milk replacer during the first week after early weaning. Therefore, this study aimed to evaluate the effect of short-term milk replacer supplementation (from day 22 to day 29 of life) for low-birth-weight piglets early weaned from hyperprolific sows on growth performance, survival rate, feed intake, feed conversion, cost structure, and overall economic efficiency compared to the traditional feeding system.

MATERIALS AND METHODS

The experiment involved 2,700 low-birth-weight piglets (≈ 5 kg at weaning), selected according to the protocol outlined in [17]. These animals were allocated randomly to either a control group or an experimental group of equal size. All environmental factors, including housing setup, space per pen, microclimate regulation, and equipment, were kept consistent across both groups.

The sole procedural variation was the diet offered between days 22 and 29 of life. Control pigs consumed only the routine compound feed. Meanwhile, experimental pigs were given an extra 130 g/pig dose of Nutrimilk Power liquid milk replacer, delivered concurrently with their main feed via the HydroMix Pro system.

During the suckling period, both groups received the Piggy Mill milk replacer starting from the second day of life. From day 17, they were additionally offered the Diamant prestarter feed, which, after transfer to the rearing unit (from day 22), was fed in liquid form. Once piglets reached 12 kg of body weight, they were switched to the Cargill Start 12–30 starter mix, which was used until the end of the rearing phase.

During the fattening phase, feeding was performed in a multiphase mode using liquid complete compound feeds (Cargill 30–60 Grower, Cargill 60–90 Finisher I, and Cargill 90–130 Finisher II) with the Megamix system. Feeding occurred 12 times per day, with a feeding front of 18 cm per head.

To monitor growth and fattening efficiency, four control pens were identified in each group, where animals were weighed at the beginning and end of each phase. Based on the collected data, average daily gain, feed conversion ratio, dry matter intake, and economic indicators (cost price, profit, and profitability) were calculated.

This study was conducted exclusively on low-body-weight piglets at weaning (approximately 5 kg), which limits the direct applicability of the results to piglets with average or higher body weight. Moreover, the experiment was performed under intensive commercial conditions using a liquid feeding system and controlled microclimate. Therefore, the effectiveness of milk replacer supplementation may differ under alternative housing, feeding systems, or management practices. In addition, only a short-term supplementation period of seven days after weaning was evaluated, and the effects of longer or alternative supplementation strategies require further investigation.

Statistical analysis was carried out using methods of variation statistics [16] in Microsoft Excel 2016. Differences between mean values were considered statistically significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$.

RESULTS AND DISCUSSIONS

To compare the seasonal variability in the ratio of body weight and proportion of low-birth-weight piglets relative to those of the main (standard-weight) group, an analysis was conducted using data from 2023 and 2024. The results, presented in Figure 1, demonstrate a distinct annual dynamic in both weight and the structural composition of the groups by body condition. The proportion of standard (main)

piglets among all weaned animals fluctuated throughout the year from 61.9% in summer to 69.4% in winter, while the share of low-birth-weight piglets showed the opposite pattern – being highest in summer (38.1%) and lowest in winter (30.6%). In our estimation, this difference could stem from the detrimental effects of elevated summer temperatures. These conditions typically diminish sow feed intake, which in turn hinders piglet growth during the crucial pre-weaning stage.

Seasonal factors influenced the mean weight of piglets as they began the rearing phase. The main group's weight ranged from 6.63 kg to 6.87 kg, whereas the low-birth-weight group's mass varied from 4.91 kg to 5.33 kg. The minimum difference (1.30 kg) occurred in summer. Expressed as a ratio, the low-birth-weight group's mass rose from 72.1% of the main group's mass in spring to 80.3% in summer, clearly demonstrating a relative convergence in weight during the summer season.

Overall, throughout the year, a trend toward a reduction in the proportion of low-birth-weight piglets and equalization of weight indicators in autumn was observed, followed by an increase in differences during winter. This pattern is likely related to microclimatic conditions and seasonal variations in housing management. Therefore, the findings confirm the importance of considering seasonal factors when organizing technological processes in piglet rearing, particularly regarding the optimization of housing conditions for sows and piglets during the summer–winter period.

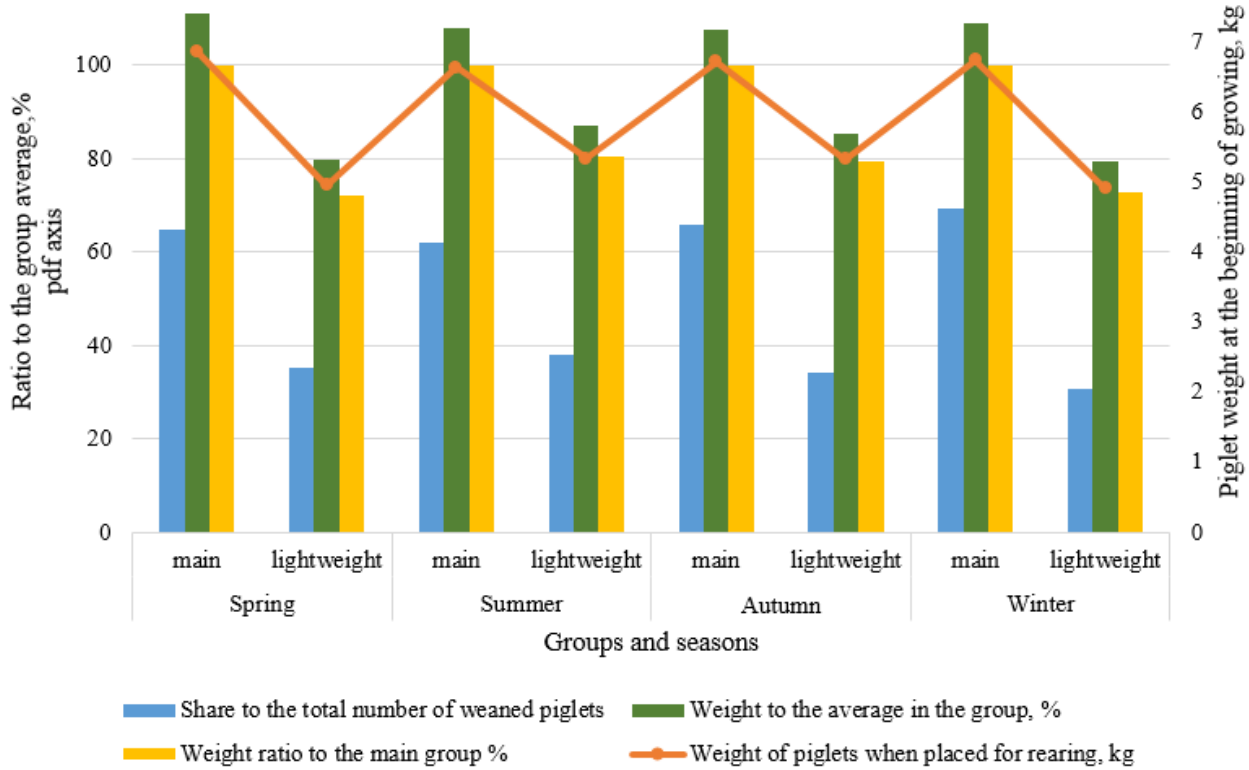


Fig. 1. Annual dynamics of mass and ratio of underweight and healthy piglets
Source: own calculations.

Due to the frequent occurrence of low-birth-weight pigs, a research project was launched to reduce the impact of early growth delay on the lifetime performance of piglets from hyperprolific sows. The results showed that the use of a pig milk replacer notably improved the growth rate and live weight progression of the experimental group. Specifically, as Figure 2 shows, Control Piglets (Group I), fed only a standard ration between day 22 and day 70, did not grow as quickly as the Experimental Piglets (Group II). This superior outcome in Group II, marked by greater live weights at the end of both the nursery and finishing phases, is attributed to the milk replacer supplement

provided during the first week of the nursery period (days 22–29).

During the fattening phase, the relative advantage in live weight declined to 6.2% as a result of compensatory growth among control pigs, but the absolute difference increased – by the end of the production cycle it reached 7.5 kg (129.3 kg vs. 121.8 kg).

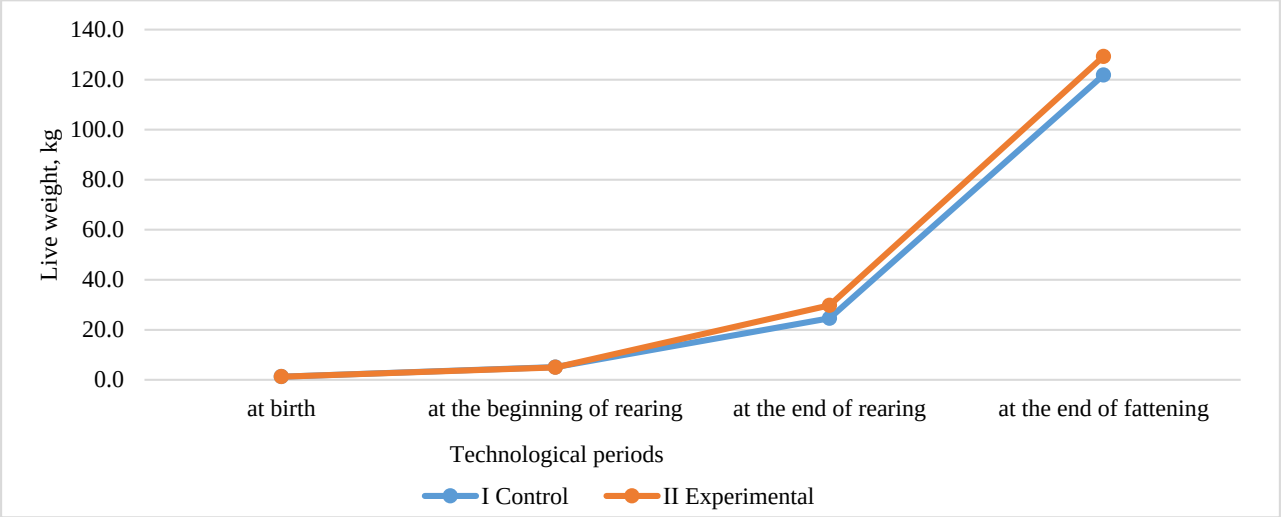


Fig. 2. Dynamics of live weight of pigs from birth to slaughter
Source: own calculations.

Hence, short-term administration of the pig milk replacer during the first week of rearing markedly enhanced growth intensity, yielding higher average weights at both post-rearing and post-fattening stages.

As summarized in Table 1, the experimental cohort also demonstrated slightly higher survival (93.0% vs. 92.7%) and significantly improved average daily gain – 823.0 g compared to 773.3 g in the control, a 6.4% increase ($p < 0.001$). Consequently, their total live weight gain over the combined rearing and fattening phases was 7.5 kg greater (124.3 kg vs. 116.8 kg; $p < 0.001$), though relative growth rates between the two groups remained statistically similar.

Table 1. Survival and growth rate of pigs throughout their lives

Indicator	I Control	II Experimental
Livestock survival during rearing and fattening, %	92.7	93.0
Absolute gain for rearing and fattening, kg	116.8±1.11	124.3±0.97***
Relative gain for rearing and fattening, %	159.7±0.93	156.3±0.88
Average daily gain for rearing and fattening, g	773.3±9.06	823.0±8.16***
Absolute gain for life, kg	120.5±1.09	128.0±0.93***
Relative gain for life, %	195.8±1.03	196.0±1.07
Average daily gain for life, g	700.9±8.09	744.1±8.03***

Note: *** - p<0.001
Source: own calculations.

Similar trends were evident when considering the pigs' entire lifespan. Supplementing the main diet with the pig milk replacer boosted the lifetime average daily gain by 43.2 g, representing a 6.2% increase (744.1 g vs. 700.9 g in the standard-fed control group; $p < 0.001$). This acceleration in growth intensity led to a 7.5 kg (6.2%) higher total live weight gain ($p < 0.001$), with experimental pigs achieving 128.0 kg compared to the control group's 120.5 kg. Consequently, incorporating the milk replacer during the nursery phase successfully promoted greater growth intensity, evidenced by significantly higher absolute and average daily weight gains, while having no observable adverse effect on the animal survival rate. To

fully assess growth intensity across the production cycle, relative and average daily gains were computed for each technological stage. As depicted in Figure 3, the growth rates during the suckling period were comparable between the two groups: relative gain was 118.5% (control) and 117.6% (experimental), with ADG figures of 180.0 g and 176.7 g, respectively.

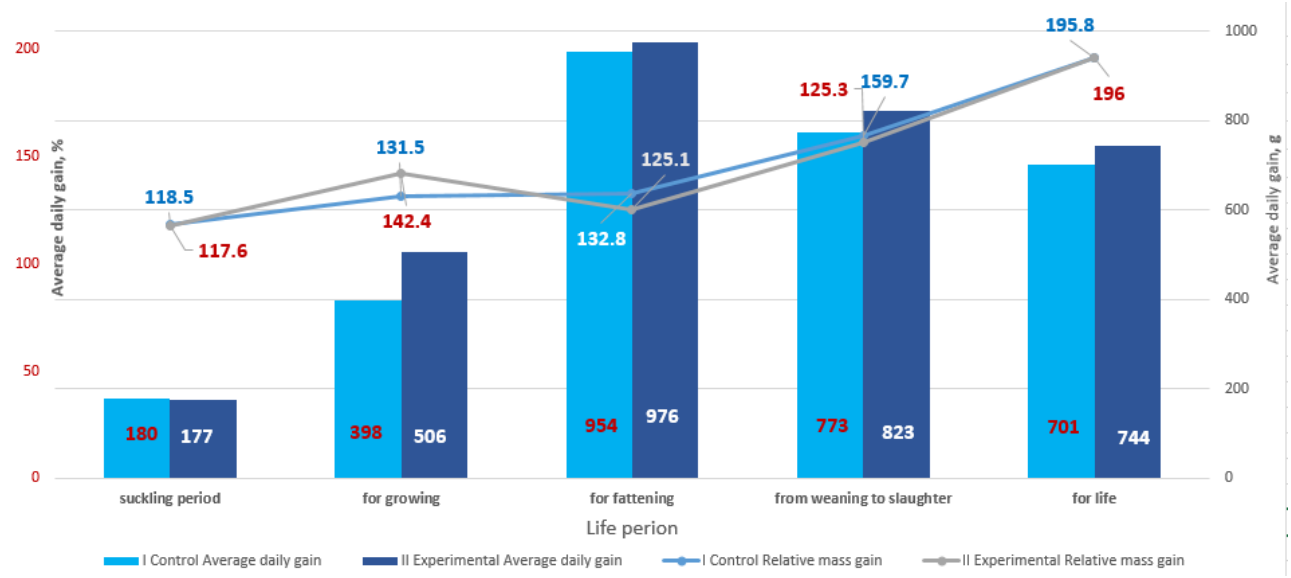


Fig. 3. Dynamics of average daily growth of pigs from birth to slaughter
Source: own calculations.

The most significant divergence between the groups occurred during the rearing phase. Owing to the supplemental pig milk replacer, Group II piglets achieved a relative weight gain of 142.4%, which was 10.9% greater than the control group's 131.5%. These figures clearly demonstrate more intensive growth and a superior realization of growth potential in the piglets that received the milk replacer. During the subsequent fattening period, the experimental group exhibited a slight deceleration in growth rate compared to the control group (relative gain 125.1% vs. 132.8%). This shift may be interpreted as a compensatory response, where the accelerated growth achieved during rearing partially leveled off. Despite this, the average daily gain during fattening still remained marginally higher for the experimental pigs (975.5 g vs. 953.5 g). Across the entire life period, pigs from Group II maintained higher average daily gains (744.1 g vs. 700.9 g) while achieving an almost identical relative gain (196.0% vs. 195.8%). This collectively indicates that the short-term provision of a pig milk replacer during the rearing phase effectively enhanced growth intensity and had a beneficial long-term influence on the pigs' overall productivity, successfully initiating a compensatory growth effect.

Considering that feed costs are the largest factor in pork production expenses and are continually increasing, we examined the feed consumption patterns of the two groups, presented in Figure 4. The data shows that the control group piglets, kept on the standard diet, consumed approximately 21 kg of various prestarter feeds. This consumption level was identical to that of the experimental group, despite the latter receiving the milk replacer supplement during the rearing period. However, due to the different prices per kilogram of the consumed feed types and the additional 0.9 kg of milk replacer costing 2.57 EUR/kg, the total cost of prestarter feeds was 2.51 EUR higher for the experimental pigs.

At the same time, due to their faster growth, experimental pigs reached the transition weight earlier and therefore consumed 4.3 kg more of the cheaper starter feed, adding only 1.53 EUR to total feed expenses during the rearing period.

Thus, although feed intake during rearing increased by 14.7% (39 kg vs. 34 kg in the control), the total feed cost rose by 23.0% or 4.02 EUR, mainly due to the use of more expensive prestarter and starter feeds, particularly the 12–30-day starter (19 kg vs. 14 kg in the control group).

The pigs from the experimental group consumed 5 kg less feed overall throughout their lifetime (319 kg versus 324 kg in the control), while the total feeding expenses remained nearly equivalent – 97.62 EUR compared to 97.26 EUR.

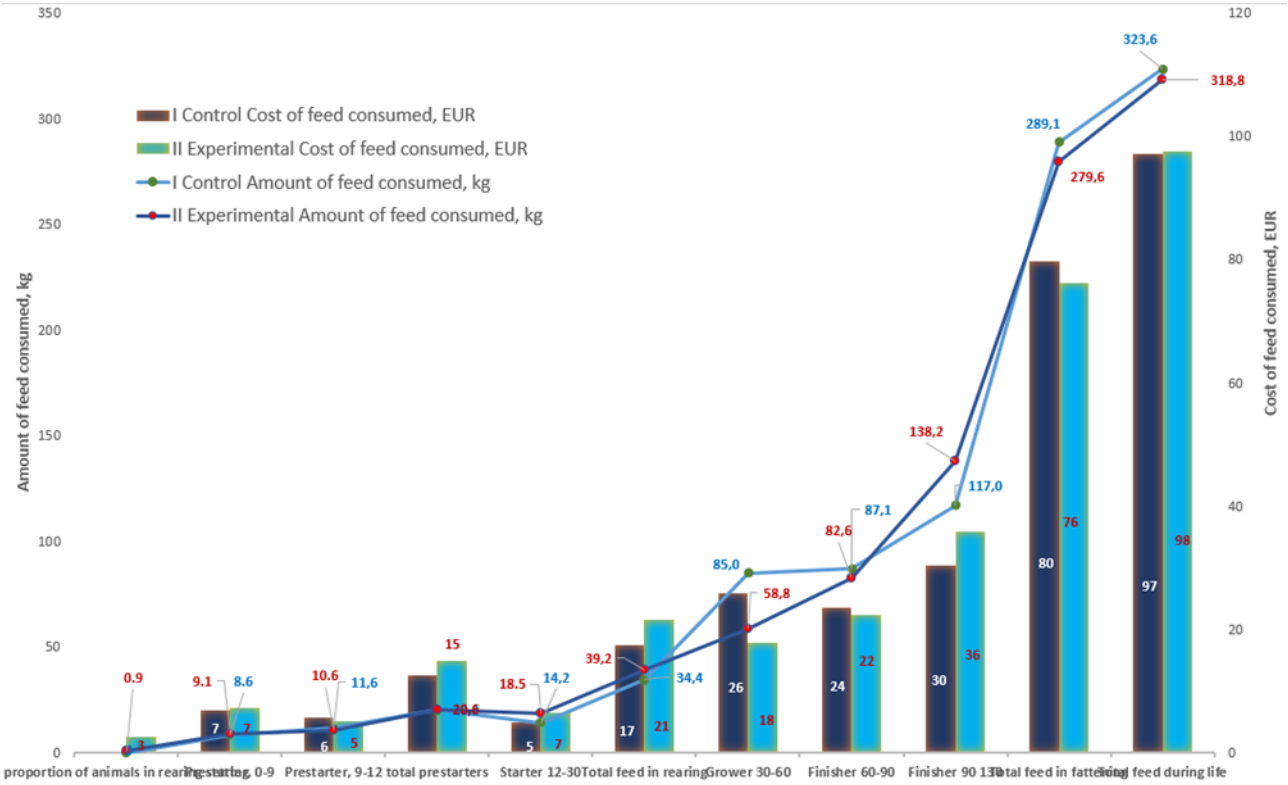


Fig. 4. Dynamics of the use of feeds of different formulations during rearing and fattening
Source: own calculations.

Although the cumulative feed cost was almost identical between the groups, the composition and cost distribution of the feed types varied considerably. As illustrated in Figure 5, which presents the breakdown of feed consumption by formulation for both the control and experimental cohorts – in terms of both quantity and monetary value – notable differences emerged in the proportional and financial structure of the diets.

Specifically, the experimental pigs received 0.3% milk replacer, which, despite its small share in total intake, accounted for 2.6% of the total feed expenditure, underscoring the relatively high price of the milk replacer compared with other feed components.

During the rearing phase, the experimental group's share of total feed consumption was marginally higher (12.3% vs. 10.6% for the control group), yet the cost of these feeds saw a disproportionately larger increase (from 22.8% to 24.7%).

The most significant factor in the experimental group's increased cost was a 5.8% rise in starter feed quantity and a 6.7% rise in its cost, compared to 4.4% and 5.0% in the control group, respectively.

The structure of pre-starter feeds remained largely similar. This pattern is attributed to the higher growth rate and consequent earlier, longer duration of starter feed usage by piglets that received the milk replacer early in the rearing period.

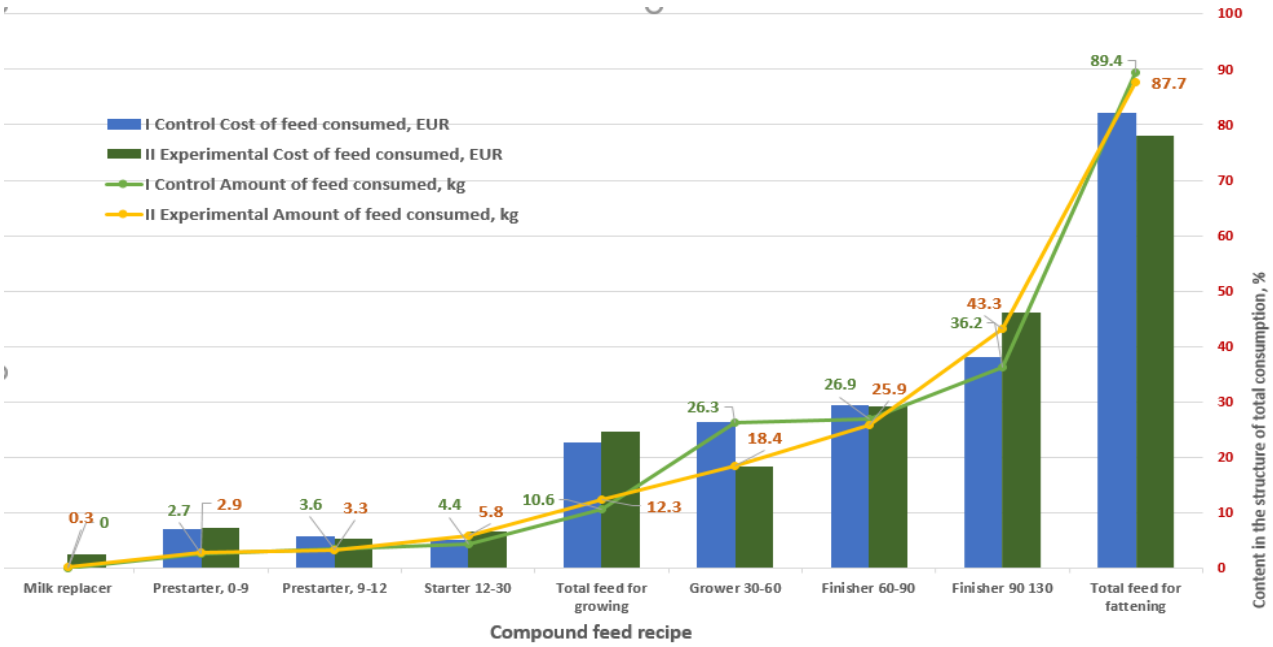


Fig. 5. Changes in the structure of feed consumption of different formulations during rearing and fattening and their cost
Source: own calculations.

The fattening phase showed a reverse trend in the feed consumption structure by cost category. This finding suggests the experimental pigs grew faster, enabling them to reach the necessary body weight threshold earlier and switch to less expensive finisher feeds. While consumption and cost shares of the first finisher feed (60–90 kg formula) were similar (26.9% and 25.9% by quantity; 19.5% and 29.3% by cost in control and experimental groups, respectively), the portion of the final finisher feed (90–130 kg) increased from 36.2% in the control to 43.3% in the experimental group. Its cost share similarly rose from 38.1% to 46.2%. This shift occurred because the experimental pigs achieved 90 kg live weight faster, leading to a longer reliance on the final fattening diet.

Overall, the feed structure by rearing phase differed: in the experimental pigs, the fattening phase accounted for 87.7% of total feed consumption vs. 89.4% in the control, while its cost share was 78.0% vs. 82.1%, respectively. Because of the uneven growth patterns, pigs in the experimental group consumed a smaller proportion of expensive starter feeds and a larger proportion of cheaper finisher feeds.

Thus, the inclusion of milk replacer during the rearing period increased feed costs at the early stages, but allowed faster weight gain, enabling earlier transition to cheaper feed formulations. As a result, overall feeding costs did not rise, while feed efficiency and growth rates improved.

Table 2 presents comparative data on feed consumption, average cost, and feed cost per kg of live weight and weight gain for the control (Group I) and experimental (Group II) pigs. Piglets in Group II, which received milk replacer during rearing, demonstrated more intensive growth and better feed utilization.

Over the entire rearing and fattening period, the pigs in the experimental group consumed 4.8 kg (1.5%) less feed in total (318.8 kg) compared to the control animals (323.6 kg). Importantly, with a greater overall weight gain, the experimental pigs demonstrated markedly higher feed efficiency: they required only 2.6 kg of feed per 1 kg of gain, whereas the control group needed 2.8 kg.

This corresponds to an improvement in feed utilization efficiency by 7.1%, reflecting better nutrient absorption and a more effective realization of the animals' genetic growth potential.

Table 2. Consumption of feeds of different formulations, their average cost and feed cost per 1 kg of live weight and gain

Indicator	I Control	II Experimental
Feed consumed during rearing and fattening, kg	7.19	7.08
Conversion of feed for rearing and fattening, kg	0.06	0.06
Average cost of all 1 kg of feed during fattening, EUR	0.28	0.27
Average cost of all 1 kg of feed from weaning to slaughter, EUR	0.30	0.31
Feed cost of 1 kg of live weight upon completion of fattening, EUR	0.80	0.76
Feed cost of 1 kg of gain from weaning to slaughter, EUR	0.83	0.79

Source: own calculations.

The comparative assessment of feeding costs revealed that, although the experimental pigs consumed feed with a marginally higher price per unit, the total expenditure per kilogram of live weight was lower than in the control group. Specifically, the average feed cost from weaning to slaughter was reduced by approximately 5–6% in the experimental cohort. This economic advantage stemmed from more efficient nutrient utilization and faster growth rates, leading to a lower feed cost per kilogram of weight gain. The inclusion of milk replacer in the diet contributed to improved feed conversion efficiency, thereby enhancing overall production profitability.

In summary, introducing pig milk replacer during the rearing phase promoted more intensive growth, reduced feed intake per unit of gain, and lowered the cost per kilogram of both weight gain and final live mass. These findings underscore the economic benefit and practical applicability of incorporating milk replacer feeding into modern pig production systems. As profitability remains the key goal of commercial pork production, Table 3 outlines a comparative economic analysis for low-birth-weight piglets in the control group (standard diet) and the experimental group (supplemented with milk replacer during rearing).

Table 3. Economic indicators of growing and fattening low-weight piglets

Indicator	I Control	II Experimental
Cost of one piglet when placed for rearing, EUR	22.24	21.93
Operating cost of rearing 1 head excluding VAT, EUR	25.18	30.97
Cost of one piglet after completed rearing excluding VAT, EUR	47.42	52.90
Operating cost of fattening 1 head,EUR	97.34	92.85
Cost of rearing and fattening 1 head, EUR	122.51	123.82
Cost of 1 head upon completion of fattening excluding VAT, EUR	144.75	145.75
Realization price of 1 head excluding VAT, EUR	174.92	185.59
Profit from the sale of 1 head, EUR	30.17	39.84
Operating cost of 1 kg of gain, EUR	1.20	1.14
Profitability of fattening 1 head, EUR	0.69	0.95

Source: own calculations.

Due to their slightly lower initial mass, the cost of one piglet at the beginning of the nursery phase was marginally lower for the experimental group (21.93 EUR) compared to the control group (22.24 EUR). However, the necessity of utilizing more costly feeds (pre-starters and milk replacer) increased the operating cost per head during rearing to 30.97 EUR, exceeding the control group's cost by 5.79 EUR (22.9%). While this increase reflects the higher expense of the initial diet, the resulting accelerated growth intensity meant these animals achieved a greater live weight by the end of the rearing period. Consequently, the value of one weaned pig in the experimental group reached 52.90 EUR, which was 5.48 EUR (11.6%) higher than the control.

Despite the elevated costs during rearing, the subsequent fattening phase proved more financially advantageous for the experimental group: their operating cost per head for fattening was lower at 92.85 EUR, a 4.6% reduction compared to the control's 97.33 EUR.

The total accumulated cost for rearing and fattening showed only a minor difference (123.82 EUR in the experimental group vs. 122.51 EUR in the control). Nevertheless, the experimental group demonstrated superior production efficiency due to their faster growth and better feed utilization (operating cost per 1 kg of gain was 1.14 EUR vs. 1.20 EUR).

With an identical selling price per kilogram of live weight, the final selling price per pig at the end of fattening was 185.59 EUR for the experimental group, which was 10.67 EUR (6.1%) higher than the control. This resulted in a substantial increase in profit from sales by 9.67 EUR (39.84 EUR vs. 30.17 EUR), and the profitability level of fattening significantly rose from 31.0% to 42.9%.

The study concludes that the short-term use of a pig milk replacer during the initial rearing period enhanced growth intensity, improved feed conversion, and reduced the cost per unit of gain. This strategy successfully ensured higher profitability when raising low-birth-weight piglets, even when incorporating slightly costlier starter feeds.

These findings affirm the critical influence of feeding strategies during the first week of the nursery phase on the later growth, development, and economic viability of raising low-birth-weight piglets. Piglets that received the milk replacer (days 22–29) exhibited enhanced growth, better feed efficiency, and lower feed cost per kilogram of live weight compared to the control group. This aligns with research [5, 13] showing that milk replacers in the transitional period support the development of intestinal barrier function and digestive stabilization post-weaning.

The motivation for this intervention is rooted in the challenge of sow hyperprolificacy in modern pig farming, which yields many low-birth-weight piglets [25, 27] characterized by lower viability and slow adaptation to solid feed [18]. Furthermore, shorter industrial lactation periods intensify stress at weaning (Pluske et al., 2018). The milk replacer served as a countermeasure, compensating for nutrient deficiencies and ensuring a smoother transition to solid feed, thereby promoting compensatory growth during the rearing phase, consistent with observations on the benefits of early digestible protein components [26].

The observed improvements in ADG and FCR are partially explained by the experimental group's earlier attainment of the target weight for switching to cheaper feed formulations, which positively contributed to the overall economic outcome. The experimental results, therefore, confirm that supplementary feeding with pig milk replacer during the first week of rearing is an effective strategy for boosting productivity and profitability in the management of low-birth-weight piglets, supporting current trends in production intensification.

CONCLUSIONS

The study established that incorporating a pig milk replacer into the diet during the first week of the rearing phase (days 22 to 29 of life) positively influenced animal growth intensity. Piglets receiving the supplement gained live weight more quickly, achieving 6–27% higher average daily gains compared to those on a traditional feeding system. This accelerated growth allowed them to reach the body weight threshold for transitioning to more cost-effective feed formulations earlier, which optimized the overall feed structure and improved production efficiency.

It was found that, although the experimental pigs consumed a somewhat higher share of costly starter feed due to the inclusion of the milk replacer, their overall feed intake was actually 1.5% lower than that of the control group. In addition, their feed conversion ratio showed a 7.7% improvement, decreasing from 2.8 kg to 2.6 kg of feed per kilogram of weight gain.

This increase in feeding efficiency led to a 5.4% reduction in the average feed cost required to achieve one kilogram of live weight

gain compared with animals that received the standard diet.

The combination of faster growth, improved feed efficiency, and a lower production cost per unit of output resulted in a significant financial benefit. Profit increased by 9.7 EUR per head, and the overall profitability level rose from 31.0% to 42.9%.

In conclusion, the short-term use of a pig milk replacer in the rearing system for low-birth-weight piglets is an economically sound technological practice that successfully enhances the productivity and profitability of pork production without negatively affecting animal survival.

Milk replacer supplementation is most beneficial for low-body-weight piglets (≤5.5 kg at weaning), particularly in herds with high sow prolificacy and early weaning. Short-term supplementation during the first seven days post-weaning at approximately 130 g per piglet per day, integrated into a liquid feeding system, supports growth and eases the transition to solid feed. For optimal economic efficiency, milk replacer should be used as a targeted management tool, combined with high-quality prestarter diets and stable microclimatic conditions, rather than as a universal feeding strategy.

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UNDERSTANDING RICE FARMERS' ASSETS AND LEVEL OF RESILIENCE FOR TYPHOON: A MULTI-GEOGRAPHICAL ANALYSIS

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Abstract

This study investigates the resilience of rice farmers and the influence of five livelihood assets such as social, human, natural, physical, and financial across upland, inland, and coastal landscapes in Hinunangan, Southern Leyte, Philippines. Using the Torrens Resilience Institute (TRI) framework, data were collected from 277 rice farmers across 41 barangays through proportionate stratified sampling and Slovin's formula. Results indicate that overall resilience indicators including connectedness, risk/vulnerability, procedures, and resources had mean scores of 161.1, 154.8, and 161.7 for upland, inland, and coastal areas, respectively, situating farmers in the caution zone, the second-highest resilience level. Among the assets assessed, financial, natural, and human assets exhibited the strongest correlations with resilience, whereas social and physical assets showed no significant associations in certain contexts. Based on these findings, policy recommendations focus on strengthening social assets through formalized community networks, farmer cooperatives, and structured knowledge-sharing platforms. Resilience programs should be tailored to local contexts, with upland areas emphasizing financial, natural, and human assets, inland areas prioritizing physical infrastructure and social support systems, and coastal areas targeting human, natural, and physical assets. In addition, integrated resilience strategies that combine asset development, risk management, and efficient resource allocation are essential to help farmers progress from the caution zone to higher levels of resilience.

Key words: *rice farming, livelihood assets, typhoon resilience, correlation analysis, Philippines*

INTRODUCTION

The Philippines is recognized as one of the most disaster-prone countries in the world, with typhoons posing persistent and severe threats to rural livelihoods. In Eastern Visayas, specifically the provinces of Samar, Leyte, and Southern Leyte, super typhoons have become recurring shocks that repeatedly undermine agricultural productivity and exacerbate socioeconomic vulnerabilities among farming communities [33]. Rice farmers, who form the backbone of local food production, consistently bear the brunt of these events as strong winds, flooding, and saltwater intrusion destroy standing crops, damage irrigation systems, erode soils, and disrupt local markets and farmers' income [13]. While national and local governments have strengthened disaster risk reduction initiatives in recent years, many rural households continue to struggle with long-term recovery, highlighting the need to better understand the factors that enable or hinder resilience at the community level. Within disaster and livelihood research, resilience is commonly understood as the capacity of individuals, households, or communities to absorb shocks, adapt, and recover in a manner that preserves or improves their well-being [48]. A growing body of literature emphasizes that resilience is shaped not only by exposure to hazards but also by access to livelihood assets human, social, natural, physical, and financial, which influence a farmer's ability to prepare for, cope with, and recover from climatic disturbances [4], [7]. However, despite the Philippines' long history of typhoon impacts, empirical studies that systematically analyze how these different forms of capital relate to resilience across distinct geographical settings remain limited [26], [49]. Landscapes such as coastal plains, uplands, inland valleys, and isolated island communities differ significantly in terms of environmental conditions, accessibility, exposure to hazards, and availability of

livelihood resources [16]. These variations may produce different resilience outcomes, yet they remain understudied in the local context [14].

Understanding these geographical nuances is especially crucial for municipalities like Hinunangan in Southern Leyte, where rice farmers are dispersed across diverse landscapes with varying degrees of vulnerability. While previous assessments often adopt a uniform approach to resilience, there is increasing recognition that such generalized frameworks overlook the spatial and socioeconomic variability that shapes farmers' adaptive capacities. A multi-geographical analysis therefore, offers a more comprehensive perspective on how location-specific constraints and opportunities influence recovery trajectories after typhoon events.

Guided by the Torrens Resilience Institute (TRI) framework, this study examines the resilience of rice farmers in 41 barangays across upland, inland, and coastal environments in Hinunangan. It investigates not only the overall resilience levels in these areas captured through indicators of connectedness, risk and vulnerability, procedures, and resources, but also the extent to which different livelihood assets contribute to resilience outcomes. By analysing how social, human, natural, physical, and financial assets interact with the geographical context, the study seeks to identify which forms of assets most strongly support farmers in coping with and recovering from typhoon-induced disruptions.

Ultimately, this research contributes to the growing discourse on climate resilience in agricultural communities by providing localized, evidence-based insights relevant to both policymaking and development planning. By clarifying the asset–resilience relationships unique to various landscapes, the study offers valuable guidance to government agencies, non-government organizations, and local stakeholders in designing targeted, area-specific interventions. Strengthening key livelihood assets in a geographically informed manner can significantly enhance the long-term resilience of rice farmers living in the typhoon-vulnerable landscapes of Eastern Visayas.

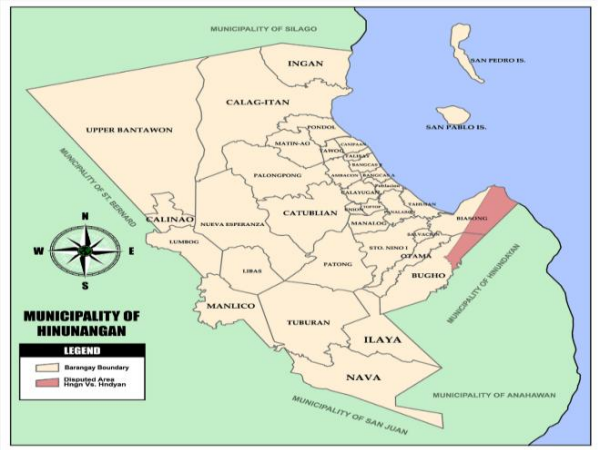
MATERIALS AND METHODS

Research Design

This study utilized a descriptive-correlational research design to analyze the livelihood assets and levels of typhoon resilience among rice farmers across upland, inland/lowland, and coastal zones in Hinunangan, Southern Leyte. This design is appropriate for describing the characteristics of populations and examining relationships among variables without manipulation [11], [24]. The multi-geographical approach enabled a comparative assessment of variations in farmer resilience across different environmental contexts.

Research Locale

The research was conducted in the municipality of Hinunangan in Southern Leyte, identified as one of the areas severely affected by typhoons (Map 1).



Map 1. Map of Hinunangan Southern Leyte
Source: Google Map.

The municipality is geographically distinct due to the presence of San Pedro and San Pablo Islands, the widest coastline in the province, and extensive lowland rice-producing areas [12]. Hinunangan is subdivided into three major geographical zones: the Upland Zone, consisting of nine barangays; the Inland/Lowland Zone, comprising eighteen barangays; and the Coastal Zone, consisting of fourteen barangays. These natural divisions

provided the basis for the study's multi-geographical analysis.

Respondents, Sampling Techniques and Ethics

The study considered all rice farmers and Slovin's formula was employed to determine the sample size of the study. Because the farmer population was naturally grouped into three geographical zones, proportionate stratified sampling was applied to ensure accurate representation of each stratum [20]. The respondents were distributed from upland barangays, from coastal barangays, and from inland/lowland barangays. After determining the proportional allocation, simple random sampling was employed within each stratum to provide equal chances of selection for all eligible farmers [6]. Hence, a total of 277 rice farmers were selected as respondents for the study. Ethical procedures were followed by securing informed consent from all participants, ensuring voluntary participation, confidentiality, and compliance with guidelines for research involving human participants [5].

Research Instrument and Data Collection

Primary data were collected using a structured questionnaire administered through assisted personal interviews. The instrument was adapted and modified from the Torrens Resilience Institute (TRI) Community Disaster Resilience Scorecard, which is designed to assess community resilience capacities [45]. Content modifications were undertaken to ensure alignment with the socio-geographical context of Hinunangan. The questionnaire comprised three main sections: (1) socio-demographic characteristics, (2) assessment of livelihood assets, and (3) community disaster resilience indicators. The socio-demographic and farming profile of rice farmers included variables such as: (i) age, (ii) sex, (iii) marital status, (iv) educational attainment, (v) sources of income aside from rice farming, (vi) rice farm size (in hectares), and (vii) years of farming experience. To ensure the validity and reliability of the instrument, expert validation and pre-testing were conducted in accordance with established guidelines for research instrument development [17], [44]. Assisted personal interviews were employed to enhance the accuracy and completeness of responses, particularly in rural settings where literacy levels and accessibility constraints may affect self-administered surveys [9]. The resilience levels were interpreted in a zone-based classification system with scores in Red Zone (≤25%), Caution Zone (26–75%), and Going Well Zone (76–100%).

Data Analysis

Data were encoded and analyzed using appropriate statistical techniques. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were employed to summarize socio-demographic characteristics, livelihood assets, and resilience indicators. Comparative analysis was conducted by examining differences in mean scores between geographical settings. Farmers' perceived levels of community assets: human, social, financial, natural, and physical, as well as resilience were measured using Likert-scale items, a widely accepted method for assessing attitudes and behavioral indicators [28]. The scores of the resilience were summed by analyzing the Likert answers of the respondents to each of the indicators. The average score was then calculated using each geographical location. The relationships between livelihood assets and resilience levels were analyzed using Spearman's rho correlation, a non-parametric test suitable for ordinal data and non-normal distributions [25].

RESULTS AND DISCUSSIONS

Demographic Profile of the Respondents

The 277 rice farmers surveyed in Hinunangan, Southern Leyte, exhibit a demographic profile that reflects a mature, predominantly female, and farming-dependent community. The majority of respondents are middle-aged to senior, with 58.34% between 41 and 70 years old, and the largest single group falling within the 51–60 age range (29.6%). This indicates a farming population that may face physical constraints and challenges in adopting new technologies, consistent with [27], who highlighted that older farmers often persist with traditional practices but may be less

adaptable to innovation. Females make up 63.2% of the respondents, underscoring the central role of women in agricultural labor, asset management, and disaster coping strategies. This aligns with studies emphasizing the contributions of women to sustainable farming practices and climate resilience [21], [23].

Most respondents are married (76.5%), suggesting that family units are key support systems in both farming and disaster preparedness. Strong family cohesion can facilitate shared responsibilities, resource pooling, and collective coping strategies, which are important assets in resilience-building programs [10]. In terms of educational attainment, the majority of farmers have not progressed beyond high school, with 28.5% completing only elementary level and 23.5% being high school graduates. Limited formal education may restrict understanding of modern agricultural technologies and disaster risk reduction practices, as noted by [36] highlighting the need for practical, accessible training methods in resilience programs.

Farming is overwhelmingly the primary source of livelihood, accounting for 96% of respondents, while only 4% rely on fishing. This heavy dependence on agriculture underscores the community's vulnerability to typhoons and other environmental shocks, reinforcing the importance of targeted interventions to protect livelihoods and enhance adaptive capacity [3], [41]. Overall, the demographic characteristics of rice farmers in Hinunangan predominantly female, middle-aged to senior, married, moderately educated, and highly reliant on farming—provide essential context for designing resilience strategies that are sensitive to the social, economic, and generational realities of the community.

Overall, the demographic profile of Hinunangan's rice farmers predominantly female, middle-aged to senior, married, and moderately educated—provides essential context for understanding the community's social and economic dynamics (Table 1).

Table 1. Socio-demographic profile of rice farmers

Variable	No. of Farmers (n=277)	Percent
Age		
21-30	6	2.17
31-40	43	15.52
41-50	63	22.74
51-60	82	29.60
61-70	59	21.30
71-80	20	7.22
81 yrs. above	4	1.44
Total	277	100
Mean	54	
Range	27-80	
Sex		
Male	102	36.8
Female	175	63.2
Civil Status		
Married	212	76.5
Single	26	9.4
Separated	8	2.9
Widowed	31	11.2
Total	277	100
Educational Attainment		
College graduate	19	6.90
College level	13	4.70
High school graduate	65	23.5
High school level	46	16.6
Elementary graduate	55	19.90
Elementary level	79	28.50
Total	277	100
Number of household members		
1-3	97	34
4-6	137	47
7-9	43	15
Above 10		
Total	277	
Mean	4.7	
Range	1-10	
Primary Source of Livelihood		
Fishing	11	4.0
Farming	266	96.0
Total	277	100
Number of years in Farming		
5 years below	25	9.02
6-15	50	18.05
16-30	97	35.01
31-45	68	24.54
46-60	31	11.19
More than 60 yrs.	6	2.17
Total	277	100
Mean	29	
Range	5-85	

Source: Authors' computation (2026).

These characteristics form the foundation for examining the distribution of livelihood assets and the capacity of farmers to cope with and recover from typhoon-related disruptions,

which will be explored in the following section.

Livelihood Assets of Rice Farmer Communities Across Three Geographical Settings

Results indicate that the distribution across upland, inland, and coastal communities which maintains a high level of social assets in the groups and networks and solidarity and trust categories (3.40–4.19). Mean scores were comparable 3.61 in upland, 3.60 in inland, and 3.58 in coastal areas indicating that farmers across the municipality are well-connected to formal and informal organizations that provide support before, during, and after natural disasters. Such networks are particularly valuable in rural farming communities where institutional support may be limited. This aligns with the notion that strong social capital facilitates access to information, mutual support, and collective action, which are critical in disaster-prone environments [3], [38]. In contrast, the collective action dimension showed more variation. Upland farmers (3.48) reported higher engagement than inland and coastal farmers. This implies that although social cohesion is present in all areas, upland communities exhibit comparatively stronger collective agency Table 2).

Table 2. Social assets across three geographical settings

SOCIAL ASSETS	LOCATION	MEAN	MEDIAN	SD
Groups and Networks	Upland	3.61	3.60	0.51
	Inland	3.60	4.00	0.52
	Coastal	3.58	3.80	0.60
Solidarity and Trust	Upland	3.76	3.80	0.38
	Inland	3.45	3.60	0.62
	Coastal	3.70	3.80	0.44
Collective Action	Upland	3.48	3.50	0.39
	Inland	3.46	3.53	0.35
	Coastal	3.34	3.40	0.65
OVER ALL	**Upland**	**3.61**	**3.67**	**0.29**
	Inland	**3.46**	**3.53**	**0.35**
	Coastal	**3.54**	**3.60**	**0.43**

Note: 1.00 – 1.79 (Very low level), 1.80 – 2.59 (Low level), 2.60 – 3.39 (Medium level), 3.40– 4.19 (High level), s& 4.20 – 5.00 (Very high level).
Source: Authors' computation (2026).

This may reflect stronger civic participation is consistent with findings that geographic and socio-cultural contexts influence community participation [37].

Table 3 shows marked variations in human assets across the three ecological zones. Upland farmers were the only group to achieve a high level of educational attainment (M=3.47), implying that upland areas may have better historical or physical access to formal schooling. Informal education was rated high among upland (M = 3.72) and coastal farmers (M = 3.54), suggesting greater engagement in skills training, capacity-building activities, and agricultural extension programs. These findings support previous studies emphasizing the role of both formal and informal knowledge in enhancing adaptive capacity [22]. Formal education equips farmers with analytical and technical skills, whereas informal learning, including farmer-to-farmer exchanges and extension programs, enables practical adaptation strategies [29]. In terms of health, coastal farmers achieved the highest rating (M = 3.50, high level), implying more consistent access to health services or stronger prioritization of health within households. Upland and inland communities rated this dimension at the medium level, which may reflect disparities in healthcare infrastructure and service availability.

Table 3. Human assets across three geographical settings

HUMAN ASSETS	LOCATION	MEAN	MEDIAN	SD
Educational Attainment	Upland	3.47	3.50	0.39
	Inland	3.28	3.17	0.47
	Coastal	3.12	3.08	0.58
Informal Education	Upland	3.72	3.67	0.55
	Inland	3.36	3.25	0.49
	Coastal	3.54	3.50	0.53
Health	Upland	3.27	3.29	0.30
	Inland	3.14	3.29	0.65
	Coastal	3.50	3.43	0.30
OVERALL	**Upland**	**3.47**	**3.47**	**0.31**
	Inland	**3.25**	**3.26**	**0.32**
	Coastal	**3.39**	**3.45**	**0.31**

Note: 1.00 – 1.79 (Very low level), 1.80 – 2.59 (Low level), 2.60 – 3.39 (Medium level), 3.40– 4.19 (High level), s& 4.20 – 5.00 (Very high level).
Source: Authors' computation (2026).

In terms of community-owned natural assets, coastal areas registered the highest mean (M = 3.46), reflecting stronger access to shared resources such as communal fishing grounds and mangrove areas, followed by upland areas

(M = 3.11) and inland areas (M = 2.96). This pattern aligns with [32] theory of common-pool resource management, which emphasizes that effective collective governance enhances adaptive capacity and resource sustainability. Overall, coastal areas also had the highest combined natural asset score (M = 3.45), followed by upland (M = 3.36) and inland areas (M = 3.14), with lower inland scores likely reflecting limited access to irrigation systems, communal land, and shared water resources, constraining their ability to buffer against climate-related shocks (Table 4) [39]. While higher natural asset endowments in upland and coastal areas can strengthen resilience, they may also promote over-reliance on resources, potentially limiting livelihood diversification, farming knowledge, and adopting new technologies, highlighting the need for complementary social and financial capital to fully leverage these assets for sustainable livelihoods [34], [41].

Table 4. Natural assets across different geographical locations

NATURAL ASSETS	LOCATION	MEAN	MEDIAN	SD
Privately-owned asset	Upland	3.76	3.80	0.48
	Inland	3.32	3.20	0.50
	Coastal	3.45	3.60	0.57
Community -owned assets	Upland	3.11	3.31	0.71
	Inland	2.96	3.00	0.73
	Coastal	3.46	3.63	0.50
OVERALL	**Upland**	**3.36**	**3.54**	**0.57**
	Inland	**3.14**	**3.18**	**0.51**
	Coastal	**3.45**	**3.51**	**0.46**

Note: 1.00 – 1.79 (Very low level), 1.80 – 2.59 (Low level), 2.60 – 3.39 (Medium level), 3.40– 4.19 (High level), s& 4.20 – 5.00 (Very high level).
Source: Authors' computation (2026).

Table 5 shows that upland farmers have the strongest household infrastructure, with a high mean (M=3.72), indicating more durable housing, reliable water access, and stable energy systems, which enhance resilience to environmental hazards [46]. Inland households scored a medium mean (M=3.07), while coastal households were lowest (M= 2.82), reflecting greater exposure to disruptions in low-lying or hazard-prone areas. For property and equipment, inland areas led slightly (M = 2.92), followed by upland (M = 2.72) and coastal (M = 2.57), all at medium levels, suggesting that limited access to agricultural machinery and post-harvest technology may constrain productivity and adaptive capacity (Barrett et al., 2001). Overall, upland communities had the highest combined physical asset score (M = 3.22), with inland (M = 2.99) and coastal (M = 2.69) communities trailing, highlighting the importance of physical assets in supporting resilience while revealing the vulnerability of inland and coastal households due to lower asset endowments[47].

Table 5. Physical assets across different geographical locations

PHYSICAL ASSETS	LOCATION	MEAN	MEDIAN	SD
Household Infrastructure	Upland	3.72	3.80	0.32
	Inland	3.07	3.00	0.97
	Coastal	2.82	3.00	0.89
Property & Equipment	Upland	2.72	2.90	0.58
	Inland	2.92	3.00	0.93
	Coastal	2.57	2.60	0.84
OVERALL	**Upland**	**3.22**	**3.30**	**0.33**
	Inland	**2.99**	**3.00**	**0.88**
	Coastal	**2.69**	**2.70**	**0.77**

Note: 1.00 – 1.79 (Very low level), 1.80 – 2.59 (Low level), 2.60 – 3.39 (Medium level), 3.40– 4.19 (High level), s& 4.20 – 5.00 (Very high level).
Source: Authors' computation (2026)

Findings in Table 6 indicate that only upland farmers achieved a high level of financial assets in terms of income sources (M=3.48). This suggests diversified livelihood strategies such as livestock, off-farm work, or small enterprises, making them less reliant on rice farming alone, consistent with the literature on livelihood diversification as a risk-spreading strategy [19]. Meanwhile Inland (M=2.63) and coastal farmers (M=2.76) remained in the medium level, signalling more mono-crop dependence and greater vulnerability to climate and market fluctuations. Financial management across all areas remained at the medium level, implying insufficient capacity to save, invest, or allocate resources for long-term needs. Supported with findings that financial capital, particularly liquidity and access to credit, is crucial for implementing adaptive strategies and disaster recovery [18], [50].

Table 6. Financial assets across geographical settings

FINANCIAL ASSETS	LOCATION	MEAN	MEDIAN	SD
Income Sources	Upland	3.48	3.50	0.51
	Inland	2.63	2.50	0.63
	Coastal	2.76	2.83	0.82
Financial Management	Upland	3.05	3.00	0.64
	Inland	0.64	2.32	2.00
	Coastal	2.64	2.70	0.77
OVERALL	**Upland**	**3.26**	**3.31**	**0.51**
	Inland	**2.48**	**2.31**	**0.55**
	Coastal	**2.70**	**2.49**	**0.69**

Note: 1.00 – 1.79 (Very low level), 1.80 – 2.59 (Low level), 2.60 – 3.39 (Medium level), 3.40– 4.19 (High level), s& 4.20 – 5.00 (Very high level).
Source: Authors' computation (2026).

Resilience Levels Across the Three Geographical Settings

Table 7 shows that the overall resilience scores across the three geographical settings fell within the Caution Zone, indicating a moderate level of resilience that requires further reinforcement. Upland (M=161.1) and coastal farmers (M=161.7) exhibited slightly higher resilience levels than inland farmers (M=154.8). Across the indicators, coastal farmers recorded the highest score (34.9) in Connectedness, suggesting strong relational ties and robust community support systems.

Table 7. Resilience Level of Rice Farmers Across Geographical Locations

INDICATORS	LOCATION	MEAN	INTERPRETATION
Connectedness	Upland	32.9	Caution Zone
	Inland	32.8	Caution Zone
	Coastal	34.9	Caution Zone
Risk/Vulnerability	Upland	49.5	Caution Zone
	Inland	45.2	Caution Zone
	Coastal	46.3	Caution Zone
Procedures	Upland	38.7	Caution Zone
	Inland	38.7	Caution Zone
	Coastal	40.7	Caution Zone
Resources	Upland	40.0	Caution Zone
	Inland	38.1	Caution Zone
	Coastal	39.8	Caution Zone
Overall	**Upland**	**161.1**	**Caution Zone**
	Inland	**154.8**	**Caution Zone**
	Coastal	**161.7**	**Caution Zone**

Source: Authors' computation (2026).

This finding supports the assertion that social capital is a key determinant of disaster resilience [3], [30]. In terms of risk and vulnerability awareness and resources, upland farmers scored the highest (M=49.5), indicating greater awareness and recognition of risks, consistent with the observations of [35]. Meanwhile, coastal farmers achieved higher scores in procedures (M=40.7), reflecting better-established preparedness measures and protocols. This aligns with the findings of [14] and [43] who emphasized the importance of local adaptation protocols in flood-prone areas. Fig. 1 shows the comparison of disaster resilience as perceived by rice farmers in different agro-ecological zones. Overall, these results highlight that resilience is multidimensional and influenced not only by physical exposure but also by social, financial, and human capital. Integrating multiple livelihood assets can therefore enhance overall adaptive capacity, reinforcing theoretical frameworks on sustainable livelihoods and community resilience [1], [42].

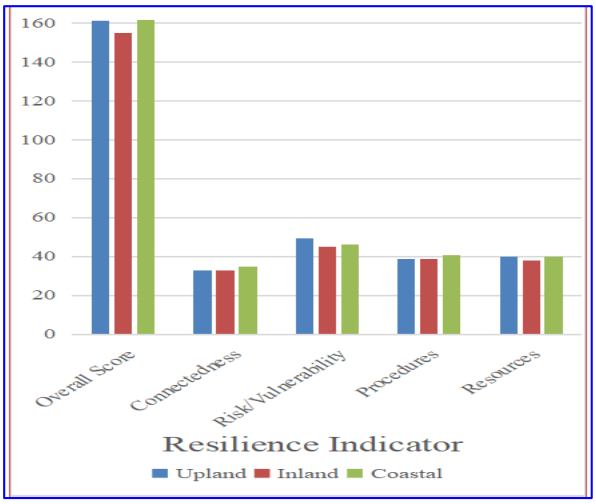


Fig. 1. Comparison of Disaster Resilience as Perceived by Rice Farmers in different Agro-Ecological Zones
Source: Authors' construction (2026).

Relationship of Livelihood Assets and the Level of Resilience

Table 8 shows that among the five livelihood assets, only human, natural, and physical assets were significantly related to the resilience of coastal rice farmers. Human assets had a strong positive relationship with resilience (r=0.501, p-value<0.001), indicating that education, health, and informal learning improve farmers' ability to adopt sustainable practices and adapt to climate and market changes [8], [15], [43]. Natural assets also showed a strong positive association with resilience (r=0.401, p-

value=0.003), suggesting that access to and proper management of resources such as irrigation systems and salt-tolerant rice varieties enhance farmers' capacity to manage climate-related risks [40].

Physical assets were likewise positively related to resilience (r=0.280, p-value=0.044), showing that improved infrastructure, equipment, and flood protection reduce vulnerability to flooding and saltwater intrusion, helping sustain farm productivity over time [37].

Table 8. Relationship of livelihood assets and the level of resilience of coastal rice farmers

Livelihood Assets	Level of Resilience	
	Coefficient	p-value
Social Assets	0.199	0.157^{ns}
Human Assets	0.501	0.000***
Natural Assets	0.401	0.003***
Financial Assets	0.205	0.145^{ns}
Physical Assets	0.280	0.044**

Note: ns-not significant; ***p-value<0.01; **p-value<0.05; *p-value<0.10
Source: Authors' computation (2026).

Table 9 shows that only social (r=0.414, p-value<0.001) and physical assets (r=0.350, p-value<0.001) significantly influence the resilience of inland rice farmers, while the other three assets showed no significant effect. Strong social connections with organizations and community groups enhance resilience by promoting knowledge sharing, resource exchange, and collective solutions to climate and economic challenges [31].

Physical assets, such as improved irrigation, water storage, housing, and energy systems, support stable agricultural productivity, protect families during extreme weather, and reduce household costs, allowing reinvestment in farming [2], [11].

Together, these assets help inland farmers adapt to climate risks and sustain livelihoods.

Findings indicate that three of the five community assets: human, natural, and financial were significantly related to the resilience of upland rice farmers, while the other two showed no significant relationship (Table 10).

Table 9. Relationship of livelihood assets and the level of resiliency of inland rice farmers

Livelihood Assets	Level of Resilience	
	Coefficient	p-value
Social Assets	0.414	<0.001***
Human Assets	0.088	0.258^{ns}
Natural Assets	-0.025	0.752^{ns}
Financial Assets	0.123	0.114^{ns}
Physical Assets	0.350	<0.001***

Note: ns-not significant; ***p-value<0.01;**p-value<0.05; *p-value<0.10
Source: Authors' computation (2026).

Human assets showed a strong negative correlation with resilience (r=−0.436, p-value=0.001), suggesting that larger households, higher dependency ratios, and the out-migration of educated or skilled members may reduce farm labor availability and weaken adaptive capacity. Natural assets also showed a weak negative relationship with resilience (r=−0.227, p-value=0.087), indicating that greater access to land and natural resources may lead to overdependence on existing practices and increased vulnerability to climate risks when livelihood diversification and resource management are limited. In contrast, financial assets were positively associated with resilience (r=0.228, p-value=0.085), highlighting that access to financial resources enhances farmers' ability to diversify income, invest in technology, and recover from climate-related shocks.

Table 10. Relationship of livelihood assets and the level of resiliency of upland rice farmers

Livelihood Assets	Level of Resilience	
	Coefficient	P-value
Social Assets	-0.143	0.285^{ns}
Human Assets	-0.436	0.001***
Natural Assets	-0.227	0.087*
Financial Assets	0.228	0.085*
Physical Assets	0.185	0.164^{ns}

Note: ns-not significant; ***p-value<0.01; **p-value<0.05; *p-value<0.10
Source: Authors' computation (2026).

CONCLUSIONS

This study examined the role of various community assets in enhancing the resilience of rice farmers in upland, inland, and coastal areas of Hinunangan, Southern Leyte, Philippines. Among the assets examined, social, financial, natural, physical, and human,

the social connections stood out as the strongest contributor, highlighting the importance of community ties, cooperation, and shared knowledge. Other assets demonstrated a moderate role in supporting farmers, indicating a secondary but meaningful contribution. Resilience indicators, including connectedness, risk/vulnerability, procedures, and resources, fell within the "caution zone," meaning that while communities show some ability to cope with challenges, vulnerabilities remain. Asset-resilience relationships differed by location: upland farmers' resilience was influenced by financial, natural, and human assets; inland farmers' resilience depended on social and physical assets; and coastal farmers' resilience was associated with human, natural, and physical assets. These results highlight the importance of tailored, location-specific interventions while recognizing the universal significance of social networks. Based on the findings, several policy recommendations are proposed to strengthen community resilience. First, social assets should be prioritized, as they consistently contribute to resilience across different areas; thus, policies should promote community networks, farmer cooperatives, and knowledge-sharing platforms. Second, resilience-building efforts should be tailored to local contexts in upland, inland, and coastal areas. For upland areas programs should focus on enhancing financial, natural, and human assets through improved access to credit, sustainable farming training, and soil and water conservation, while in inland areas, investments should emphasize physical infrastructure and social support systems including irrigation facilities and storage and in coastal areas, efforts should concentrate on strengthening human, natural, and physical assets, particularly in disaster preparedness, adaptive farming practices, and resource management. Moreover, policymakers' adoption of holistic resilience programs that combine asset development, risk management strategies, and effective resource allocation to help communities move from a caution zone to higher levels of resilience must be considered. For future research, studies should expand the geographic scope to include more municipalities and high-risk areas, incorporate qualitative approaches to capture local coping strategies, examine additional factors influencing resilience, such as government support and climate variability, and conduct longitudinal studies to assess changes in resilience over time.

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TOURISM AND GASTRONOMY IN TRANSYLVANIA, ROMANIA (2020–2024): EVOLUTIONS, TRENDS AND THE ROLE OF LOCAL PRODUCTS IN REGIONAL DEVELOPMENT

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Abstract

This study analyzes the evolutions and trends of tourism in the Transylvania region during the period 2020–2024 by correlating the dynamics of accommodation structures, tourist flows, and the role of local gastronomy in regional development. Statistical data provided by the National Institute of Statistics were integrated into a complex comparative analysis focusing on overnight stays, tourist arrivals, and types of accommodation units at the county level. The results highlight a significant increase in post-pandemic tourist activity, particularly in the counties of Brașov, Sibiu, Mureș, and Cluj, as well as the consolidation of the agritourism segment in Alba, Harghita, Covasna, and Hunedoara. Traditional gastronomy emerges as a strategic component of regional attractiveness, contributing to destination differentiation through authentic local products and integrated culinary experiences. The analysis confirms the interdependence between regional gastronomy, accommodation structures, and tourist flows, as well as Transylvania's potential to develop as a competitive destination within the framework of sustainable and experiential tourism. Thus, the study provides an integrated perspective on recent tourism transformations and on the role of gastronomy in shaping the regional tourism identity.

Key words**:** *tourism capacity and flows, gastronomy, sustainable tourism, cultural identity, Transylvania*

INTRODUCTION

Contemporary tourism is undergoing a rapid process of transformation, influenced both by structural changes in the global economy and by cultural and technological developments that shape traveler preferences. One of the most visible trends is the strengthening of the relationship between tourism and gastronomy, an aspect widely recognized in the specialized literature. Gastronomy is no longer a secondary element of the tourist experience but has become an identity vector capable of contributing to the differentiation and competitiveness of destinations [8].

The preservation of traditions, customs, and regional heritage plays a significant role in shaping Transylvania's tourism identity and enhancing its cultural attractiveness [10].

Local products, traditional culinary techniques, and elements of food heritage form what the literature refers to as *"gastronomic territories"*, spaces where culinary identity intertwines with cultural and tourism development, enhancing regional attractiveness [8].

Recent studies show that these gastronomic territories significantly contribute to building relationships between tourists and local communities, as culinary experiences become effective means of transmitting values, traditions, and cultural specificities of a region [8]. Gastronomic tourism thus reflects an emerging dimension, especially present in areas with high cultural diversity, where traditional products stand out through authenticity and continuity. Although Romania possesses significant gastronomic diversity, it is still considered an emerging culinary destination internationally, particularly in terms of external recognition of its food heritage [8].

In parallel, sustainability concerns have become essential for European tourism policies and strategies. Sustainable tourism is conceptualized as a continuous process dependent on the responsible management of resources, reducing environmental impact, and involving local communities [1]. Moreover,

changes generated by the COVID-19 pandemic have led to a reorientation of tourists toward less crowded forms of tourism, with a growing preference for rural, authentic, and gastronomic experiences [1]. This evolution has stimulated interest in agritourism, a form of tourism that combines traditional agricultural activities, local products, and direct interactions with the rural environment, becoming a driver of territorial and community development [1].

Agritourism has been identified as an effective instrument for sustainable rural development, contributing to income diversification and strengthening local economies [2].

Regarding food consumption, research highlights strong relationships between tourist flows and consumption behaviors, especially among non-resident tourists. Studies on consumer behavior conducted in agro-food markets in Sibiu demonstrate a strong preference for local products, especially traditional cheeses, purchased predominantly directly from producers [11]. Additionally, statistical analysis suggests the existence of significant relationships between tourist volume and certain categories of food expenditures, confirming the role of gastronomy as a pillar of the regional tourism economy [8].

The territorial dimension of tourism development is also influenced by physical and natural infrastructure. Evaluations of urban green and blue infrastructure show that these resources contribute to the perceived quality of destinations and tourist well-being—an aspect particularly relevant for Transylvanian counties with major urban centers. Furthermore, environmental protection literature emphasizes the importance of conserving natural resources and managing land sustainably as essential factors of territorial resilience, a principle applicable to rural regions with high tourism potential.

Another relevant contribution to understanding the socio-territorial context is found in studies on residents' identity representations, which show that perceptions of environment, culture, and lifestyle influence how communities relate to tourism and the transformations it generates [7].

By integrating these theoretical and empirical perspectives, the present study aims to analyze the evolution of tourism in Transylvania during 2020–2024 through the correlation of tourist flows (arrivals and overnight stays), accommodation structures, and regional gastronomic potential. The findings enable the construction of a coherent representation of regional tourism dynamics and the increasingly important role that gastronomy plays in defining the attractiveness and competitiveness of Transylvania within the context of contemporary tourism.

The aim of this article is to analyze the evolutions and trends of tourism in Transylvania during the period 2020–2024 by correlating statistical data on accommodation structures, tourist flows, and regional gastronomic development, with the objective of highlighting the role of local products in enhancing the region's attractiveness and tourism competitiveness.

MATERIALS AND METHODS

The present study employs a descriptive-analytical approach based on a comparative analysis of statistical data published by the National Institute of Statistics (INS) regarding the evolution of tourism in the counties of Transylvania during the period 2020–2024. Three main sets of indicators were used: (a) overnight stays in tourist accommodation structures by type of establishment, (b) tourist arrivals in accommodation units, and (c) the number of existing accommodation structures, covering hotels, motels, tourist villas, tourist guesthouses, and agritourism guesthouses. These data were extracted from the INS TEMPO databases, selected for their official, comparable, and territorially consistent nature [4], [5], [6].

The statistical data were processed using methods specific to time-series analysis, including the evaluation of interannual trends, identification of territorial variations, and comparison of distributions across accommodation types. The indicators were

analyzed both individually at the county level and comparatively, in order to highlight phenomena such as post-pandemic dynamics, structural differences among accommodation categories, and shifts in regional tourist behavior. Synthetic tables were generated to illustrate the evolutions, and, where relevant, graphical interpretations and complementary visual materials were included.

The methodology also integrates a qualitative analysis based on recent specialized literature, aiming to correlate statistical findings with conceptual developments in tourism, sustainability, and gastronomy. Studies on sustainable tourism and agritourism provided the theoretical foundation necessary for interpreting rural dynamics [1], while research related to food consumption, gastronomic heritage, and the role of local products in shaping destination identity contributed to understanding the relationship between tourist flows and visitors' culinary preferences [7], [8], [11]. Furthermore, studies on green and blue infrastructure, supported the contextualization of the built and natural environment in relation to tourism attractiveness, while approaches addressing territorial development and ecotourism complemented the overall picture of interactions between tourism and the regional environment [9].

The selection of indicators and analytical procedures was aligned with methodologies commonly employed in European research on regional and urban development, with emphasis on the interdependencies among tourism, economic structure, and local cultural resources. In this sense, the study aimed not only to quantify observable phenomena but also to interpret the connections between tourism dynamics and Transylvania's gastronomic potential, considered a strategic element in strengthening regional competitiveness [9].

Previous analyses of Transylvania's tourism supply underline the importance of accommodation capacity, structural classification, and occupancy performance in determining regional competitiveness [14].

Overall, the applied methodology enables an integrated and coherent assessment of how changes in the tourism sector, accommodation infrastructure, and gastronomic heritage contribute to the current profile of Transylvanian tourism, providing a solid foundation for the interpretations and discussions presented in the following section.

RESULTS AND DISCUSSIONS

The analysis of tourism in Transylvania for the period 2020–2024 is based on the integrated interpretation of key statistical indicators essential for understanding the structure and dynamics of the sector: overnight stays in tourist accommodation structures, tourist arrivals, and the number of existing accommodation units. All data originate from the official database of the National Institute of Statistics and are reported annually at the county level.

Specialized literature emphasizes that tourism assessment must rely on complex territorial analyses, as the uneven distribution of infrastructure, natural potential, and cultural resources generates significant differences between regions.

At the same time, European literature shows that regions with a distinct cultural identity (including those in Central and Eastern Europe) experience accelerated tourism growth when natural heritage is correlated with authentic gastronomic experiences, leading to longer stays and diversification of tourist flows [9].

Based on these perspectives, the statistical analysis presented in this section aims to:

-outline the post-pandemic trends of Transylvanian tourism;

-highlight territorial contrasts between counties;

-describe the accelerated growth of rural and agritourism, a phenomenon closely linked to regional food diversity;

-prepare the interpretative framework for the subsequent integration of traditional gastronomy as a strategic factor in Transylvania's tourism development.

This approach allows for a coherent and in-depth evaluation of how tourism dynamics intersect with the region's cultural and culinary resources, providing a solid foundation for the subsequent discussions.

a) Overnight stays in tourist accommodation structures, by type of establishment

1) In Hotels

Table 1 presents the evolution of the number of overnight stays in hotel structures across the counties of Transylvania during the period 2020–2024. This indicator is essential for assessing the tourism attractiveness of urban and peri-urban destinations, reflecting both the capacity of destinations to retain visitors and the overall dynamics of tourism demand.

Table 1. Evolution of overnight stays in hotel accommodation structures in Transylvania

County	2020	2021	2022	2023	2024
	MU =Number				
Alba	61,202	85,996	133,039	143,568	154,917
Bistrița-Năsăud	49,151	99,371	97,255	108,289	109,808
Brașov	785,008	1,134,589	1,346,845	1,448,085	1,433,561
Cluj	250,865	424,239	619,467	705,031	648,208
Covasna	229,400	352,643	438,429	449,745	439,811
Harghita	96,894	163,814	206,228	230,948	229,056
Hunedoara	71,273	155,374	157,960	187,044	199,178
Mureș	364,858	553,877	652,710	673,561	646,104
Sibiu	257,923	406,082	523,231	567,030	578,350

Source: NIS, http://statistici.insse.ro [6].

Table 1 shows that Brașov is, without exception, the leading tourism hub of Transylvania, maintaining more than 1.4 million overnight stays in both 2023 and 2024 values which exceed the combined totals of several smaller counties. This performance is associated with:

-its mountainous geographical position,

-its strong tourism brand (Poiana Brașov, Bran, Râșnov),

-gastronomic events and culinary traditions that extend the length of stay.



Photo 1. Representative image of a certified product from Sibiu: aged Telemea de Sibiu sheep cheese (IGP). Source: FOODHUB SIBIU [3].

Sibiu, Cluj, and Mureș form the second tier, with values ranging between 500,000 and 700,000 in peak years. These results reflect urban dynamism, business mobility, as well as local gastronomy (e.g., Sibiu IGP Telemea cheese (Photo 1), Saxon culinary dishes, Mureș-style goulash).

Urban tourism and gastronomy are closely interconnected, with studies showing that culinary diversity increases the likelihood of extending the length of stay [9]. Harghita, Covasna, and Hunedoara register moderate but steadily increasing values, explained by their profiles in spa tourism, ecotourism, and the distinct Székely culinary identity (e.g., *kürtőskalács*, and smoked meat specialties).

Alba and Bistrița-Năsăud experience constant growth, surpassing 100,000 overnight stays in 2024, supported in part by cultural and gastronomic tourism (e.g., *plăcinte moțești*, Hunedoara *virșli*, officially recognized as a traditional product).

2) In Motels

Table 2 summarizes the evolution of overnight stays in motels across the Transylvanian counties. Unlike hotels, this category is strongly influenced by road mobility and transit tourism, offering relevant insights into short-term tourist flows and the efficiency of transport infrastructure.

The data on motels indicate an unstable sector that is highly dependent on regional road traffic rather than traditional tourism dynamics.

Several patterns can be observed:
-Brașov remains the leader (≈ 36,000 overnight stays in 2024), due to its position along major road corridors.
-Mureș and Sibiu maintain consistently high values in most years, influenced by transit along the Olt Valley and DN1.
-Harghita displays an atypical evolution, with a spectacular peak in 2022 (14,374) followed by a sharp decline in 2023–2024.

Table 2. Overnight stays in motel accommodation structures in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	4,206	5,110	2,623	3,392	2,972
Bistrița-Năsăud	973	440	1,112	245	471
Brașov	32,599	20,711	24,223	36,695	36,520
Cluj	1,446	2,127	2,796	2,117	961
Covasna	850	1,148	1,881	1,435	974
Harghita	3,289	7,750	14,374	1,185	580
Hunedoara	4,161	5,598	5,107	5,016	6,741
Mureș	13,759	22,913	26,061	21,928	25,176
Sibiu	6,974	11,404	11,892	14,675	7,662

Source: NIS, http://statistici.insse.ro [6].

This pattern may be explained by:
-the refunctionalization of certain units,
-changes in the classification of accommodation structures,
-a shift in tourist flows from road-based travel toward agritourism.



Photo 2. Representative image of the unique *"Brașovence"*, a culinary delicacy from the Transylvania region
Source: TASTEATLAS [15].

Alba, Hunedoara, and Covasna show moderate oscillations, reflecting the influence of road infrastructure and rapid food consumption patterns (fast-casual services, traditional dishes offered in transit areas such as *mici*, grilled meats, or stews).
Interestingly, motels represent the only accommodation category where roadside gastronomy (grills, *mici*, soups, *"Brașovence"*) can directly influence the number of stops and overnight stays - a phenomenon also noted in the specialized literature on road tourism (Photo 2).

3) In Tourist Villas

Table 3 highlights the dynamics of overnight stays in tourist villas across Transylvania during the 2020–2024 interval. These accommodation structures are primarily associated with leisure and nature-based tourism, which is why this indicator provides a useful perspective on visitors' preferences for more intimate and flexible lodging options.

Table 3. Overnight stays in tourist villas across Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	20,186	26,495	26,912	20,613	19,264
Bistrița-Năsăud	1,057	2,224	2,032	2,087	1,649
Brașov	81,799	112,009	111,412	111,935	94,422
Cluj	12,017	19,975	29,087	18,546	19,522
Covasna	16,952	24,410	26,571	28,688	19,287
Harghita	6,460	9,350	10,328	24,644	13,673
Hunedoara	13,314	18,788	18,392	17,391	25,435
Mureș	9,934	11,822	11,045	8,653	8,919
Sibiu	32,611	60,404	47,641	36,539	31,327

Source: NIS, http://statistici.insse.ro [6].

Tourist villas represent a segment strongly influenced by: mountain tourism, group travel, tourism consumption patterns oriented toward relaxation and local gastronomy.



Photo 3. Local traditional products at Piața Volantă Transilvania, Sibiu (a representative example of direct interaction between local producers and tourists within the regional gastronomic ecosystem).
Source: SIBIU-TURISM [12].

Brașov also dominates this category, with values around 100,000–112,000, although a slight decrease can be observed in 2024, possibly explained by a shift of tourists toward guesthouses or integrated resort-type accommodations. Sibiu, Covasna, and Harghita display interesting variations:

-Harghita shows a major increase in 2023 (24,644), likely linked to the rise of rural gourmet tourism and outdoor culinary experiences (*ceaun*, *balmoș*, Székely traditional dishes).
-Sibiu shows a gradual decrease after 2021, suggesting a shift toward other forms of accommodation (authentic guesthouses). Alba and Hunedoara maintain stable values, associated with mountain tourism and traditional gastronomy (*balmoș moțesc*, *virșli*, Transylvanian stews).
Tourist villas appear to be the category where the gastronomic effect is felt most rapidly, as visitors often choose chalet- or cabin-type structures to enjoy culinary experiences in natural settings.

4) In Tourist Guesthouses

Table 4 presents the number of overnight stays recorded in tourist guesthouses, a type of accommodation that facilitates direct interaction with the cultural and culinary identity of the region. The values for the 2020–2024 period allow the analysis of demand for local experiences and the role guesthouses play in diversifying Transylvania's tourism offer.

Table 4. Overnight stays in tourist guesthouses in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	31,277	39,727	49,690	54,552	52,191
Bistrița-Năsăud	12,281	15,297	17,639	13,866	13,124
Brașov	213,678	273,156	295,401	318,738	302,981
Cluj	76,385	87,562	114,509	117,395	110,071
Covasna	15,540	28,633	32,925	35,821	30,689
Harghita	35,409	47,922	64,180	80,027	82,064
Hunedoara	19,559	26,733	21,417	22,950	26,211
Mureș	69,517	96,314	109,201	119,498	122,641
Sibiu	60,127	103,357	104,897	86,624	75,884

Source: NIS, http://statistici.insse.ro [6].

Tourist guesthouses best reflect the interaction between tourism and local gastronomy. The trends indicate that:
-Brașov remains the absolute leader in this segment, surpassing 300,000 overnight stays in several years (peak in 2023: 318,738).
-Harghita and Mureș show strong growth, suggesting that visitors are increasingly seeking local experiences connected to Székely cuisine (goulash, *papricaș*, *kürtőskalács*).

-Sibiu and Cluj record high values, reflecting the popularity of Saxon cuisine and gastronomic festivals (e.g., CibinFEST).
Counties with lower values (Bistrița-Năsăud, Hunedoara) do not have equally developed guesthouse infrastructure, yet traditional products (*plăcinte de Bistrița*, *virșli*) are becoming increasingly important in their tourism strategies.

5) Agritourism Guesthouses

Table 5 illustrates the evolution of overnight stays in agritourism guesthouses, a category closely connected to rural tourism and traditional gastronomic practices. This indicator is fundamental for understanding how agro-culinary experiences contribute to the economic and social development of Transylvania's rural areas.

Table 5. Overnight stays in agritourism guesthouses in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	92,991	113,086	124,083	144,009	135,518
Bistrița-Năsăud	32,260	30,234	38,643	50,780	58,485
Brașov	251,391	358,225	363,693	385,958	347,797
Cluj	82,648	130,619	152,929	157,965	145,767
Covasna	26,529	42,270	48,483	53,506	51,137
Harghita	52,289	82,837	100,225	123,014	115,816
Hunedoara	10,386	14,735	12,984	13,152	17,312
Mureș	23,669	22,788	25,991	34,155	42,054
Sibiu	62,202	102,618	99,542	103,928	88,335

Source: NIS, http://statistici.insse.ro [6].

We observe the following:
-Brașov dominates with more than 340,000 overnight stays in 2024, confirming the rapid expansion of agritourism in the mountain area.
-Harghita, Covasna, and Mureș show consistent increases, in line with the growing popularity of local culinary experiences (e.g., artisanal dairy products, Székely smoked meats, homemade bread).
-Cluj and Sibiu record high values, influenced by the notoriety of local products (Sibiu IGP Telemea cheese, traditional cheeses from Mărginime).

In agritourism, gastronomy is not merely a complementary element but the primary driver of demand, consistent with European trends in rural tourism [9].

b) Tourist arrivals in accommodation structures, by type of establishment

1) Hotels (Arrivals)

The values presented in Table 6 reflect the evolution of tourist arrivals in hotel structures across Transylvania during the period 2020–2024. This indicator is essential for understanding the actual volume of tourist demand and for assessing the attractiveness of urban and peri-urban destinations.

Table 6. Evolution of tourist arrivals in hotel structures in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number of persons				
Alba	39,718	55,872	83,688	87,407	101,832
Bistrița-Năsăud	28,459	50,278	54,252	64,621	64,936
Brașov	398,665	588,754	740,385	792,452	789,341
Cluj	143,432	236,244	348,356	393,663	368,264
Covasna	50,153	80,999	106,097	112,431	112,034
Harghita	45,384	69,495	85,855	96,178	93,484
Hunedoara	30,898	63,169	66,094	79,103	92,398
Mureș	163,318	249,844	302,762	318,774	329,378
Sibiu	159,077	254,544	318,625	360,890	382,266

Source: NIS, http://statistici.insse.ro [5].

Tourist arrivals in hotels once again confirm the dominant position of Brașov County, which reaches a peak of nearly 800,000 visitors in 2023, a remarkable value that remains stable in 2024 (789,341). This performance correlates with its status as a major mountain destination, as well as with the presence of a rich gastronomic heritage specific to the Carpathian region (*balmoș*, *brânză de burduf*, *bulz*), which significantly enhances its attractiveness.

Sibiu and Cluj stand out through accelerated post-pandemic growth rates, surpassing 360,000–390,000 arrivals in 2023–2024. In their case, urban tourism and local gastronomy have a strong synergistic role (Sibiu being known for its Saxon culinary traditions, and Cluj for its modern culinary scene and emerging gastronomic festivals).

Mureș, Harghita, and Covasna show moderate upward trends, reflecting increased attractiveness for spa and cultural tourism. Harghita, for example, relies heavily on its Székely gastronomic identity (goulash, stews, *kürtőskalács*), which is increasingly valued in experience-based tourism.

Hunedoara, Alba, and Bistrița-Năsăud follow a sustainable upward trend, significantly surpassing their 2020 levels and indicating a diversification of visiting motivations, including gastronomic ones (*virșli*, *plăcinte moțești*, traditional Transylvanian dishes).

2) Motels (Arrivals)

Table 7 presents the evolution of tourist arrivals in motels, accommodation structures predominantly associated with transit tourism and road mobility. This indicator provides specific insights into the intensity of short-distance travel and the use of regional road infrastructure.

Table 7. Tourist arrivals in motels in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number of persons				
Alba	3,039	2,780	2,261	3,072	2,579
Bistrița-Năsăud	365	151	390	146	221
Brașov	17,843	11,467	12,748	19,534	22,387
Cluj	1,181	2,031	2,705	1,957	869
Covasna	676	862	1,161	1,080	774
Harghita	2,195	5,596	7,924	978	429
Hunedoara	3,187	4,191	3,911	3,950	5,265
Mureș	10,950	17,375	21,472	16,500	18,032
Sibiu	3,670	6,886	7,567	8,462	5,023

Source: NIS, http://statistici.insse.ro [5].

Tourist arrivals in motels show pronounced variability, confirming their dependence on road transport. Overall, the values are significantly lower compared to hotels or guesthouses.

Brașov remains the leader in this category in 2023–2024 (19,534 → 22,387), confirming both the intensity of traffic and its strategic position along national routes.

Mureș and Sibiu register high values in 2020–2021, correlated with transit flows along the DN7 and DN1 corridors. The relative decrease in 2024 may indicate a shift of tourists toward other accommodation types.

Harghita shows a spectacular peak in 2021–2022, followed by a sharp decline. This phenomenon suggests changes in unit classification or evolving tourist behavior, with increasing preference for guesthouses and agritourism.

The motel segment is also influenced by roadside gastronomy, an important component for short stops (*grill specialties, mici, traditional soups*), recognized in the specialized literature as a secondary motivational factor in road tourism.

3) Tourist villas (arrivals)

Table 8 illustrates the evolution of tourist arrivals in tourist villas across Transylvania, a category predominantly associated with leisure tourism, nature-based activities, and small visitor groups.

Table 8. Tourist arrivals in tourist villas in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number of persons				
Alba	10,898	12,371	13,418	10,633	10,794
Bistrița-Năsăud	843	1,398	1,273	1,456	1,089
Brașov	42,350	57,433	56,558	53,882	45,342
Cluj	6,482	11,229	16,585	11,064	11,174
Covasna	4,332	7,420	8,243	8,990	3,598
Harghita	2,788	4,916	5,104	8,776	6,289
Hunedoara	10,156	14,206	14,047	13,165	19,399
Mureș	4,610	4,636	5,048	3,982	4,810
Sibiu	15,163	27,586	25,962	22,017	14,537

Source: NIS, http://statistici.insse.ro [5].

Tourist villas display a distinct behavior compared to hotels and guesthouses (moderate values influenced by seasonality and nature-oriented tourism).
Brașov remains the leading county in this segment, but arrivals gradually decline after 2021, suggesting a shift toward guesthouses or integrated resort facilities.
Harghita records a spectacular increase in 2023 (8,776), supported by the development of Székely mountain tourism and traditional gastronomic packages (*ceaun*, *papricaș*, smoked dishes).
Hunedoara shows a remarkable increase in 2024 (19,399), possibly due to the valorization of the Retezat area and the introduction of local culinary experiences in accommodation packages.
Sibiu fluctuates but maintains high values in the early period (2020–2021), supported by rural Saxon tourism.
According to European studies, consumers of tourist villas tend to prefer outdoor culinary experiences, which explains their attraction to mountain areas with strong gastronomic traditions.

4) Tourist guesthouses (arrivals)

Table 9 presents the data regarding tourist arrivals in tourist guesthouses, structures that facilitate direct interaction with the local cultural and gastronomic identity.

Table 9. Tourist arrivals in tourist guesthouses in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number of persons				
Alba	19,320	25,648	31,572	35,329	32,642
Bistrița-Năsăud	9,368	11,020	13,046	10,044	9,804
Brașov	108,114	143,537	155,122	170,742	161,374
Cluj	45,815	55,551	70,360	71,499	66,754
Covasna	6,793	10,907	12,996	11,598	10,588
Harghita	20,550	28,795	35,354	38,104	41,144
Hunedoara	14,680	19,813	16,367	17,934	21,161
Mureș	43,432	61,941	70,110	81,153	82,595
Sibiu	36,786	61,640	59,706	53,044	46,175

Source: NIS, http://statistici.insse.ro [5].

Tourist guesthouses are the most sensitive indicator of experience-based and tradition-oriented tourism. Here we observe:
-Brașov remains the leader, with over 170,000 arrivals in 2023, confirming tourists' preference for authentic mountain and gastronomic experiences.
-Harghita and Mureș show consistent increases, driven by Székely cuisine and integrated rural offerings.
-Cluj and Sibiu reach high values, reflecting the synergy between urban tourism and rural Saxon heritage.
-Bistrița-Năsăud and Hunedoara remain at moderate but stable levels.
Guesthouses are becoming a key vector of gastronomic tourism, as they offer local dishes directly on-site (*bulz, plăcinte, smoked trout, virșli*, etc.).

5) Agritourism guesthouses (arrivals)

Table 10 highlights tourist arrivals in agritourism guesthouses, an essential indicator for evaluating rural tourism and the growing interest in authentic gastronomic and cultural experiences.

Table 10. Evolution of tourist arrivals in agritourism guesthouses in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number of persons				
Alba	42,408	54,561	55,475	65,937	64,661
Bistrița-Năsăud	13,992	15,247	18,064	25,577	29,385
Brașov	119,681	178,666	184,897	191,651	170,451
Cluj	42,323	72,033	84,082	84,960	78,941
Covasna	14,046	22,985	21,376	21,196	21,132
Harghita	23,863	35,116	42,744	51,569	53,094
Hunedoara	6,961	9,377	9,214	9,288	12,260
Mureș	17,062	15,569	17,150	22,871	30,993
Sibiu	32,115	54,596	54,279	56,342	46,809

Source: NIS, http://statistici.insse.ro [5].

Brașov is the absolute leader, surpassing 190,000 arrivals in 2023. Harghita, Mureș, and Cluj show clear increases, confirming tourists' growing orientation toward rural experiences with a distinct culinary profile. Sibiu records solid values, influenced by the notoriety of its local products (Sibiu IGP Telemea). Bistrița-Năsăud and Hunedoara grow slowly but steadily.

In agritourism, gastronomy is not a complementary element but a central one, often the primary reason for choosing a destination [9].

c) Accommodation structures by type

1) Hotels (accommodation structures)

Table 11 presents the evolution of the number of hotels in Transylvania between 2020 and 2024, highlighting the region's structural capacity to support urban and peri-urban tourist flows.

Table 11. Evolution of the number of hotels in the counties of Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	19	18	19	17	18
Bistrița-Năsăud	12	15	16	15	15
Brașov	118	121	120	121	119
Cluj	68	61	57	63	61
Covasna	15	16	17	17	18
Harghita	20	20	19	18	18
Hunedoara	27	26	30	31	32
Mureș	58	57	57	53	55
Sibiu	41	46	46	42	45

Source: NIS, http://statistici.insse.ro [4].

The number of hotels remains relatively stable across the region, with minor variations, indicating a mature market. The most developed county continues to be Brașov, with values close to 120 hotels throughout the analyzed period. This structural stability consistently supports the area's mountain, cultural, and gastronomic tourism (e.g., mountain dishes, traditional cheeses).

Cluj, Sibiu, and Mureș form the second tier, with between 40 and 68 hotels, reflecting their status as university and cultural centers where modern urban gastronomy has developed strongly.

In counties such as Alba, Bistrița-Năsăud, or Hunedoara, variations are small but relevant: -Alba shows a slight increase in 2024 (18 hotels),

- Hunedoara registers the most notable progress, reaching 32 hotels in 2024.

These increases are linked to the revitalization of heritage tourism (Alba Carolina Fortress, Corvin Castle) and traditional gastronomy (*virșli*, *plăcinte moțești*).

2) Motels (accommodation structures)

Table 12 summarizes the evolution of the number of motels at the regional level, a type of accommodation structure influenced primarily by road mobility and transit tourism.

Table 12. Number of motels in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	6	6	6	4	4
Bistrița-Năsăud	1	1	1	0	0
Brașov	9	9	9	9	10
Cluj	6	6	6	6	6
Covasna	3	3	3	3	3
Harghita	5	5	5	5	7
Hunedoara	10	7	8	10	10
Mureș	18	18	19	19	22
Sibiu	5	5	5	5	3

Source: NIS, http://statistici.insse.ro [4].

The number of motels remains consistently low across all counties, confirming the region's orientation toward stay-based tourism rather than transit tourism.

Brașov, Mureș, and Hunedoara have the most consistent values, ranging between 9 and 22 units, supported by heavily trafficked national roads (DN1, DN7, Olt Valley).

The most interesting case is Harghita, which increases from 5 to 7 motels in 2024—an indicator of intensified internal mobility and growing demand for quick stops along mountain routes. Bistrița-Năsăud completely disappears from the statistics after 2022 (0 units), suggesting a reorientation toward guesthouses and agritourism, where gastronomic experiences are better integrated and monetized.

3) Tourist villas (accommodation structures)

Table 13 presents the dynamics of the number of tourist villas, a type of accommodation primarily associated with mountain and recreational tourism.

Table 13. Number of tourist villas in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	29	23	22	20	20
Bistrița-Năsăud	3	3	3	2	2
Brașov	77	69	64	57	51
Cluj	14	15	17	15	17
Covasna	7	7	7	7	7
Harghita	4	3	3	3	5
Hunedoara	46	44	43	45	49
Mureș	21	23	22	23	24
Sibiu	24	28	23	26	24

Source: NIS, http://statistici.insse.ro [4].

Brașov, once again the leader, decreases from 77 tourist villas in 2020 to 51 in 2024 (a considerable reduction), likely explained by reclassification into tourist guesthouses or by the transformation of villas into integrated accommodation units.

Hunedoara remains the second major hub for tourist villas (reaching 49 in 2024), confirming the attractiveness of the Retezat area and of mountain culinary tourism (*ceaun* dishes, *brânză de burduf*, traditional cured pork fat).

Sibiu and Mureș maintain moderate but stable values.

The decreases recorded in Alba (29 → 20) and Brașov indicate a structural reorganization in favor of guesthouses, a category increasingly suited to gastronomic tourism.

4) Tourist guesthouses (accommodation structures)

Table 14 presents the distribution and evolution of tourist guesthouses, a key segment for experiential tourism and for direct interaction with local gastronomy.

Table 14. Number of tourist guesthouses in the counties of Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	27	29	30	28	29
Bistrița-Năsăud	12	13	10	10	11
Brașov	242	240	230	217	213
Cluj	65	64	64	61	61
Covasna	22	22	21	20	18
Harghita	98	90	103	149	101
Hunedoara	81	72	74	72	71
Mureș	133	121	118	109	117
Sibiu	89	83	87	76	72

Source: NIS, http://statistici.insse.ro [4].

Brașov hosts the largest number of tourist guesthouses, decreasing gradually from 242 (2020) to 213 (2024). Although their number declines, tourist inflow into guesthouses continues to rise—an indication that the remaining units have become more competitive or have transitioned into agritourism guesthouses.

Harghita shows a spectacular evolution: from 98 guesthouses in 2020 to 149 in 2023, followed by an adjustment to 101 in 2024. This

pattern likely reflects a structural reallocation within the Székely rural tourism sector.
Sibiu, Cluj, and Mureș experience moderate decreases, yet remain among the counties with the strongest cultural and gastronomic tourism infrastructure.

5)Agritourism guesthouses (accommodation structures)

Table 15 highlights the evolution of agritourism guesthouses, a central component of rural and gastronomic tourism development in Transylvania.

Table 15. Distribution of agritourism guesthouses in Transylvania

County	2020	2021	2022	2023	2024
	MU=Number				
Alba	126	131	132	139	151
Bistrița-Năsăud	73	86	110	103	110
Brașov	379	387	380	372	377
Cluj	166	203	220	227	228
Covasna	56	45	45	50	52
Harghita	229	229	265	231	236
Hunedoara	81	95	107	112	129
Mureș	51	51	56	62	64
Sibiu	126	146	141	134	137

Source: NIS, http://statistici.insse.ro [4].

Brașov dominates with the highest density of agritourism guesthouses (379–387 units), confirming its role as a core center of mountain rural tourism.
Cluj, Sibiu, and Harghita are also counties with a well-developed agritourism sector, supported by strong culinary traditions (local cheeses, Székely dishes, IGP-certified products). Hunedoara shows a significant increase (81 → 129), signaling the revitalization of rural communities and the integration of gastronomy into the tourism offer. Bistrița-Năsăud and Covasna maintain moderate yet stable values, confirming the steady demand for authentic rural tourism (*plăcinte de Bistrița*, Székely dishes).
The integrated analysis of overnight stays, tourist arrivals, and accommodation structures in Transylvania for the 2020–2024 period reveals a robust tourism dynamic marked by clear territorial differences and a rapid reconstruction following the pandemic period. First, the counties of Brașov, Sibiu, Cluj, and Mureș emerge as major poles of tourism development, supported by high flows of arrivals and overnight stays as well as by a diversified accommodation infrastructure. In contrast, counties such as Alba, Hunedoara, or Harghita show steady growth trends, but built on different structural foundations (ranging from cultural tourism to agritourism or mountain tourism).

A comparison of the three categories of data confirms that regional tourism development is not uniform but influenced by the complementarity between accommodation capacity, cultural attractiveness, and local gastronomic identity. Counties with a well-established hotel infrastructure tend to attract larger visitor numbers, yet the most impressive increases are observed in the segment of guesthouses and agritourism guesthouses, structures that offer authentic experiences in which gastronomy becomes a differentiating element.
Thus, areas with strong culinary traditions (such as the Székely Land, Mărginimea Sibiului, or Țara Moților) record notable developments both in the number of accommodation units and in the volume of arrivals and overnight stays. Recent case studies from Sibiu County highlight how integrated rural tourism models combining landscape, accommodation quality, and authentic gastronomy significantly increase destination attractiveness and popularity [13].
Overall, the data confirm that the tourism development of Transylvania is shaped by a complex interaction between natural attractiveness, cultural heritage, and gastronomic identity.
Urban tourism maintains its pace through infrastructure and cultural events, while rural and agrogastronomic tourism becomes the main driver of regional diversification.

This complementarity strengthens Transylvania's position as a multidimensional destination, where culinary experiences, local traditions, and natural landscapes collectively build the foundations for long-term sustainable development.

CONCLUSIONS

The analysis of tourism evolution in Transylvania for the period 2020–2024 highlights a complex process of regional reconstruction and consolidation, supported both by the dynamics of tourist flows and by structural adjustments in the accommodation sector. Overnight stays and tourist arrivals show continuous growth following the pandemic period, with significantly higher values in 2023–2024 compared to 2020, confirming the resilience and attractiveness of Transylvanian destinations. The counties of Brașov, Sibiu, Cluj, and Mureș continue to function as major tourism hubs, due to the combination of well-developed infrastructure, dense cultural offerings, and a clearly defined regional gastronomy.

At the same time, counties such as Harghita, Covasna, Alba, and Hunedoara are affirming their touristic identity through the consolidation of agritourism and rural tourism segments, where traditional culinary experiences represent a major competitive advantage. The increase in overnight stays in agritourism guesthouses, as well as the intensification of tourist flows in rural areas, confirms visitors' orientation toward sustainable, experiential, and authentic forms of tourism. In this context, gastronomy becomes not merely a complementary element, but a strategic driver of tourism development (one capable of creating direct connections between visitors and local communities).

Accommodation structures reflect this reconfiguration: while the number of hotels remains relatively stable, guesthouses and agritourism units register some of the most dynamic changes. This trend suggests a gradual shift in tourist preferences toward personalized, flexible, and rural-integrated spaces, where local products (traditional cheeses, Székely dishes, *moți* recipes, IGP-certified foods, and artisanal preparations) become a fundamental part of the lived experience. In this dynamic, gastronomy does not simply accompany tourism; it redefines its trajectory.

The study's results also underline the importance of territorial and infrastructural factors. Regions with valuable natural landscapes, competitive transport networks, and well-preserved cultural resources consistently attract high tourist flows and create the conditions for sustainable development. At the same time, the observed territorial differences suggest that the future development of tourism in Transylvania will depend on each county's capacity to coherently integrate its tourism offer, gastronomic resources, and local development strategies.

Overall, the conclusions indicate that Transylvania is in a favorable position to strengthen its touristic identity by simultaneously capitalizing on its cultural, natural, and gastronomic heritage. The combination of culinary tradition, infrastructure, and the diversity of tourist experiences positions the region as a model of integrated development, with strong growth potential in the coming years. Gastronomic tourism, in particular, emerges as a strategic vector capable of generating economic, social, and cultural value, contributing to Transylvania's long-term sustainability and competitiveness as a destination.

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KINEMATIC ANALYSIS SIMULATION AND THE RELATED COSTS FOR RICE TRANSPLANTING MECHANISM

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Abstract

The kinematic motion was used to operate the transplanting mechanism in the rice transplanting machine, using SolidWorks software, to run the theoretical and simulation modle .Numerous mechanisms exist within the four-bar linkage experiment, the crank-rocker mechanism was selected as the most suitable for the transplanting unit, which utilises the shortest link rotating through a complete rotation while the rocker link pivots and the fixed link oscillates.It consists of four links of different lengths. One of the rotating links is the operating arm, and the other is the rocker arm. The operating arm connects the rocker arm to the fixed link in the frame.The crank is the shortest linkage and makes a complete revolution. The lengths of links were 50, 100, 150, and 150 mm for the crank, rocker, fixed link, and the coupler, respectively.Thekinematic simulation aims to show where all the parts of an assembly are in time as it goes through a cycle. The motion analysis by SolidWorks software is useful for simulating steady-state motion (without accelerations) and evaluating motions for interference. According to the findings of this study, all the simulation results are nearly identical to the theoretical calculations in all theanalysis results, and the motion behaviour of angular velocities, angular accelerations,andangular displacements is approximately similar. Finally, the crank-rocker mechanism is considered the best tool for operating the rice transplanting mechanism in the rice transplanting machines.Also, the cost for manufacturing the transplanting mechanism was 1,000 L.E., which represents 6.67% of the production cost for the rice transplanting machine.

Key words**:** *crank-rocker mechanism, four-bar link mechanism, kinematic motion, rice transplanting mechanism*

INTRODUCTION

The transplanting mechanism is the mostvitalportionof the transplanter machines. It picks several seedlings at a time from the seedling mat and transplants them into the soil. It also carries these seedlings to the soil surface in an erect posture. It contains two mechanisms,the first one is transplantation mechanism which consists of a transplanting arm (four-bar linkage mechanism), a finger holder with five planting tines, and a crankshaft that operates the mechanism. The second mechanism is the seedling push mechanism, which includes five seedling push rods mounted on one bar called the push rod holder, two cams equipped with two levers, and four springs [3]. The four-bar link mechanism is the most efficient system for operating transplanter fingers. This mechanism is powered by the ground wheel, which transfers motion through a chain and sprocket setup. This helps the implanted finger movement remain synchronized and consistent, contributing to smooth and precise transplanting operations[5]. The four-bar link is the best method to realise the mechanisms of transplanting, and it is also mentioned that the crank transmits 360 degrees of rotation. The crank has a drive chain to provide drive motion to the gears; therefore, the connection shaft can move first, and the pair connector also moves second. Only oscillate while the crank rotates about the fixed link. The bar links must be mechanically fastened to the fixed link. With advanced development based on power transfer and a driven engine, this mechanism could be used in various rice fields transplanting machines. The speed of the shaft can be changed to control this mechanism. If the shaft moves more swiftly, the picker finger will move more quickly. The spacing between rice rows will depend on how the picking finger moves [6]. Thomas [9] developed a

transplanting mechanism to transplant rice seedlings.The mechanism was developed using analytical synthesis. The basic design was found to be a four-bar link with coupler extension. The movement generated by the four-bar mechanism was drawn on a computer application. Changing the lengths of different links inside the mechanism resulted in distinct output motion routes for the coupler point. The selection of suitable link dimensions was guided by how well the resulting motion supported seedling picking, smooth mechanism operation, effective transplanting, and efficient return movement. The transplanting mechanisms used in power-operated transplanters are based on planar four-bar linkages with a transplanting finger at the extension of the coupler. They cannot be designed directly, and a combined analysis and synthesis method is to be followed. Thus, it is almost impossible to get a unique solution. Design of the transplanting mechanism would require consideration of choosing a correct ratio of forward speed to the crank speed, appropriate angle of the finger fork regarding the seedlings for ensuring proper picking of seedlings, appropriate angle of the finger concerning the coupler link for proper orientation angle of the seedlings at the time of transplanting. Design considerations should ensure that the fingers do not disturb the seedling stacked on the tray during the return motion. While a minimum crank speed is required to ensure proper transport of seedlings from the tray to the transplanting point, an excessively high crank would introduce undesirable inertia forces on the mechanism members [10]. Chaudhary [2] designed and built a manual rice transplanter by altering a simple four-bar linkage mechanism to transplant rice seedlings.in the farmers' field. This mechanism will have no motion from the fixed or frame link, and the crank will have a fully rotatory motion of 360 degrees. The coupler link transfers motion to the rocker link, enabling the transplanting fork—an extension of the coupler—to pick seedlings from the seedling mat. As the crank rotates, the transplanting fork oscillates vertically, following a curved path during its downward motion. At a specific point along this path, it collects a seedling and places it into the moist soil. After completing the transplanting action, the fork returns to its upper position, and the cycle repeats as long as the crank continues to rotate. Meanwhile, the rocker arm performs a limited-angle oscillatory motion. Bhowmik [1] designed and fabricated a manual rice transplanting machine, and the transplanter comprises a lug drive wheel, a mat for seedlings, a power transmission system, sprockets and chains, and a handle arm. When a power is made to pull the transplanter in the forward direction, the drive wheel axle rotates. The driver sprocket is installed with the drive wheel axle, and when the axle rotates, it transfers power to the follower sprocket installed on the follower shaft. The four-bar (transplanting mechanism) is fixed with the follower shaft that makes it oscillate and catch the seedling from the mat to transplant it into muddy soil. Wen [11] designed a revolutionary rice transplanting mechanism. A 3 dimension simulation model was produced using SolidWorks software. to assess the feasibility of the design. The vibration characteristic, a key index for transplanter performance, should be analyzed further based on the analysis. The vibration model of the designed structure was analysed using ANSYS software.An interpolation method is presented to cope with these challenges and further incorporates the transplanting mechanism with a picking robot arm, called the picking arm. The seed-picking process can operate independently, without combining the picking and inserting actions into a single step. The robotic picking arm is mounted above the planting arm, positioned centrally over the chain box of the mobile frame. A crank-rocker mechanism is employed, where the crank serves as the driving component, rotating at a constant speed. The rocker swings back and forth around the follower, while the connecting rod undergoes planar compound motion. The majority of mechanical applications require a single input and output. As a result, the most prevalent mechanisms are those with only one degree of freedom. If one of its connections is greater than the total length of the other three a

four-bar mechanism cannot function Inversion, or changing which link is fixed in a four-bar linkage, can yield a variety of mechanisms. When one of the two links connected to the shortest link is fixed, the result is a crank-rocker mechanism[8]. Kinematic analysis plays a crucial role in determining the appropriate dimensions of the link bars to ensure smooth and continuous motion of the mechanism. The lengths of each link in the four-bar system can be defined through precise calculations. These dimensions are analysed using the Newton-Raphson method, incorporating the Jacobian matrix to evaluate the motion of the connecting link [4].

This study aimed to analyze the kinematic motion of the four-bar link mechanismto reduce processing costs.

MATERIALS AND METHODS

The transplantion unit mechanism is the most important mechanism in the rice transplanting machine, since it catch the suitable seedlings from the seedling mat and places them in the soil. It also lifts and presents these seedlings to the soil surface vertically using a four-bar linkage mechanism.

As shown in Figure 1, continuous relative rotation between two links is achievable if the sum of the lengths of the shortest and longest links is less than or equal to the sum of the other two links, according to Grashof's law. Let s represent the shortest link, l represent the longest, and p and q represent the other two links.

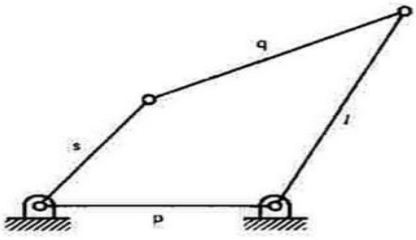


Fig. 1. Basic four-bar linkage mechanism
Source: Authors'illustration.

In this mechanism, the shortest link rotates fully while the rocker link pivoted to the fixed link oscillates as shown in Fig. 2. The coupler is the part that connects the crank to the rocker, while the frame is the permanent link. The crank is the shortest link and makes a full revolution. The sum of the shortest link and the longest link must be less than or equal to the sum of the remaining links to ensure smooth movement.It must be ensured that the crank can rotate 360 degrees. The lengths of links were 50, 150, 100, and 150 mm for the crank, fixed link, rocker, and coupler, respectively.

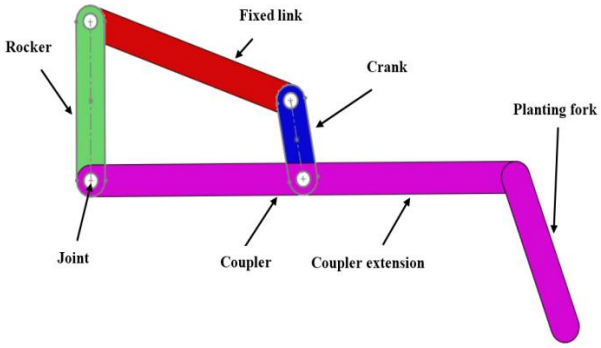


Fig. 2. A schematic diagram of the transplanting machine four-bar links mechanism (crank-rocker mechanism)
Source: Authors' drawing.

Kinematics analysis of four-bar links

To allow the mechanism to move and rotate smoothly, motion analysis requires determining the dimensions of the link rod. To determine the relationship between the angles and lengths of the links, we use the links as vectors, as shown in Figure 3.

Crank Length, a (r_2) is 50 mm, Coupler Length, b (r_3) is 150 mm, Rocker Length, c (r_4) is 100 mm, and Fixed linkLength, d (r_1) is 150 mm.

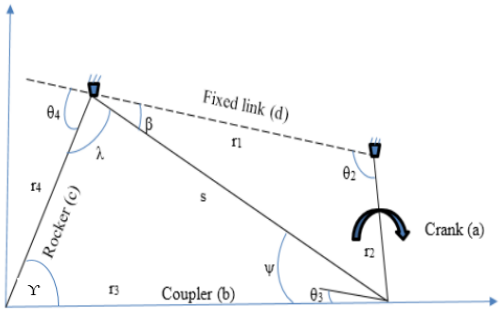


Fig. 3. The four-bar link mechanism's kinematic diagram
Source: Authors' drawing.

The linkage parameters shown in Fig. 3 are provided:

(1)Fixed link length, r_1.
(2)Cranklength, r_2.
(3)Couplerlength, r_3.
(4)Rockerlength, r_4.
(5) Angle between coupler and rocker, γ.
(6) Crank angle, θ_2
(7) Coupler angle, θ_3
(8)Rockerangle, θ_4.
(9) Crank angular velocity, ω_2
(10) Coupler angular velocity, ω_3
(11) Rocker angular velocity, ω_4
(12)Crankangular acceleration, α_2
(13)Couplerangular acceleration, α_3
(14)Rockerangular acceleration, α_4
Using the following equations according to calculat kinematic analysis of the four-bar linkage mechanism [7]:

Displacement analysis

$$s = \sqrt{(r_1)^2 + (r_2)^2 - 2r_1 r_2\, cos\theta_2} \quad \text{.....(1)}$$

$$\gamma = cos^{-1}\left(\frac{(r_3)^2 - s^2 + (r_4)^2}{2\, r_3 r_4}\right) \quad \text{.....(2)}$$

$$\theta_3 = 2\tan^{-1}\left(\frac{(-r_2 * \sin\theta_2) + (r_4 * \sin\gamma)}{r_1 + r_3 - (r_2 * cos\theta_2) - (r_4 * \cos\gamma)}\right) \quad \text{.....(3)}$$

$$\theta_4 = 2\tan^{-1}\left(\frac{(r_2 * \sin\theta_2) - (r_3 * \sin\gamma)}{r_4 - r_1 + (r_2 * cos\theta_2) - (r_3 * \cos\gamma)}\right) \quad \text{.....(4)}$$

Theoretical angular velocity calculations

Where, ω_2 = 104.08 rpm then ω_2 = 10.90 rad/s

$$\omega_3 = -\omega_2\left(\frac{r_2\, sin(\theta_4 - \theta_2)}{r_3\, sin\gamma}\right) \quad \text{.....(5)}$$

$$\omega_4 = -\omega_2\left(\frac{r_2\, sin(\theta_3 - \theta_2)}{r_4\, sin\gamma}\right) \quad \text{.....(6)}$$

Theoretical angular accelerations calculations

Where, ω_2 is constant then $\alpha_2 = 0$ rad/s^2

$$\alpha_3 = \frac{\alpha_2 r_2\, sin(\theta_4 - \theta_2) + r_2{\omega_2}^2\, cos(\theta_2 - \theta_4) - r_4{\omega_4}^2 + r_3{\omega_3}^2 cos(\theta_4 - \theta_3)}{r_3\, sin(\theta_4 - \theta_3)}$$

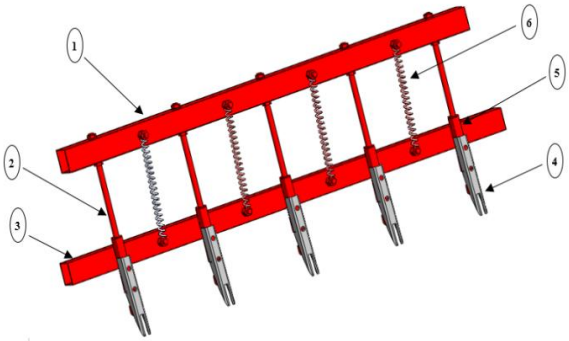
.....(7)

$$\alpha_4 = \frac{\alpha_2 r_2\, sin(\theta_2 - \theta_3) + r_2{\omega_2}^2\, cos(\theta_2 - \theta_3) + r_3{\omega_3}^2 - r_4{\omega_3}^2 cos(\theta_4 - \theta_3)}{r_4\, sin(\theta_4 - \theta_3)}$$

.....(8)

Working theory of the transplantingmechanism

When the engine is turned on, the primary sprocket drives the transmission system;the transplanting unit receives motion from the intermediate reduction unit via sprockets and chains. As the transplanting unit's sprocket rotates, the crankshaft turns and moves the transplanting arm through a four-bar linkage system, creating the arc of motion that will travel in an elliptical motion.



No.	Item	No.	Item
1	Push rod holder	4	Tine
2	Seedling push rod	5	Tine base
3	Transplanting tine holder	6	Tension spring

Fig. 4. The transplanting mechanism components
Source: Authors'drawing.



Photo. 1. The transplanting mechanism at field during rice transplanting operation
Source: Authors'illustration.

When the planting arm is elevated, the planting tines pick up seedlings from the seedling mat

through holes in the guide rail. At the same time, the cams press on levers to raise the seedling push holder with five pushing rods, allowing the tines to pick them up. As the rotation proceeds, the transplanting arm lowers and the planting tines bring the seedlings to the soil surface in an upright position. The cams release the levers, and the springs force the seedling push holder downwards, pushing the seedlings into the soil at a specific depth using seedling push rods, as shown in Photo 1.
The transplanting mechanism components are shown in Fig. 4.

Simulation and modelling

Kinematic analysis of the transplanting mechanism (four-bar linkage) was modelling via Excel software and simulated via SolidWorks 2016 software to determine angular displacement, velocities and accelerations.The "ABS function" in Excel was used to convert the collected data to absolute values for comparison with SolidWorks' data.

RESULTS AND DISCUSSIONS

The data attained from this study can be summarized below the subsequent headings.

Theoretical calculations fordisplacement analysis

Table 1. Displacements analysis using Excel software

θ_2, deg	S, mm	γ, deg	θ_3, deg	θ_4, deg
0	100.00	41.41	41.41	82.82
30	109.59	46.92	28.61	75.53
60	132.29	60.00	21.79	81.79
90	158.11	75.52	19.33	94.85
120	180.28	90.00	19.79	109.79
150	194.91	100.55	22.92	123.47
180	200.00	104.48	28.96	133.43
210	194.91	100.55	37.66	138.21
240	180.28	90.00	47.59	137.59
270	158.11	75.52	56.20	131.72
300	132.29	60.00	60.00	120.00
330	109.59	46.92	54.98	101.90
360	100.00	41.41	41.41	82.82

Source: Authors' determination.

Data in Table 1 and Fig. 5 demonstrate the relationship between the various crank angles and their effects on the other link angles. The data revealed that increasing the crank angle from 0 to 360° by using Microsoft Excel software had a direct impact on both θ_3 and θ_4 angles. As a result, it will give an early description of the transplanting mechanism that will be constructed.

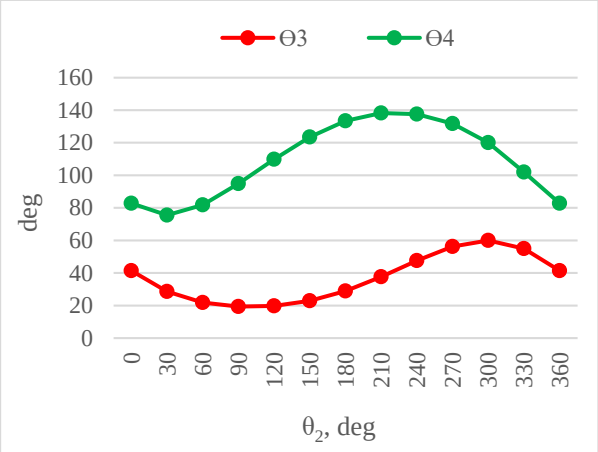


Fig. 5. Angular displacement behavior of angles θ_3 and θ_4 changes related to θ_2 angle
Source: Authors' determination.

Theoretical calculations of the angular velocities

The kinematic analysis calculations for the four-bar link angular velocities are provided in Table 2.

Table. 2. Angular velocities analysis using Excel software

θ_2, deg	ω_2, deg/s	ω_3, deg/s	ω_4, deg/s
0	624.42	312.21	312.21
30	624.42	203.36	10.36
60	624.42	89.20	223.01
90	624.42	18.17	304.28
120	624.42	36.89	307.27
150	624.42	94.58	253.36
180	624.42	156.10	156.10
210	624.42	201.12	42.33
240	624.42	203.27	67.11
270	624.42	143.05	179.39
300	624.42	0.00	312.21
330	624.42	212.09	425.81
360	624.42	312.21	312.21

Source: Authors' determination.

The supplied data was computed using mathematical calculations using Microsoft Excel software.Thedefault angular speedof the crank link was constant at 104.07 rpm (624.42 deg/s) at $0 \leq \theta_2 \leq 360^{\circ}$. Also, the behaviour of

the angular velocities ω_2, ω_3, and ω_4 changes related to θ_2 angle is shown in Fig. 6.

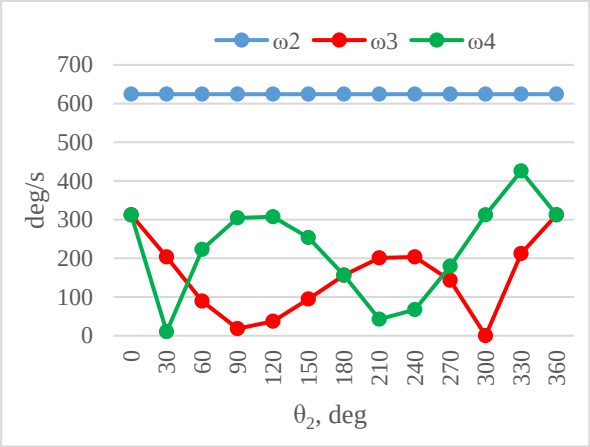


Fig. 6. The behavior of the different angular velocities related to θ_2 angle
Source: Authors' determination.

Theoretical calculations of the angular accelerations

Angular acceleration is the rate at which angular velocity changes over time. Table 3 shows the kinematic analysis of the four-bar linkage's angular accelerations. Because the angular velocity is constant, the angular acceleration equals zero.

Table. 3. Angular accelerations analysis using Excel software

θ_2, deg	α_2, deg/s^2	α_3, deg/s^2	α_4, deg/s^2
0	0.00	643.07	5,787.67
30	0.00	2,849.04	5,464.87
60	0.00	1,844.34	3,247.65
90	0.00	1,223.34	1,170.53
120	0.00	1,133.99	567.42
150	0.00	1,275.60	1,819.56
180	0.00	1,208.09	2,306.35
210	0.00	568.29	2,221.75
240	0.00	540.01	2,241.42
270	0.00	2,043.38	2,459.16
300	0.00	3,929.25	1,964.63
330	0.00	4,228.85	1,285.52
360	0.00	643.07	5,787.67

Source: Authors' determination.

The angular acceleration data was obtained using mathematical calculations in Microsoft Excel software, and the behaviour of the angular accelerations α2, α3, and α4 changes related to θ2 angle is shown in Fig. 7.

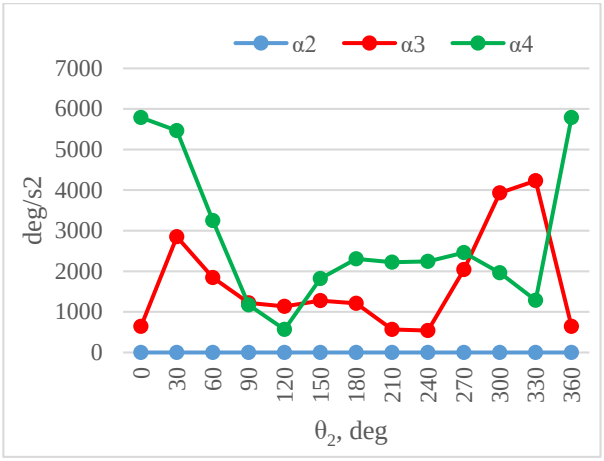


Fig. 7. The behavior of the angular accelerations changes related to θ_2 angle
Source: Authors' determination.

Kinematic simulation for the rice transplanting mechanism via SolidWorks software

The transplanting mechanism of the rice transplanting machine was sketched by SolidWorks software to simulate the kinematic motion of the four-bar linkage (crank-rocker mechanism) and show where all the parts in an assembly are in time as it goes through a cycle. The motion analysis feature in SolidWorks software is helpful for simulating steady-state motion (without accelerations) and analysing motions for interference.

In motion analysis, a graph can analyse each link displacement, and the software automatically generates the trace paths for the various links.

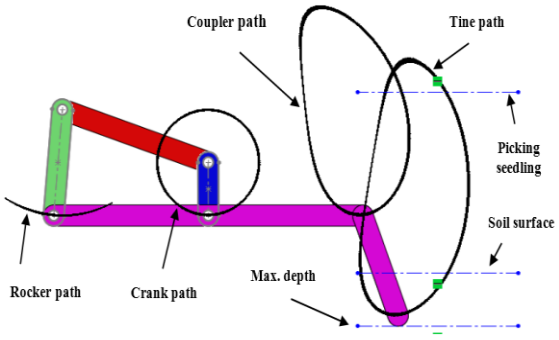


Fig. 8. The path of the transplantation mechanism
Source: Authors' drawing.

The seedling's fingerrotates in an elliptical path, and the crank link rotates with full circular rotation of 360 degrees, while the rocker link swingsasshown in Fig. 8.

Angular displacement, velocity, and acceleration simulationof the transplantation mechanism

After designing the implant mechanism and determining all relevant dimensions, a kinematic analysis was performed.

This analysis simulated the angular displacement, velocity, and acceleration of each component in the crank arm system. Figures 9, 10, and 11 compare the simulation results with theoretical calculations to ensure the mechanism's accuracy and performance.

The simulation results are nearly identical to the theoretical calculations in all the analysis results.

Graphic observation shows that the motion behaviour of angular displacements, angular velocities, and angular accelerations is approximately identical.

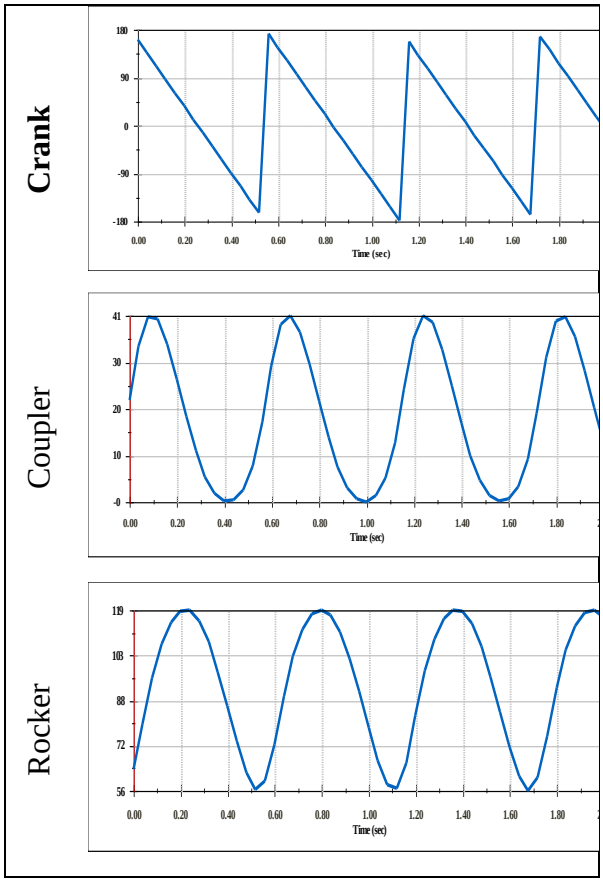


Fig. 9. Angular displacement simulation of the transplantation mechanism
Source: Authors' determination.

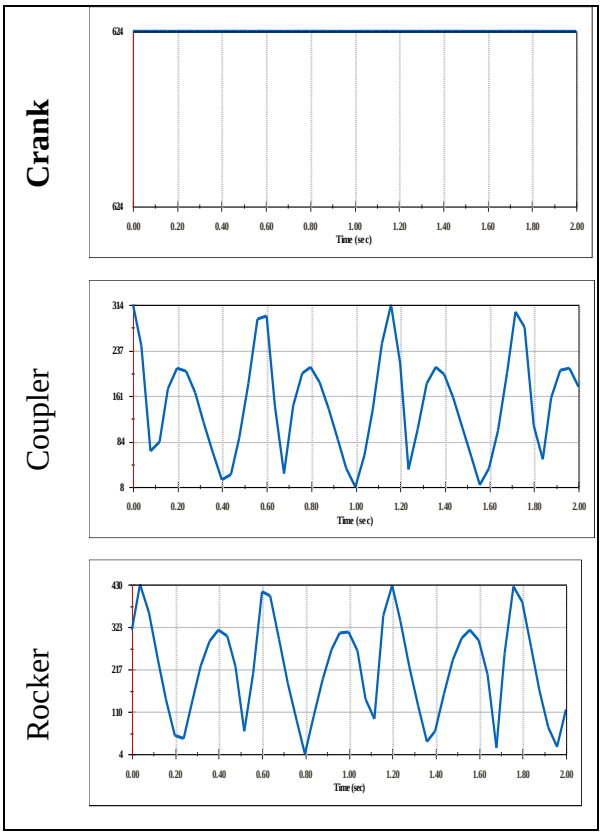


Fig. 10. Angular velocitysimulation of the transplanttion mechanism
Source: Authors' determination.

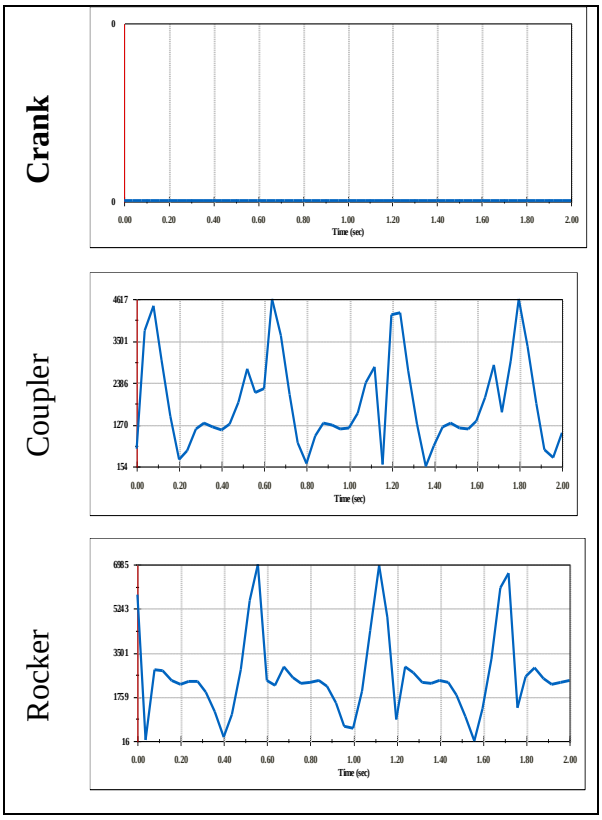


Fig. 11. Angular acceleration simulationof the transplantation mechanism
Source: Authors' determination.

Costs for producing the transplanting mechanism and its impact on the production costs of a rice transplanting machine.

Table 4 outlines the costs of producing each component of the machine independently, with a focus on the transplanting mechanism.

Table 4. Machine parts costs.

No.	Part	Cost, L.E.
1	Main frame	1,100
2	Engine	5,000
3	Shafts	500
4	Sprockets and Chains	700
5	Bearings	400
6	**Transplanting mechanism**	**1,000**
7	Guide rail	300
8	Seedlings mat	600
9	Mat movement mechanism	400
10	Floats	600
11	Drive wheels and Handle arm	700
12	Others (machine assembly, welding, and tools)	3,500
Total		**14,800**

Source: Authors' determination.

CONCLUSIONS

The primary purpose of this research is to develop, model, and simulate the rice transplanting mechanism (four-bar linkage mechanism) using theoretical calculations in Microsoft Excel software, mechanism principles, and simulation in SolidWorks software to compare outcomes. The core concepts of four-bar linkage (crank-rocker mechanism) were initially defined. Later, the angular displacements, velocities, and accelerations were calculated. According to the findings of this study, all the simulation results are nearly identical to the theoretical calculations in all theanalysis results. By the graphics observation, it is determined that the motion behaviors of angular displacements, angular velocities, and angular accelerations are approximately identical. Finally, the crank-rocker mechanism is considered the best for operating the rice transplanting mechanism in rice transplanting machines. Also, the cost for manufacturingthe transplanting mechanism was 1,000 L.E.,which represents 6.67% of the production cost for the rice transplanting machine.

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CHALLENGES OF DIGITAL TRANSFORMATION IN AGRICULTURE OF AZERBAIJAN

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Abstract

The purpose of this paper is to study the impact of digital technologies on agriculture, to identify the problems arising in the process of digitalization of agriculture, and to evaluate the advantages and disadvantages of the digital transformation. The study included materials and data from national and international institutions and organizations. Theoretical and empirical methods were used in the study. The main results showed that digital technologies help farmers to improve the precision, productivity, and sustainability of their practices. Also, they offer new tools to connect producers and consumers and expand consumer choice by increasing production transparency. However, digital adoption does not automatically bring benefits. The successful implementation of digital solutions requires coordination of efforts by the state, farmers and technology providers. Rural areas in many countries still lag behind in the adoption of new technologies due to both poor infrastructure, low affordability and accessibility of existing solutions and services, lack of digital skills, and regulatory issues. Based on the study, it can be concluded that the problems of digital transformation in agriculture are not only in the lack of financial resources and digital illiteracy of farmers, but also in their approach of farming, which is due to the presence of traditional and social factors.

Key words**:** *digital technologies, digital transformation, farmers, agriculture, Azerbaijan*

INTRODUCTION

One of the most important tasks of sustainable development — ensuring food security by 2030 — remains an unresolved global problem. To meet growing demand for agricultural products, the global food system will need to produce 50% more food, animal feed, and biofuels by 2050 than it did in 2012 [7]. At the same time, population growth, ongoing political instability and conflicts, significant changes in weather conditions in some regions and countries of the world exacerbate the food problem. The solution to this problem is directly related to the development of agriculture at the global, regional and national levels. Faced with such a difficult situation, all states are trying to find innovative ways to eliminate hunger, including through import substitution and the development of national agricultural production. In this context, digital transformation plays an important role, providing innovative solutions to improve the efficiency of the agro-industrial complex and the entire food supply chain.

The development of agricultural production has progressed through a series of scientific and technological revolutions that continuously enhanced its efficiency and profitability [8]. In the 20th century, several main stages in the development of agriculture can be distinguished. Firstly, the mechanization of agriculture in the early 20th century, secondly, the "green revolution" of the 1960s [5], and thirdly, the development of genetic engineering in the 1990s [15]. In the 21st century, the most important breakthrough factor in the development of agriculture has been its digital transformation.

Today, digital technologies are being introduced into all areas of economic activity, and agriculture is no exception. New technologies have given a significant boost to the development of agribusiness and the agricultural industry. A wide range of technologies are being introduced into agriculture to promote productivity and profitability: the Internet of Things (IoT),

artificial intelligence (AI) and big data, blockchain, automation and robotics. In the context of the rapid development of the digital economy, it is necessary to combine agriculture with digitalization, create an information base of agricultural data, use digital methods, including for the effective prevention of natural disaster risks, minimize losses, reduce production costs, etc. [2].

Digital transformation plays a decisive role in ensuring food security both at the national and global levels. Thus, digital technologies help to implement precise control over the processes of production and storage of agricultural products, which contributes to increased productivity and reduces losses, thereby increasing the availability of food.

The quality and safety of products are ensured by traceability technologies, thereby minimizing the risks of food poisoning.

Reducing production and logistics costs through digital technologies increases economic accessibility, making products more accessible to the population.

The use of modern digital platforms by farmers reduces the number of intermediaries, ensuring the availability of markets and setting a fair price.

Also, the most important advantage of digitalization of agriculture is the rationalization of the use of natural resources, reducing greenhouse gas emissions and reducing environmental pollution.

The purpose of this study is to study the level of implementation of digital technologies in agriculture in Azerbaijan, identify the challenges of digital transformation, and determine the advantages and disadvantages of digital transformation.

MATERIALS AND METHODS

The information base of the study included data from the State Statistics Committee of the Republic of Azerbaijan, the Ministry of Economy, the Ministry of Agriculture, legislations and international conventions, as well as regulatory documents, programs on digitalization of agriculture, particularly Concept of Digital Development in the Republic of Azerbaijan. The work used data from scientific and analytical materials, reports of international organizations (FAO, World Bank, United Nations).

In order to assess the level of digital transformation of agriculture, indicators such as the level of Internet accessibility in urban and rural areas, the distribution of reasons for not using the Internet, the level of ICT use for various types of work activities, etc. were analyzed.

Also, the study analyzed the work of the Electronic Agricultural Information System (EAIS), projects on digitalization of agriculture and rural areas, in particular, the Digital Village and Digital Agriculture. Theoretical and empirical methods were used in the study, in particular analysis and synthesis, comparison, graphical and statistical processing of data.

RESULTS AND DISCUSSIONS

The impact of digital technologies on agriculture has been studied by many researchers.

Households access to internet

The studies have shown that in recent years there has been a positive trend in households' access to the Internet [16]. In this context, the rapid growth of rural internet access does indicate improvements in digital infrastructure, but additional investments will be needed to close the gap. The study therefore highlights the importance of continued efforts to improve rural digital literacy and ensure universal connectivity, but especially to implement digital agricultural technologies [1]. Nonetheless, substantial cross-country disparities remain in the adoption and integration of such technologies within the agricultural sector [21].

However, digital adoption does not automatically bring benefits.

Digital Development Concept

The basis for digital transformation, including the creation of e-government, the use of information technology and ensuring cybersecurity in Azerbaijan have become the relevant regulatory legal acts adopted in recent years.

The Presidential Decree "On Accelerating Digital Transformation in Public Administration" (2021) outlined measures for the digitalization of government agencies, the creation of a "digital government cloud" and the integration of public services. Documents related to the creation of the "Asan" service and the "myGov" platforms formed the legal and institutional basis for the provision of digital services to citizens. The program "Azerbaijan 2030: National Priorities of Socioeconomic Development" defined the creation of a digital economy and an innovative society as a priority.

The latest document adopted to combine digitalization processes and accelerate the digital transformation of public administration was the "Concept of Digital Development in the Republic of Azerbaijan", approved on January 16, 2025. That document provides for the formation of a digital economy in the country with the widespread introduction of digital technologies, as well as further digitalization of public services and ensuring cybersecurity at the national level.

The concept covers the following main areas (Table 1) [3].

Table 1. Main directions of the Digital Development Concept

Digitalization of Public Administration – improvement of e-government systems, integration of digital government platforms, expansion of portals such as MyGov and ASAN Login
Development of the Digital Economy – support for the ICT sector, promotion of the startup ecosystem, expansion of e-commerce and digital payments.
Cybersecurity and Data Protection - protection of critical information infrastructure, implementation of data management standards
Investments in Digital İnfrastructure – expansion of fiber-optic internet, preparation for the introduction of 5G networks and the introduction of cloud technologies
Digital Skills and Human Capital – development of education and professional development in the field of ICT, large-scale awareness-raising programs on digital literacy

Source: Authors 'own elaboration based on Digital Development Concept in the Republic of Azerbaijan [3].

According to statistics, up to 90% of the population of Azerbaijan are Internet users. In the World Bank's Government Technology Maturity Index (GtMI) 2023, our country changed its place in the list and moved up from Group B to Group A (leaders) in 2022 [19]. According to the E-Government Development Index 2022 (EGDI), in the UN e-Government Outlook report [19], Azerbaijan ranked 83rd among 193 countries. The online services index was 61 out of 100 points (global average score 56), the telecommunications infrastructure development index was 68 points (global average score 58) and the human capital index was 70 points (global average score 70) [3].

In terms of household access to the Internet, Azerbaijan is the leading country in the South Caucasus, reaching 90% in 2023.

Georgia and Armenia show growth dynamics of 76% and 77%, respectively, in 2023. All three countries are seeing increased investment in infrastructure and increased access speeds (Fig 1).

To estimate the level of digitalization of agriculture, some indicators related to the Internet of the country should be considered.

First of all, this is an indicator of the availability of the Internet in urban and rural areas.

Figure 2 shows the dynamics of the share of households with internet access in urban and rural areas from 2018 to 2023. As can be seen, the level of internet access in urban areas has always been high, reaching 92.0% in 2023. Growth is also observed in rural areas, increasing from 71.7% in 2018 to 84.1% in 2023. The gap between urban and rural areas is 8%, which indicates the progress achieved in the development of internet infrastructure in our country in recent years.

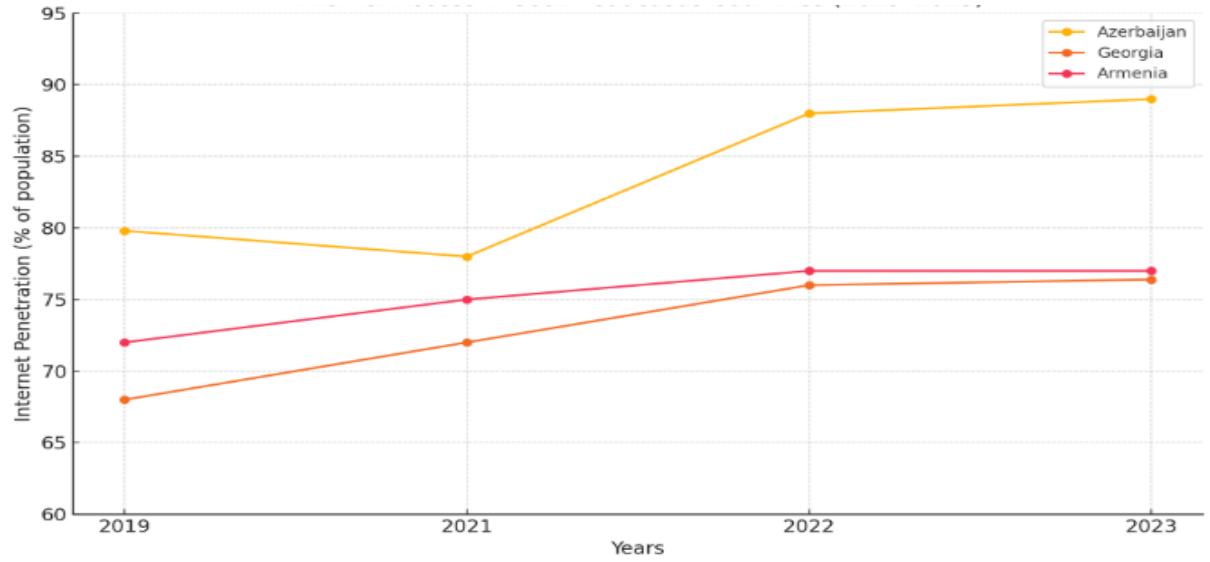


Fig. 1. Household access to the Internet in the South Caucasus countries
Source: Authors 'own elaboration based on statistic data.

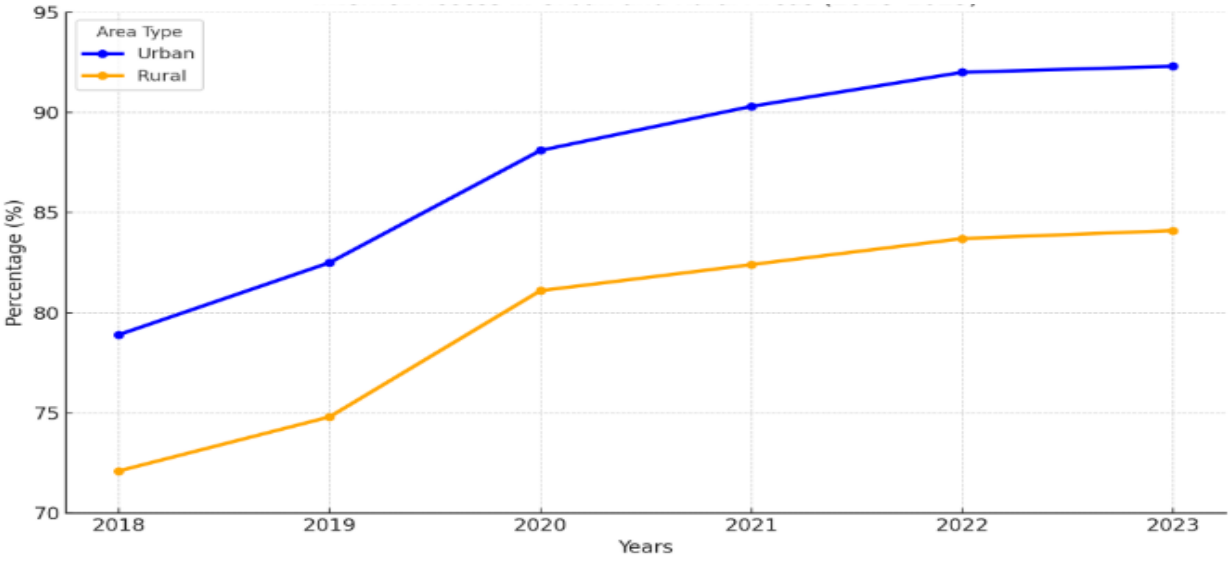


Fig. 2. Household access to the Internet in urban and rural areas in Azerbaijan
Source: Authors 'own elaboration based on statistic data [18].

Looking at household internet coverage by region, the following trends can be highlighted. The country's capital, Baku, leads with the highest rate of 98.1% in 2023. In the Nakhchivan Autonomous Republic, the rates remained stable in 2018-2021, but there has been a decline in recent years. The rate of growth can be seen in the Karabakh, Nagorno-Shirvan and Shirvan-Salyan regions. Thus, most regions reached 80% or more in 2023 [18].

Figure 3 shows that refusal to use the Internet is associated with both objective and subjective reasons. In addition to technical and financial difficulties, many people do not have the necessary digital skills or do not see the practical benefits of the Internet. This emphasizes the importance of conducting special educational and information programs aimed at increasing the level of digital literacy of the population in rural areas.

ICT usage rate in various activities

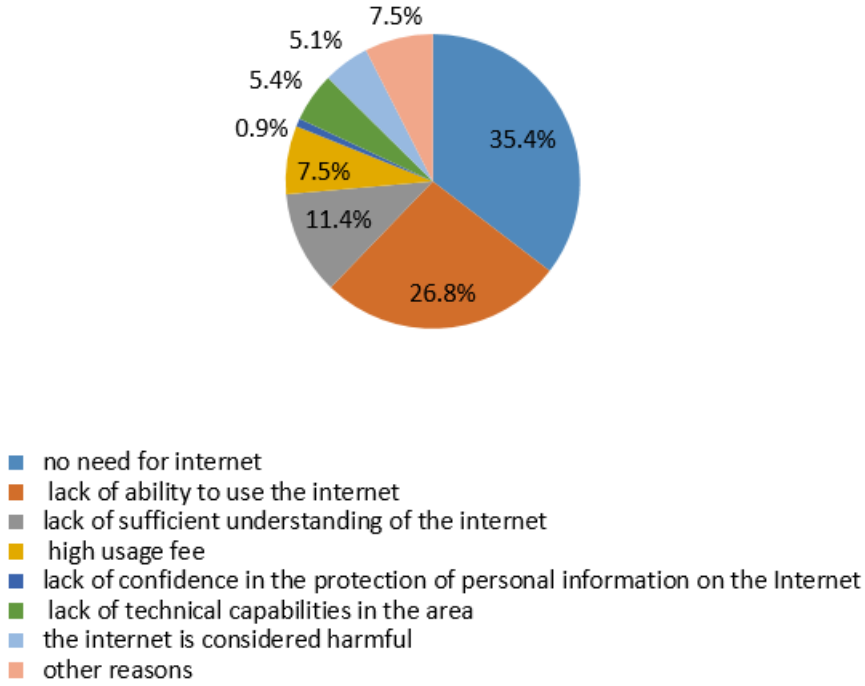


Fig. 3. Distribution of reasons for not using the Internet, in percentages
Source: Authors 'own elaboration based on data.

Table 2. Indicators of digital technologies use in Azerbaijan, 2023

İndicators	**Proportions**
Population using the Internet	88%
Households with Internet by urban-rural location	in urban - 92%, rural - 84%
Internet by region's	Baku, Absheron-Khizi, Nakhchivan – 93-98%; Mountainous Shirvan, Lankaran-Astara, Central Aran, Shaki-Zagatala, Mil-Mughan, Quba-Khachmaz – 84%; Ganja-Dashkasan – 87%, Karabakh – 80%, Qazakh-Tovuz: - 85%; Shirvan-Salya – 83%
Percentage of Internet users by profession	Legislators, senior officials and managers – 21.5; Professionals – 9.1; Technicians and associate professionals – 32.1; Skilled agricultural, forestry and fishery workers – 4.3
Proportion of individuals using the Internet, by type of portable device used to access the Internet	mobile telephone – 68.4%, tablet – 8.5; portable computers (laptops, netbooks) – 34.1
Proportion of individuals not using the Internet, by type of reason, as % to total	Internet is not needed – 35.4; lack of Internet skills – 26.8; insufficient understanding of the Internet – 11.4; high usage fee – 7.5
Proportion farms with an area of more than 50 hectares	0.4 %
Digital technologies using in the agricultural companies and large farms (Agro Dairy, Green Tech, Grand Agro İnvitro etc.)	GPS/GİS, IoT Sensors, Drones, AI&Machine Learning, Robotics, Farm Software, Blockchain

Source: Authors 'own elaboration based on data [18].

Structural changes are observed in the level of ICT use in various types of work activities. Here we can see increasing in the share of low- and middle-level specialists and a relative decrease in the share of top-level specialists (managers and specialists).

The ICT usage rate of skilled workers in agriculture, forestry and fisheries increased from 3.4% in 2021 to 5% in 2023. This indicates that digitalization has begun to penetrate all segments of the labor market. However, it should be emphasized that in agriculture this figure is significantly lower

than in other sectors, which is mainly due to digital illiteracy.

The spread of Internet access and the use of digital technologies in agriculture

The priority of the economic policy of Azerbaijan is the development of agriculture, as this sector ensures food security of the country and is a source of income for the population. According to statistics, 36% of the economically active population is employed in this sector [18]. In this context, issues of digital transformation of agricultural production are of crucial importance.

Last years, Azerbaijan is implementing a number of important measures to digitize agriculture. These measures aim to increase the productivity and efficiency of the sector, as well as support rural development.

Electronic Agricultural Information System (EAIS)

The Ministry of Agriculture of the Republic of Azerbaijan established the Electronic Agricultural Information System (EAIS) [4], which is a system destined to provide various electronic services to farmers. Through EAIS, farmers can apply for subsidies, register land and crop data, and use other agricultural services. The goal of EAIS is to increase transparency and efficiency in the agricultural sector.

In EAIS, there are registered 545,712 farms of 546,018 individuals, 1,123 farms of 891 legal entities and a personal cabinet since 2019 [4].

It should be noted that one of the reasons for the rapid increase in the number of registered farmers was the subsidy mechanism, which requires each farmer wishing to receive a subsidy to register in this system. Following the "Order on subsidizing the production of agricultural products" starting from 2020, subsidies to farmers in the field of plant-growing and livestock have been provided only through EAIS without alternatives [14].

Projects for digitalization in agriculture and rural areas

The country is implementing projects on the digitalization of agriculture jointly with the Food and Agriculture Organization of the United Nations (FAO). FAO Regional Office for Europe and Central Asia actively supports its member countries in accelerating the digital transformation of agriculture. This support is implemented through three interrelated but independent pillars:

1) addressing community-level challenges in agriculture and food systems through the Digital Villages initiative;

2) developing e-government systems to improve the transparency, efficiency and accessibility of governance and administrative processes in agriculture and food systems; and

3) supporting countries in developing national agricultural digitalization strategies to transform agriculture and food systems at the national level [6].

It should be emphasized that specific work has been done in almost all areas in Azerbaijan and significant results have been achieved.

Among these projects, the introduction of digital technologies and the Digital Villages initiative occupy a special place. The Digital Villages initiative aims to provide rural communities with tools and knowledge to effectively use digital technologies. The goal is to increase labor productivity in each village and improve living conditions by using local potential and digital innovations.

However, despite the obvious benefits of digitalization, some problems remain, such as limited access to ICT infrastructure in remote rural areas and the need to train local populations in new technologies.

Cooperation between Ministry of Agriculture and Azerspace

One of the steps to support digitalization is the expansion of cooperation between the Ministry of Agriculture and Azerspace. Thus, using satellite images and space technologies, a map of agricultural crops in the active agricultural areas of the country was prepared, including a digital map to update the geographic database of pivot irrigation systems. The main goal of the project was to assess the impact of climate on agriculture based on satellite images as part of the fight against climate change. The Digital Agriculture project has been implemented in a pilot mode in Guba and Gusar districts since 2021. At the initial stage, SMS alerts about plant diseases and the invasion of apple scale were sent to more than 5,800 farmers growing

apple, cherry, peach and nectarine trees within the framework of 4 climate stations operating in these regions all year round. Sensors installed at the stations collect data on air temperature, humidity, precipitation amount, leaf moisture, precipitation time and wind speed. After processing this data using artificial intelligence, the final results are analyzed by employees of the Ministry of Agriculture. If conditions favorable for the spread of diseases and pests are identified, SMS notifications are sent to farmers about the existing risk.

Risks and challenges of the implementation of digital technologies in agriculture

In the coming years, the level of digital penetration and its real impact on agriculture will increase. At the same time, digital technologies will entail serious risks and challenges that will require special attention.

First. With the development of digital technologies in agriculture, traditional methods of conducting agribusiness are gradually being replaced, which entails both advantages and a number of risks. First, digitalization affects traditional methods of conducting agriculture: experience is replaced by algorithms. Farmers rely on intuition, long-term experience and observation of nature, and artificial intelligence algorithms analyze data and make recommendations, which leads to dependence on technology.

Second, agricultural technologies are changing. Old farming methods (for example, traditional plowing) are being replaced by conservative farming with minimal intervention. Some local plant species are disappearing, as digital platforms recommend only hybrid and GMO varieties.

Third, the automation of manual labor is accelerating. Drones, robots and unmanned combines replace the labor of farmers and agricultural workers. This reduces the need to transfer knowledge from generation to generation.

Fourth, digitalization is changing the agroecosystem. The use of digital pesticide systems may disrupt traditional pest control methods (e.g. crop rotation, manual harvesting). Farmers may lose the ability to visually analyze soil and plant health, as they will have to rely on satellite and sensor data.

According to the conducted research, it can be said that the introduction of digital technologies has its advantages and disadvantages (Table 3).

Table 3. The advantages and disadvantages of digital agriculture

Advantages	Disadvantages
Increased productivity and efficiency	High cost of technology – financial difficulties for small and medium farmers
Accurate analytics and risk management	Low level of digital literacy – weak use of technology
Improving the quality and quantity of manufactured products	No fixed internet – problems with connection in rural areas (mainly in remote villages)
Sustainable development and reducing environmental damage	Cyber risks and data dependency – data leaks and dependency on software vendors
Simplifying manual labor and reducing risks associated with the human factor	Market monopolization – control over digital platforms by large corporations
	Problems with harmonization of the regulatory framework – legal uncertainty

Source: Authors 'own elaboration based on research.

Sixth. Unfair competition between large and small and medium-sized farms

Digital transformation is a powerful tool for solving food security problems. The introduction of innovative technologies in agriculture and supply chains helps to increase production, reduce losses, improve product quality and increase the availability of food products. However, the successful implementation of digital solutions requires coordination of efforts by the state, business and the scientific community. In the future, digital technologies will become an integral part of the food system, ensuring sustainable agricultural development and access to quality food for all.

However, the digitalization of agriculture may lead to large technology corporations and agro holdings controlling key platforms, data, and technologies. This, in turn, may lead to unfair competition and make it difficult for small and medium farmers to enter the market. Large corporations (e.g. Bayer, John Deere, Cargill) create closed ecosystems, as a result of which farmers are forced to use only software, equipment, and services from these companies [9]. John Deere prohibits repairs of its equipment without official dealers. Bayer and Monsanto dominate the seed and pesticide markets, dictating prices [10].

There are more than 570 million farms in the world, and 95% of them are less than 5 hectares in size [11]. In Azerbaijan, farms with a sown area of less than 5 hectares' account for 88% of all farms. These small farms own 49.5 % of the country's arable land.

Farms with an area of more than 50 hectares in the country account for 0.4 % of the total number of farms, while large farms account for 17.6 % of arable land [17]. The share of large farms in terms of numbers is very small, but their weight in terms of land use is significant. Large farmers can easily invest in advanced digital agricultural technologies due to their financial capabilities. However, small farmers need financial support to implement such technologies. Therefore, governments around the world support the implementation of digital technologies in agriculture by providing financial assistance to farmers. According to studies conducted in different countries, although farmers with high capital are using digital technologies to increase productivity, the vast majority of family farmers are unable to take advantage of the opportunities offered by digitalization [12, 14]. That is also relevant for Azerbaijan.

It is obvious that digital transformation goes beyond a simple technological tool: it is a comprehensive, systemic and complex technological revolution and industrial innovation that encompasses digital thinking, data elements and digital technologies. The positive impact of digitalization on agricultural development can be realized when the digital economy reaches the stage of intensive agricultural practices and the growth rate of total factor productivity, enhanced by digital technologies, exceeds the growth rate of costs.

CONCLUSIONS

Thus, we can conclude that the problems of digital transformation of agriculture are not only in the lack of financial resources and digital illiteracy of farmers, but also in their approach to farming, which is due to the presence of traditional and social factors.

Obviously, all this increases the risks: dependence on technology – without the Internet and software, a farmer can lose control over processes; loss of biodiversity – local plant varieties and traditional agricultural technologies may disappear; decreased autonomy of farmers – it becomes difficult to work without digital tools; cultural changes – the likelihood of losing traditional knowledge and practices of rural communities increases. As a result, the question of maintaining a balance between tradition and technology may arise, which requires a balanced approach.

So, it is important to combine digital and traditional methods. Use sensors and artificial intelligence, but do not forget about visual observation and traditional methods. Of particular importance is the development of agricultural education, that is, the adaptation of traditional knowledge to modern realities and its transfer to new generations. On the other hand, to preserve biodiversity, it is necessary to preserve local varieties, use organic farming and control the degree of automation so that key decisions are fully entrusted to people, not algorithms.

Some of the problems listed above can be solved through public policy. Some barriers (such as the lack of skilled labor and relatively high implementation costs) can be overcome through close collaboration between farmers, researchers, and technology providers. Combining technological advances with practical solutions tailored to the specifics of the region will allow for better integration of digital technologies into the agribusiness sector and ensure the growth and sustainability of the industry.

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THE POTENTIAL BIOMASS WASTE AS A SOURCE FOR GREEN BIOENERGY ORIGINATING FROM AGRICULTURE - CASE STUDY SIBIU COUNTY, ROMANIA

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Abstract

The energy transition promoted by the European Green Deal emphasizes the valorization of local renewable sources, including bioenergy from agriculture. This study evaluates the theoretical and technical potential for bioenergy obtained from agriculture as a result of crop cultivation and animal breeding for Sibiu County, Romania. Based on this analysis, and due to a specific agricultural profile of the county (i.e., a mix between animal husbandry in mountainous/sub-mountainous areas and plant crops dominance for the Târnavelor Plateau), it is consistent evidence that the region is suitable to further take into consideration the valorization of all potential unvalorized agricultural residues for further inclusion into the future circular bioeconomy strategy. The analysis is based on official data recorded for agriculture, and by applying biomass production indices, sustainable collection rates and energy conversion factors specific to each type of residue. Based on our calculations, the minimum available biomass produced for crops and vegetables production for one year for Sibiu County (average for 7 consecutive years) for 118,498 ha, it can be considered 1,030,932.60 $t \cdot y^{-1}$ for Sibiu County. The total manure produced by livestock in Sibiu County, which can also be added for biomass, can be 50% at least 600,000.00 $t \cdot y^{-1}$ Sibiu County. The major constraint is the infrastructure needed for transport and storage, as well as the type and the place where a bioenergy plant should be best built. Thus, agricultural bioenergy can significantly contribute to local energy security, social inclusion, and further cultural development, and furthermore contribute to the reduction of greenhouse gas emissions in Sibiu County.

Key words**:** *bioenergy, biomass, crops, livestock, manure, circular economy, Sibiu County*

INTRODUCTION

The transition towards renewable energy is increasingly required worldwide. This economic objective has become a central pillar of the European Union (EU), particularly under the EU Green Deal Policy, which paved the way for the recently amended and adopted Renewable Energy Directive (RED II and RED III). The current regulatory framework for renewable energy aims to achieve climate neutrality by 2050 and increase its share across all the EU Member States [8, 9, 11]. In this context, bioenergy plays a strategic role due to its capacity to provide dispatchable, transferable, and storable chemical energy while simultaneously supporting organic waste valorization. Also, this strategy is in line with the main objectives of the EU circular economy strategy [35]. Worldwide, bioenergy is derived mainly from agricultural residues and livestock manure, and it is a valuable resource in providing a continuous and locally available energy supply [34]. On the other hand, the reuse of available agricultural waste as biomass also contributes to greenhouse gas (GHG) mitigation by reducing methane emissions and substituting fossil fuels [16, 37]. When sustainably bio-based solutions are implemented for agriculture, the use of agricultural wastes does not compete with food production chain. On the contrary, it can be

integrated into existing farming systems with limited environmental trade-offs [15, 19]. Among the EU member states as well as among the South-Eastern European (SEE) countries, Romania possesses significant agricultural and livestock waste resources, ranking among the leading agricultural producers in Eastern Europe [30]. However, despite this favorable resource base, the exploitation of agricultural waste biomass for energy production remains limited, particularly at the regional and local levels. There are different barriers, such as the lack of clear strategic plans at national, regional, and county levels, as well as the lack of a coherent national program, and the lack of a coherent communication strategy and system down to the local level. The EU strategies on this subject emphasize the importance of decentralized renewable energy systems to enhance rural energy security and reduce regional disparities [9]. Consequently, regional-scale assessments are essential to identify feasible bioenergy pathways adapted to specific territorial conditions. This study is focused on Sibiu County, part of the Central Region of Romania, which may represent a relevant case study due to its heterogeneous agricultural structure imposed by the richness of the landscape (i.e., from mountains plateau to hilly mountain areas and fields), and covered for more than 52%, with protected areas Natura 2000 [24, 32]. The county combines extensive livestock farming, especially cattle and sheep breeding in the hilly–mountain areas, with crop production concentrated mainly in the northern part of Sibiu County, namely Târnavelor Plateau [24]. This mixed farming system generates diverse biomass streams, including crop residues and livestock manure, with different seasonal availability. Similar regional profiles across Europe have demonstrated a strong potential for integrating livestock-based biogas systems with complementary crop residue utilization [6, 21]. While numerous studies have evaluated biomass availability at national or macro-regional scales, fewer analyses focused on county-level assessments that integrate both crop-based and livestock-based resources under sustainability constraints. Such localized studies are particularly relevant for policy design, infrastructure planning for further sustainable developments, and the development of replicable circular economy models for rural regions in Romania as well as in other similar SEE countries [3, 34].

The scope of this article is to quantify the theoretical technical bioenergy potential derived from agriculture and animal husbandry in Sibiu County, Romania. The assessment is based on region-specific production data and standardized biomass-to-energy conversion factors, providing a science-based estimation of available bioenergy. The study aims to support evidence-based decision-making for renewable energy planning and sustainable rural development.

MATERIALS AND METHODS

Study area description

Sibiu County is located in central Romania, within the historical region of Transylvania, and covers an area of approximately 5,432 km² [25]. The county is characterized by a highly diversified relief, ranging from mountainous areas in the southern part – dominated by the Făgăraș' and Cindrel Mountains - to hilly areas and plateaus extending northwards [24]. This altitudinal gradient strongly influences land use patterns, agricultural systems, and biomass availability.

Agricultural land occupies a significant share of the county's territory, with permanent grasslands prevailing in mountainous and sub-mountainous areas, where extensive livestock farming is the dominant agricultural activity. In contrast, agricultural land is concentrated mainly in the Târnave Plateau, an area characterized by more favorable pedoclimatic conditions for crop production [24]. Due to this landscape heterogeneity, we are witnessing today a mixed agricultural activity, combining livestock-based systems with crop-oriented farming. Livestock farming plays a central role in the rural economy of Sibiu County, with cattle and sheep representing the dominant species, particularly in grassland-rich areas. However, pork and poultry farming are present to a lesser extent and are generally associated

with more localized and semi-intensive production systems [17, 30]. Crop production is primarily oriented towards cereals and potatoes. However, a very good place occupies vegetables. All these agricultural activities are responsible for generating a range of organic residues suitable for bioenergy production and recovery [15]. The coexistence of diverse agricultural practices and land use types makes Sibiu County a representative case study for assessing the bioenergy potential of agriculture and animal husbandry in regions with heterogeneous topography and mixed farming systems.

Data sources

The assessment is based exclusively on agricultural and livestock data for Sibiu County obtained from two official statistical sources: (1) the National Institute for Statistics or NIS (i.e., Tempo Online: http://statistici.insse.ro:8077/tempo-online/), version 2014 [25], (2) the Agricultural Directorate for Sibiu County and (3) Sibiu County Directorate for Sanitary and Veterinary Control and Food Safety (DSVSA Sibiu). These official data include two major components: agricultural biomass production and manure generated by livestock farming.

Data collection – agricultural biomass of Sibiu County. All data were collected for the total agricultural area and complemented by detailed information on the cultivated area, total production, and average yields of the main crops. The dataset covers a seven-year period (2018–2024), allowing the derivation of representative average values. These data were used to estimate the availability of agricultural residues by applying crop-specific residue-to-product ratios, forming the basis for evaluating the theoretical bioenergy potential from crop biomass at the county level.

Data collection – animal husbandry in Sibiu County. All data related to animal husbandry provides a detailed overview of livestock resources and associated production parameters, with animal population figures referring specifically to May 2025, while complementary indicators cover the period 2023–2025. The collected data include livestock population structure (total number of animals, disaggregated by species, sex, and age categories), poultry farms (a detailed list of individual poultry farms, including farm names and the number of birds per holding, as well as aggregated totals at the county level), livestock density indicators (number of animals per 100 hectares of agricultural land for the 2023-2025 period, disaggregated by major livestock categories), average production parameters, and data regarding the estimated quantities of livestock manure generated, used as input for assessing the bioenergy potential from animal waste. All data are presented in a structured tabular format, organized by livestock species and specific production categories (e.g., cows and heifers, sows, broilers), ensuring consistency and comparability for subsequent bioenergy potential calculations.

Data processing and analysis for Sibiu County. All official collected data were processed and analyzed using descriptive statistical methods. Annual totals and averages were calculated to assess the general dynamics of the agricultural sector. The processing methodology included the analysis of cultivated areas (ha) and annual crop production (tons), allowing the identification of market trends and the evolution of the crop sector. To assess agricultural efficiency, the average yield of crops (to/ha) was calculated, using the formula:

$$\text{Crop Yield (to/ha)} = \text{Production (to)} / \text{Cultivated Area (ha)}. \quad (1)$$

For the livestock sector, the total livestock numbers and their structure by species, sex, and age (e.g., cattle, sheep, pigs, poultry) were analyzed, based on the situation from May 2025. A time trend analysis was performed to observe annual fluctuations in yields and productions, as well as the evolution of animal density per 100 ha of agricultural land during the period 2023-2025. All data were managed, aggregated, and analyzed using spreadsheet software, Microsoft Excel. All results were used to estimate the potential of unused biomass for Sibiu County.

RESULTS AND DISCUSSIONS

Available residual biomass estimation from crop production. In 2014, the total agricultural land area registered in Sibiu County was 303,619 hectares (ha), representing 55.88% of the total land of the County (Table 1).

Table 1. Agricultural land use for the period 2018-2024 in Sibiu County, Romania

No crt	Land use type	Land area (ha)	Land area (%)
1	**Agricultural land, of which:**	**303,619**	**55.88**
2	Arable land	118,498	39.03
3	Pastures	105,660	34.80
4	Hayfields	71,575	23.57
5	Vineries and grapevine nurseries	2,839	0.94
6	Orchards and fruit tree nurseries	5,047	1.66
7	**Non-agricultural land**	**239,629**	**44.12**
	TOTAL	**543,248**	**100,00**

Source: Original calculation based on data from Tempo Online database version 2014, NIS [25].

The distribution of this agricultural land area by use categories was predominant among crop cultivation and grasslands. Thus, agricultural land for crop cultivation constituted the largest share, covering 118,498 ha (39.02%). Grasslands occupy a significant area of 177,235 ha (i.e., 105,660 ha as pastures and 71,575 ha as hayfields), a evidence based indicator for the major importance of the grazing-based livestock sector for Sibiu County. Vineyards and orchards have a smaller contribution with a total of 2,839 ha (0.94%) and 5,047 ha (1.66%), respectively. The remaining 239,629 ha of the County consisted of non-agricultural land, representing 44.12% of the total area, and was mainly part of protected areas, highlighting a balanced distribution between agricultural and non-agricultural uses in the region.

The structure of agricultural areas in 2014 highlights a typical configuration of hilly-mountain areas of the Carpathians, where grasslands (pastures and hayfields) share similar proportions with arable land. This distribution suggests that extensive livestock production, based on grass resources, remains a key component of the County's agricultural economy [7]. Permanent grasslands not only supply fodder but also represent a significant source of plant biomass with potential renewable energy use [20]. Variations in land use patterns, such as the relatively high proportion of non-agricultural land, may reflect the prevalence of forests or natural and semi-natural ecosystems that are less suitable for intensive cropping [1]. Today's shifts toward bioenergy crop production are reshaping land use paradigms in Romania, indicating potential future transitions in agricultural land allocation [35].

Detailed data of the crop sector, highlighting the dominant crops in terms of area and productive efficiency, is presented in Table 2.

Maize for grain crop occupies the largest cultivated area, with 27,173.43 ha, generating a total production of 137,688.30 tons. Although occupying much smaller areas, potato and vegetable crops show exceptionally high yields compared to other cereals and oilseeds (16.57 to/ha for potatoes and 13.85 to/ha for vegetables). This shift is due mainly to the favorable climatic conditions. Wheat was cultivated on 6,011.85 ha, with an average yield of 3.61 to/ha. Sunflowers and soybeans had lower yields, of 2.35 to/ha and 1.81 to/ha, respectively.

Table 2. Major crop production for the period 2018-2024, Sibiu County, Romania

No crt	Crop type	Crop area (ha)	Annual production (tons)	Yield (to/ha)
1	Wheat	6,011.85	21,700.86	3.61
2	Maize for grain	27,173.43	137,688.30	5.07
3	Sunflower	1,209.00	2,806.85	2.35
4	Soybean grain	1,107.14	2,008.85	1.81
5	Potatoes	1,623.57	26,902.57	16.57
6	Vegetables	2,170.00	30,052.29	13.85
7	Alfalfa – green mass equivalent	9,518.42	147,043.60	15.44
8	Green fodder maize	2,326.00	58,625.86	25.20
9	Fallow arable land	1,048.00		

Source: Original calculation based on data from Tempo Online database version 2014, NIS [25].

The yield analysis per crop indicates a clear differentiation between the efficiency of field crops (cereals, oilseeds) and horticultural crops (potatoes, vegetables), which is a key factor when evaluating the potential of local biomass resources for green bioenergy production as well as for re-thinking the infrastructure

needed for bioenergy production. The relatively low average yields of wheat and soybeans may reflect the influence of climatic stressors, such as drought and heat, which are known to reduce cereal and oilseed yields, as well as the use of less intensive production technologies compared to other regions [2]. Climate variability and drought stress, in particular, have been shown to negatively influence photosynthesis and reduce grain formation in major crops, leading to significant yield losses under water limitation [5]. The dominance of maize in the structure of cultivated areas emphasizes its central role mainly for the local agricultural economy, both as a source of animal feed and as a potential biomass feedstock for bioenergy applications, and also taking into consideration the lack of agricultural machinery [2]. However, maize yields are also susceptible to environmental stresses, and yield stability is closely tied to climatic conditions and agronomic management [5]. In contrast, horticultural crops such as potatoes and vegetables show very high yields despite occupying smaller areas, indicating a high biomass productivity per hectare. However, the hilly areas in Sibiu provide excellent conditions for the horticultural crop cultivation, well established in the county's history for many centuries.

This distinction between area extent and yield efficiency is important for bioenergy assessments because crops with high productivity per unit area may present attractive options for biogas or biofuel production, even if their total cultivated area is limited. The observed contrast between the large areas dedicated to field crops with modest yields and the smaller but much more productive horticultural crops underscores the need to consider both yield potential and biomass quality when assessing sustainable agricultural profitability and the energetic potential of crop residues and agricultural byproducts in Sibiu County. An estimate of the quantities of plant residues generated by the main crops is presented in Table 3, calculated using crop-specific transformation coefficients to convert primary production into residual biomass, following Poincet and Parris (2004) [29]. Based on the proposed estimation, calculating the total residual biomass from the analyzed crops resulted in a total amount of 58.27 tons. Potatoes and vegetables individually contribute the largest shares of residual biomass, each accounting for 16.57 tons, reflecting a transformation coefficient of 1.0. Maize and sunflower crops are associated with a coefficient of 2.0, indicating that the resulting residual biomass (e.g., stalks, cobs, and straw) is approximately double the corresponding primary yield. Soybean exhibits the highest transformation coefficient of 5.0, generating 9.05 tons of residues from a yield of 1.81 to/ha. These estimates highlight the significant potential of crop residues as a feedstock for bioenergy production in Sibiu County.

Table 3. Residual biomass based on crop yields for the period 2018-2024, Sibiu County, Romania.

No crt	Crop type	Yield (to/ha)	Coefficient of transformation*	Residual biomass (tons)
1	Wheat	3.61	1.1	3.97
2	Maize for grain	5.07	2.0	10.14
3	Sunflower	2.35	2.0	4.69
4	Soybean grain	1.81	5.0	9.05
5	Potatoes	16.57	1.0	16.57
6	Vegetables	13.85	1.0	13.85
	TOTAL	**43.26**		**58.27**

Source: Own calculation,.*following Poincet and Parris (2004) [29].

The analysis of the data presented in Table 3 is essential for evaluating the energy and higher-value utilization potential of residual biomass. Certain crops, such as maize and soybean, generate substantial quantities of residues relative to their primary yields, as reflected by their transformation coefficients of 2.0 and 5.0, respectively. This indicates a significant source of organic material that can be exploited for various applications, including composting, biogas production, or as a raw material for industrial purposes. The total estimated residual biomass from the analyzed crops amounts to 58.27 tons, representing a considerable local resource. However, only approximately 15% of this total (about 8.7 to/ha) may be considered available for non-feed applications, as a substantial portion of the plant material is utilized within the

livestock sector as fodder. This represents the minimum annual biomass potentially available from crop and vegetable production in Sibiu County, based on a seven-year average. Extrapolated to the total arable land area of 118,498 ha, the annual residual biomass availability can be estimated at 1,030,932.60 tons per year for the County. In the context of the circular economy, quantifying the volumes of residual biomass (e.g., straw, stalks, and cobs) that remain in the field after harvesting is fundamental for assessing opportunities to close material loops and generate added value from agricultural production. Crop residues, traditionally regarded as waste, constitute a renewable source of lignocellulosic biomass that can be reintegrated into the economic cycle through various valorization pathways [23, 27]. Rather than being disposed of or burned, these residues can be repurposed in ways that contribute to soil health and reduce dependency on synthetic inputs, thereby aligning with circular agriculture objectives [18].

Specifically, one major pathway for residue valorization is soil amendment. Crop residues can be directly incorporated into soil as green manure or processed into compost, improving soil structure, enhancing organic matter content, increasing water retention capacity, and ultimately contributing to long-term soil fertility [31, 38].

Composting crop biomass also reduces the environmental burden associated with open-field burning of residues and lowers the need for chemical fertilizers [31]. In addition, the production of energy from biomass – including anaerobic digestion to generate biogas or thermochemical conversion to produce solid biofuels – represents an effective strategy to recover energy from crop residues while contributing to renewable energy goals and climate mitigation efforts [23; 28].

These data thus provide a solid foundation for discussing opportunities to transform vegetable waste and other crop residues into value-added outputs within Sibiu County, emphasizing how integrated circular economy strategies can enhance both environmental sustainability and resource efficiency in the agricultural sector.

Available residual biomass estimation from animal husbandry

The provided data for animal husbandry indicate a mixed evolution of the livestock sector in Sibiu County between 2023 and 2024, characterized by notable increases in sheep, goats, and pigs, alongside declines in cattle and poultry populations (Table 4). These dynamics reflect both regional specificities and broader national and European trends.

Table 4. Livestock in Sibiu County for the period 2023-2024

No crt	Livestock group	2023	2024	Variation
1	**Bovine – total**	**1,814.70**	**1,809.40**	**-5.30**
2	Cows, buffaloes and heifers	1,177.00	1,173.60	-3.40
3	**Porcine – total**	**3,154.10**	**3,242.60**	**+88.50**
4	Breeding sows	272.60	313.00	+40.40
5	**Ovine and caprine – total**	**11,721.20**	**11,869.50**	**+148.30**
6	Sheeps, yearlings and goats	10,063.70	10,232.70	+169.00
7	**Poultry – total**	**77,749.60**	**76,415.70**	**-1,333.90**
8	Adult laying hens	44,102.20	42,961.50	-1,140.70

Source: Own calculation based on data from Tempo Online database 2023-2024, NIS [25].

The sheep and goat sector recorded the most significant absolute increase, with a rise of approximately 148.3 thousand heads, indicating a robust expansion of small ruminant farming in Sibiu County. This trend is consistent with Romania's position as one of the leading EU countries in terms of sheep and goat populations, driven by favorable natural conditions, extensive grassland resources, and strong market demand for ovine products [7]. At the county level, this expansion aligns with national strategies promoting the sustainable use of permanent grasslands and the resilience of extensive livestock systems, which are generally less sensitive to feed price volatility compared to intensive production systems. Pig numbers increased by approximately 88.5 thousand heads, suggesting a partial recovery or expansion of pig farming activities following previous declines caused by African swine fever outbreaks. The increase of more than 40 thousand breeding sows indicates medium-term development strategies and renewed investment confidence in the sector.

Similar recovery trends have been reported at the national level, supported by biosecurity measures, targeted subsidies, and market stabilization policies under the Common Agricultural Policy [10]. Nevertheless, the sector remains vulnerable to rising feed and energy costs, which continue to exert pressure on production margins across the EU.
In contrast, the cattle sector experienced a slight decline, with total cattle numbers decreasing by approximately 5.3 thousand heads, including a reduction of 3.4 thousand heads in major subcategories. This trend mirrors the long-term decline of cattle herds observed at the national level in Romania and in several EU member states, driven by increasing production costs, labor shortages, low farm-gate milk prices, and the growing impact of climate variability on fodder availability [4]. Additionally, stricter environmental and animal welfare regulations may disproportionately affect small and medium-sized cattle farms, accelerating structural adjustments in the sector.
The poultry sector recorded the most pronounced decline, with a reduction of over 1.3 million birds, including a substantial decrease in adult laying hens. Similar downward trends in poultry production were reported at the national level in 2023, largely attributed to escalating feed and energy costs, disease pressures, and the implementation of enhanced animal welfare regulations, particularly those concerning housing systems for laying hens [12]. Across the EU, the transition toward higher welfare standards has increased production costs, contributing to restructuring and consolidation within the poultry industry. Overall, the livestock dynamics observed in Sibiu County reflect broader structural transformations occurring at national and EU levels. These changes are shaped by a complex interplay of agricultural policies, market rules, rising input costs (feed, energy, veterinary treatments), and evolving animal welfare and environmental regulations. From the perspective of green bioenergy potential, the expansion of small ruminants and pigs may enhance the availability of manure and organic residues suitable for biogas production, while declines in cattle and poultry numbers could reduce the supply of certain types of livestock biomass. Consequently, understanding these trends is essential for accurately assessing the sustainable bioenergy potential of the livestock sector in Sibiu County. The share of each meat source in Romania's total meat production (live weight) underwent notable changes between 2022 and 2023, reflecting a continued expansion of the poultry sector alongside contractions in other livestock sectors (Table 5). These shifts highlight structural transformations in Romanian livestock production that are consistent with broader European trends.

Table 5. Meat production in Romania for 2023-2024 (live weight)

No crt.	Meat source	2022 (%)	2023 (%)
1	Poultry	48.60	50.20
2	Bovine	11.50	11.30
3	Porcine	30.30	29.20
4	Ovine and caprine	9.60	9.30

Source: Own calculation based on data from Tempo Online database 2024, NIS [25].

Poultry remained the dominant source of meat, with its share increasing markedly from 48.60% in 2022 to 50.20% in 2023. The expansion of the poultry sector can largely be attributed to rising consumer demand for affordable and efficient protein sources, as well as the relatively high feed conversion efficiency and short production cycles characteristic of poultry systems [12].
According to the centralized data from the Sibiu County Directorate for Sanitary and Veterinary Control and Food Safety (DSVSA Sibiu) as of May 2025, Table 6 summarizes the poultry stock held by commercial poultry farms in Sibiu County. The distribution of poultry populations among farms reveals marked structural differences, reflecting broader trends in European poultry production. SC Transavia holds the largest cumulative poultry stock by a substantial margin, exceeding 580,000 flocks across the three listed locations.

Table 6. Poultry flocks owned by poultry farms in Sibiu County for 2024 – 2025.

No crt.	Farm name	Poultry flocks
1	SC TRANSAVIA F1	224,469
2	SC MEDIVET	13,837
3	SC TRANSAVIA F9	318,478
4	SC TRANSAVIA F17	38,606
5	SC PUIUL REGAL	9,474
6	SC OPREA AVICOM	139,808
7	SC RINADI 9007	10,920
8	SC RINADI 9005	4,776
9	SC OUA DE TARA	0
10	SC OVOSIB	0
11	SC OVOSIB INVEST	47,314
12	SC FERMA HOGHILAG	18,380
	TOTAL	**840,958**

Source: DSVSA Sibiu, 2025[33].

This concentration of poultry within a single large operator exemplifies the ongoing industrialization and consolidation of the poultry sector, consistent with EU-wide patterns where intensive poultry systems dominate production due to scale efficiencies and higher biosecurity capacities [22]. In contrast, SC Ouă de Țară SC Avigal reported zero flocks in May 2025, a situation plausibly associated with a confirmed outbreak of salmonellosis at a poultry farm in Sibiu County, which resulted in the compulsory culling of thousands of birds as part of disease control measures. Salmonellosis and other enteric pathogens remain key challenges in poultry production, with significant prevalence across European flocks and continuing food safety concerns that require comprehensive control strategies throughout the production chain [36]. The stark contrast in poultry stock levels among farms in Sibiu County, including the absence of birds at some facilities due to disease outbreaks, underscores important implications for production resilience, food safety, and supply chain stability. These dynamics also have direct consequences for the availability of livestock-derived biomass, such as poultry manure and by-products, which are relevant feedstocks for biogas production and other circular bioeconomy applications. Regular outbreaks and depopulation events can temporarily reduce the biomass supply, complicate annual estimates of renewable energy potential and necessitating adaptive strategies in livestock biomass modelling.

The share of beef production declined slightly from 11.50% to 11.30%. In absolute terms, beef production recorded a marginal decrease of approximately 0.2%, reflecting the ongoing contraction of the cattle herd in Romania. This trend is consistent with national and European patterns, where cattle numbers have declined due to high production costs, labor shortages, and relatively low profitability, compounded by stricter environmental and animal welfare regulations [4]. Climatic pressures affecting fodder availability further contribute to the vulnerability of the cattle sector.

A more pronounced decline was observed in the pig sector, with its share decreasing from 30.30% to 29.20% and carcass production falling by approximately 4%. This contraction reflects persistent structural and sanitary challenges, most notably the continued impact of African swine fever, which significantly reduced pig populations in Romania in 2023. Similar declines in pork production have been reported across several EU member states, where disease outbreaks, rising feed prices, and increased biosecurity costs have constrained recovery [10].

The share of sheep and goat meat decreased slightly from 9.60% to 9.30%. Nevertheless, data from the NIS indicate a substantial increase in the absolute production of sheep and goat meat, from approximately 62 tons in 2022 to 89 tons in 2023. This apparent contradiction suggests improvements in production efficiency, higher slaughter rates, or increased market demand, particularly for export-oriented segments. At the European level, small ruminant production remains influenced by market volatility and declining livestock numbers, although these systems continue to play an important role in extensive grazing and rural development [7, 10].

Overall, the observed changes in Romania's meat production structure between 2022 and 2023 reflect the combined effects of agricultural policies, market conditions, animal health crises, and evolving consumer preferences. From a broader European perspective, the increasing dominance of poultry and the decline of cattle and pig production illustrate ongoing structural

adjustments within the livestock sector. These dynamics are also relevant for assessing the availability of livestock-derived biomass, such as manure and processing residues, which are essential inputs for green bioenergy production and circular economy strategies.

The data presented in Table 7 provide a comparative overview of livestock distribution within Romania's Centre Region and Sibiu County, highlighting sectoral specialization, spatial concentration patterns, and potential inconsistencies in the reported statistics.

Table7. Livestock population by species in the Centre Region and Sibiu County, for 2023-2024

No crt.	Livestock group	Total for Central Region	Total for Sibiu County
1	Poultry	9,207,186	927,196
2	Bovine	386,216	46,690
3	Porcine	324,778	45,258
4	Ovine and caprine	2,447,461	526,630

Source: Own calculation based on data from Tempo Online database 2024, NIS [25].

The poultry sector dominates livestock production in the Centre Region, with a total of 9,207,186 flocks. Of these, 927,196 flocks are breeding in Sibiu County, representing approximately 10.1% of the regional total. This relatively modest share indicates that poultry production is more strongly concentrated in other counties of the region, a pattern consistent with the spatial clustering of industrial poultry operations observed at both national and European levels. Such concentration reflects the tendency of poultry production to gravitate toward large-scale, vertically integrated systems that benefit from economies of scale, advanced biosecurity, and proximity to processing facilities [22].

In contrast, the bovine sector shows a markedly different distribution. The Centre Region recorded a total of 386,216 bovines, of which 46,690 are breeding in Sibiu County, accounting for approximately 12.1% of the regional cattle population. Although lower than the poultry share, this proportion highlights the continued relevance of cattle farming in Sibiu County, supported by extensive grassland resources and traditional ruminant-based production systems. Similar relationships between grassland availability and cattle density have been documented in hilly and mountainous regions across Central and Eastern Europe [13, 14].

The pig sector is comparatively smaller in the Centre Region, with a total of 324,778 heads, of which 45,258 were recorded in Sibiu County, corresponding to about 13.9% of the regional total. This limited scale reflects the structural constraints and ongoing challenges faced by the Romanian pig sector, including African swine fever outbreaks, rising feed and energy costs, and the gradual decline of small and medium-sized farms [26].

The sheep and goat sector emerges as particularly significant in the Centre Region, with a total of 2,447,461 heads, of which 526,630 are breeding in Sibiu County. This represents approximately 21.5% of the regional total, underscoring the strong specialization of Sibiu County in small ruminant farming. This finding is consistent with national patterns, where Romania ranks among the leading EU Member States in sheep and goat numbers, and where pastoral systems remain dominant in mountainous and sub-mountainous areas [14].

From a bioenergy and circular economy perspective, the substantial presence of ruminant livestock, particularly sheep and goats, has important implications for the availability of livestock-derived biomass, such as manure, which represents a key feedstock for biogas production. Accurate livestock data are therefore essential for reliably estimating organic residue flows and for assessing the contribution of the livestock sector to renewable energy potential at county and regional levels.

Table 8 summarizes livestock and pet populations in Sibiu County in May 2025 by animal category and type of owner. Bovine livestock is dominated by cows and heifers (42,851 heads), followed by calves aged 0–6 months (7,655) and bulls (507), with individuals owning the majority of animals. The equine population is limited (1,533 heads), mainly represented by mares (1,431), predominantly owned by individuals.

The ovine and caprine sector records the highest livestock numbers, particularly ewes

and yearlings (420,267 heads), followed by rams (16,425) and goats (14,870). Although individuals account for most animals, legal entities manage substantial flocks, especially in the ewe and yearling category. The porcine sector shows low overall numbers (1,037 sows and 30 boars), with legal entities holding the majority.

Poultry populations are very high, especially chickens (956,349 heads), largely concentrated in legal entities, while turkeys, geese, and ducks are mainly owned by individuals. Rabbits are exclusively owned by individuals (2,141 heads), and no fur animals were recorded.

Table 8. Livestock and pet populations in Sibiu County by category and type of owner (May 2025)

Property type	**Livestock group**			
BOVINE				
	Bulls	Cows and heifers	Calves 0-6 months	
Individuals	325	28,464	4,373	
Legal entities	182	14,387	3,282	
Total	**507**	**42,851**	**7,655**	
EQUINE				
	Donkeys	Stallions	Mares	
Individuals	57	22	1,314	
Legal entities	8	15	117	
Total	**65**	**37**	**1,431**	
OVINE AND CAPRINE				
	Rams	Ewes and yearlings	Caprine	
Individuals	15,578	399,225	14,084	
Legal entities	847	21,042	786	
Total	**16,425**	**420,267**	**14,870**	
PORCINE				
	Boars	Sows		
Individuals	5	844		
Legal entities	25	193		
Total	**30**	**1,037**		
POULTRY				
	Chickens	Turkeys	Geese	Ducks
Individuals	114,441	720	1,555	2,731
Legal entities	841,908	0	0	0
Total	**956,349**	**720**	**1,555**	**2,731**
RABBITS, FUR ANIMALS AND BEEHIVES				
	Rabbits	Fur animals	Beehives	
Individuals	2,141	0	13,290	
Legal entities	0	0	150	
Total	**2,141**	**0**	**13,440**	
PETS				
	Dogs	Cats		
Individuals	21,785	2,402		
Legal entities	550	0		
Total	**22,335**	**2,402**		

Source: DSVSA Sibiu, 2025 [33].

Beekeeping is well represented, with 13,440 beehives, mostly owned by individuals. Pet ownership is dominated by dogs (22,335) and cats (2,402), primarily registered to individuals.

The results indicate a clear dominance of individual ownership in ruminant farming, small livestock, and pet keeping, reflecting the continued importance of family-based and traditional agricultural systems in Sibiu County. The exceptionally high numbers of sheep confirm the economic and cultural relevance of ovine farming, supported by favorable pasture conditions and long-established pastoral practices. On the contrary, legal entities play a major role in intensive livestock sectors, particularly poultry and pig production, highlighting a more industrialized production model.

Overall, the ownership structure reveals a dual agricultural system, combining traditional small-scale farming with modern, commercial livestock operations, which has important implications for rural development, animal health management, and agricultural policy planning in the region.

Table 9 presents livestock density expressed as the number of animals per 100 ha of land in Sibiu County for the period 2023–2024. The highest density is recorded for ovine and caprine livestock, with 241.26 heads per 100 ha, indicating a strong specialization in small ruminant farming. Porcine density is considerably lower, reaching 71.7 heads per 100 ha. Cattle density amounts to 20.13 heads per 100 ha, while cows and buffaloes show the lowest value, at 11.36 heads per 100 ha.

Table 9. Livestock density breeding per ha in Sibiu County for the period 2023-2024

No crt.	**Category**	**Animal numbers per 100 ha of land**
1	Ovine and caprine	241,26
2	Porcine	71,7
3	Cows and buffaloes	11,36
4	Cattles	20,13

Source: Own calculation based on data from Tempo Online database 2023-2024, NIS [25].

The livestock structure and density in Sibiu County highlight a significant potential for green bioenergy production, particularly based on manure as a main resource. The dominance of ovine and caprine livestock, both in absolute numbers and density per 100 ha, indicates a

substantial availability of organic biomass suitable for anaerobic digestion or compost-based energy systems. Extensive sheep farming, closely linked to grassland use, offers opportunities for integrated biomass valorization while maintaining low environmental pressure.

Cattle and cow–buffalo populations, although less dense, represent an important source of high-energy manure, especially in mixed farming systems where crop residues can be co-digested. The moderate cattle density suggests a stable but underexploited bioenergy potential, which could be enhanced through improved manure collection and farm-level biogas installations.

Poultry and porcine sectors, largely concentrated in legal entities, present a more intensive bioenergy potential due to higher manure output per unit area and better infrastructure for waste management. The strong concentration of poultry livestock, in particular, favors centralized biogas or energy recovery systems, contributing to renewable energy generation and nutrient recycling.

Table 10 presents the main animal and poultry production outputs in Sibiu County. Milk production represents the dominant output, with 3,100 units recorded for cow and buffalo milk, while sheep milk production is considerably lower (48 units). Wool production reaches 2.49 kg, reflecting the presence of extensive sheep farming systems. Egg production totals 193 pieces, indicating a moderate level of poultry output.

Table 10. Livestock and poultry outputs in Sibiu County in 2023

No crt.	Product	Unit	Value
1	Cow and buffalo milk	liters	3,100
2	Sheep milk	liters	48
3	Wool	kilograms	2.49
4	Eggs	pieces	193

Source: Own calculation based on data from Tempo Online database, NIS [25].

Overall, the data show that dairy production is the primary livestock-related output in the county, while secondary products such as wool and eggs contribute to a lesser extent to total animal production.

The structure of animal and poultry production in Sibiu County confirms the strong link between dairy-oriented livestock systems and green bioenergy potential. High levels of cow and buffalo milk production imply the presence of stable cattle populations, which are key contributors to manure generation suitable for biogas production. Dairy farms, particularly those operating continuously throughout the year, provide a predictable and consistent biomass supply for anaerobic digestion.

Although sheep milk production and wool output are lower in absolute terms, the extensive ovine sector remains relevant for bioenergy through manure availability rather than primary product yield. Manure from sheep farming, often associated with pasture-based systems, can be integrated into decentralized bioenergy or composting schemes, supporting circular nutrient flows.

Egg production reflects a moderate poultry sector, which, despite lower product output, may generate concentrated organic waste streams with high bioenergy efficiency, especially when managed in centralized systems.

Table 11. Estimated manure quantities in Sibiu County for 2023-2024.

Livestock group	Heads	Manure and bedding / head / day (kg)	Manure and bedding / stock (kg)	Manure / stock / year (t)
Cows and heifers	42,851	40.00	1,714,040.00	625,624.60
Bulls	507	35.00	17,745.00	6,476.93
Calves 0-6 months	7,655	8.00	61,240.00	22,352.60
Mares	1,431	30.00	42,930.00	15,669.45
Stallions	37	30.00	1,110.00	405.15
Donkeys	65	20.00	1,300.00	474.50
Sheep and yearlings	420,267	2.80	1,176,748.00	429,512.87
Rams	16,425	2.80	45,990.00	16,786.35
Goats	14,170	2.80	39,676.00	14,481.74
Sows	1,037	14.00	14,518.00	5,299.07
Boars	30	12.00	360,00	131.40
Hens	956,349	0.12	114,761.90	41,888.09
Total manure/year (t): 1,179,102.75				

Source: Own calculation.

Overall, animal production outputs indirectly reflect the scale and intensity of livestock systems, reinforcing the role of livestock-

derived biomass as a complementary resource to crop residues in the development of sustainable green bioenergy pathways in Sibiu County.

The quantitative assessment of livestock manure production in Sibiu County is summarized in Table 11, which presents the number of animals by category, the daily manure and bedding generation per head, and the resulting annual manure quantities.

The results indicate that livestock farming in Sibiu County generates a substantial quantity of organic residues with significant potential for green bioenergy production. Based on livestock census data and standard manure generation coefficients, the total quantity of manure and bedding produced annually in the county is estimated at 1,179,102.75 $t \cdot y^{-1}$.

Cattle farming represents the dominant contributor to manure production. Cows and heifers alone account for 625,624.60 $t \cdot y^{-1}$, corresponding to approximately 53.1% of the total manure output. When including bulls and calves, the bovine sector exceeds 55% of the total manure resources, highlighting its strategic importance for biogas-based energy systems. This finding is consistent with the livestock structure of Sibiu County, where cattle breeding remains a core agricultural activity.

Small ruminants also contribute significantly to the biomass resource. Sheep and yearlings generate 429,512.87 $t \cdot y^{-1}$, representing about 36.4% of the total manure production, while goats add an additional 14,481.74 $t \cdot y^{-1}$. Given the extensive grazing systems characteristic of the region, a considerable share of this manure is currently dispersed on pastures and traditionally used for soil fertilization. However, its seasonal concentration in sheepfolds offers opportunities for partial recovery and valorization through anaerobic digestion.

Equine species (mares, stallions, and donkeys) collectively produce approximately 16,549 $t \cdot y^{-1}$, while the swine sector contributes 5,430.47 $t \cdot y^{-1}$. Although these quantities are comparatively modest, they can play an important complementary role in mixed-feed biogas plants, particularly by improving substrate diversity and process stability.

Poultry farming contributes 41,888.09 $t \cdot y^{-1}$ of manure, which, despite its lower mass contribution, is characterized by higher nitrogen content and biodegradability. This makes poultry manure a valuable co-substrate in anaerobic digestion, although careful management is required to avoid ammonia inhibition.

From a bioenergy perspective, it is estimated that at least 50% of the total manure produced (≈600,000 $t \cdot y^{-1}$) could be sustainably diverted to bioenergy production without compromising current soil fertilization practices. The remaining fraction continues to play a crucial role in maintaining soil organic matter and nutrient cycling. This dual-use approach aligns with circular economy principles and supports sustainable agricultural intensification.

All the results demonstrate that livestock manure represents a key renewable biomass resource in Sibiu County, with a particularly high potential for biogas production. The integration of manure-based bioenergy systems could significantly contribute to reducing greenhouse gas emissions, improving manure management, and enhancing energy self-sufficiency at local and regional levels. When combined with energy crops and crop residues, livestock manure forms a solid foundation for the development of a resilient green bioenergy sector in the region.

CONCLUSIONS

This study provides a comprehensive county-level overview regarding the green bioenergy potential derived from agricultural crops and livestock in Sibiu County, Romania.

The analysis of these results confirms that the heterogeneous agricultural structure of the county (combining extensive grassland-based livestock systems with arable crop production) creates favorable conditions for diversified and resilient bioenergy pathways. This situation is shared among other counties in the Carpathian Range area.

The analysis shows that crop plants may generate a minimum available waste biomass of approximately 1,030,932.60 $t \cdot y^{-1}$, calculated as a seven-year average for 118,498 ha of arable land. This biomass can be valorized without competing with food production, provided that sustainable residue removal rates are respected. High-productivity crops, particularly potatoes and vegetables, exhibit the strongest biomass yields per hectare, while maize and soybean contribute significant residue volumes due to their high transformation coefficients.

Livestock farming in Sibiu County produces an estimated 1,179,102.75 $t \cdot y^{-1}$ of manure, of which at least 50% (≈600,000 $t \cdot y^{-1}$) can be sustainably allocated to bioenergy production without compromising soil fertilization practices. The bovine sector is the dominant contributor, accounting for over 55% of total manure resources, followed by small ruminants, which contribute more than 36%. Poultry and swine sectors, although smaller in mass, provide highly biodegradable substrates that can enhance anaerobic digestion efficiency when co-digested with cattle manure. The study contributes original insights by providing a detailed, data-driven bioenergy assessment at the county level, addressing a scale that is highly relevant for regional energy planning, rural development strategies, and circular economy implementation.

This methodological approach can be replicated in other Romanian counties or similar European regions characterized by mixed farming systems and heterogeneous topography. Several limitations should be acknowledged.

The analysis focuses on theoretical and technical potential and does not explicitly account for logistical constraints, seasonal availability, economic feasibility, infrastructure needs, or farmer willingness to participate in bioenergy schemes. In addition, variations in manure collection efficiency and crop residue management practices may influence the actual recoverable biomass. Future research should therefore integrate techno-economic assessments, life-cycle analyses, and spatial modeling of biomass collection and transport. Evaluating policy incentives, investment costs, and social acceptance will be essential for translating the identified bioenergy potential into operational projects.

Overall, agricultural biomass and livestock manure represent a robust foundation for advancing green bioenergy and circular bioeconomy solutions in Sibiu County and similar regions form the Easter European countries.

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DETERMINANTS OF CREDIT ACCESS OF CATFISH FARMERS: CASE STUDY OF AKURE SOUTH LOCAL GOVERNMENT AREA IN ONDO STATE, NIGERIA

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Abstract

The study analyzed the factors influencing credit access among catfish producers in Akure South Local Government Area, Ondo State, Nigeria. A multistage sampling approach was used to choose 80 respondents through a structured questionnaire. The data was examined using descriptive statistics, logit regression, and ordinary least squares regression models. The majority (75%) of the respondents were male, with an average age of 42 years. The majority (60%) of respondents were married, 71.3% had tertiary education, and just 30% had expertise in catfish farming. The average loan amount obtained was ₦578,388. Most of the farmers (38.7%) received credit from informal sources. The Logit regression study found that household size, agricultural experience, and interest rate were all important predictors of farmers' access to finance. The findings also revealed a considerable positive relationship between access to credit and net income for catfish growers. The study recommends that the government should have to expand microfinance institutions to reach farmers who are in need of credit to boost their productivity and to also find a way to reduce the amount of interest rate charged.

Key words**:** *credit access, determinants, income, catfish production, farmers, Nigeria*

INTRODUCTION

Fish is one of the cheapest forms of animal protein in Nigeria when compared to chicken, beef, and mutton [23]; [26]; [19]. Fish farming, often known as aquaculture, is the process of artificially producing fish in tanks, earthen ponds, and ocean cages for food [9]. Fish farming, often known as aquaculture, is a system characterized by the intensity of feed consumption, which separates the system into four categories: integrated, extensive, semi-intensive, and intensive [13]. Extensive aquaculture depends on natural food sources such as plankton, with no human intervention in feeding. Semi-intensive systems augment natural food with organic or inorganic fertilizers and low-cost supplementary feed. Intensive systems rely on relatively expensive feed, such as small wild fish or manufactured feed (pellet), whereas integrated systems combine fish farming with other animal or agricultural production [13]. Catfish production is unquestionably laborious [16]. Water supply, building or building setup, pond construction, oxygen supply, feeding, fish hauling, pipe drainage, transportation, fuel, electricity, preservation facilities, harvesting, chemicals and medication (drugs), and telephone services are just a few of the business-related tasks that must be completed in order to use the current production method.
Access to credit is an important factor in helping farmers to help boost their efficiency and revenue. The impact of credit helps to improve the design of financial products and services for farmers. Access to credit help farmers to invest in their farms, improve their productivity and increase their income.It also helps farmers level out revenue swings and defend against financial shocks. According to

[2], credit is the current and transient transfer of purchasing power from the owner to the buyer, which enables the latter to demand money from another individual for agricultural reasons while maintaining confidence in his capacity to pay it back later. Credit is critical to aiding agricultural modernization and encouraging farmer participation in the development process. Credit cannot only reduce financial restraints, but it can also serve as an incentive to adopt innovative technology that would otherwise be slow to gain acceptance [11]. Numerous studies in the literature have demonstrated that low technology adoption due to limited access to credit facilities, particularly in poor and developing countries like Nigeria, has been linked to low productivity and profitability caused by low quantity, poor quality, and poor delivery of fish and fish products to consumers [14]; [8].

The failure to obtain official finance constitutes one of the greatest limiting factors for small-scale manufacturers [5].Due to this, small-scale producers are now turning to friends, family, and moneylenders for funding, which is ineffective when it comes to satisfying capital needs, especially when it comes to agricultural projects. Most farmers have limited access to credit due to high interest rates, terms and conditions that borrowers cannot meet, and other factors. Although unregulated lenders charge high interest rates, borrowers continue to utilize them because they are easily accessible and documentation and collateral are not needed. Borrowing from official sources, particularly cooperatives and rural banks, has increased over the years [12]. Even though there are many studies on the subject of how farmers' agricultural output is affected by their ability to obtain financing and how their socioeconomic status influences their decision to use credit, [7], [20], [21], [1]. Empirical studies on catfish production are scarce, though, especially when it comes to farmers in the research region.

Accordingly, this study looks on the variables that affect credit availability as well as how it affects catfish farmers' net farm income in Akure South Local Government Area, Ondo State, Nigeria.

The study provides answers to the underlying research questions. What are the socioeconomic features of catfish farmers? What are the sources and quantities of credit utilized by catfish farmers? What factors influence credit availability for catfish producers? and what factors influence catfish farmers' net farm income? Therefore, this study intends to shed light on this little-known aspect of agriculture by identifying and assessing the factors that influence catfish farmers' access to credit in Akure South Local Government Area, Ondo State, Nigeria.

MATERIALS AND METHODS

The Study Area

Akure South Local Government Area, one of six (6) Local Government Areas recognized as the Ondo Central Senatorial District in Ondo State, Nigeria, is where the research took place. It is one of the eighteen (18) local government areas (LGAs) in Ondo State, with its headquarters situated in Akure, the state capital and most populous LGA.

Latitudes 7°21'N and 7°50'N and longitudes 5°50'E and 7°25'E are its coordinates. It is 331 square kilometers in size and is about 250 meters above sea level. Akure North local government area borders it on the northeast, Ifedore local government area borders it on the northwest, and Idanre local government area borders it on the south. The total number of residents of Akure South LGA was estimated to be 353,211 [22], with a 3.03% annual increase. The town's yearly increase in population is due to its administrative position as well as its long history as a hub of economic activity, which continues to draw a considerable number of immigrants.

Sampling Procedure and Data Collection

The respondents were selected using a two-stage sampling technique. Five communities within the local government region were randomly selected in the first step. In the second step, 16 catfish producers were chosen at random from a list provided by the State's

Agricultural Development Project (ADP) in each of the five localities.

As a result, the survey included 80 responses in total. Using a standardized questionnaire, primary data were collected. Socioeconomic and demographic information about respondents, including age, marital status, educational attainment, household size, and farming experience, as well as the sources and amounts of credit obtained, factors affecting catfish farmers' access to credit, and factors affecting farmers' net farm incomes, were gathered.

Analytical Technique

The data was analyzed using the ordinary least squares regression model, logit regression, and descriptive statistics. Descriptive statistics such as mean, frequency distribution, and percentages were used to explain the demographic characteristics of catfish farmers and the amount of credit received. The logit regression model was used to analyze the factors influencing farmers' credit availability, and the ordinary least square regression model was used to analyze how credit availability affected farmers' net farm income. The data was analyzed using the Stata/SE-12 statistical program.

Logit Model Specification

The factors affecting catfish farmers' ability to obtain loans were investigated using a logit regression model.

The logit model has the following specifications:

$$P_i = E(Y = 1/X_i) = 1 / (1 + e^{-z}) \quad \ldots(1)$$

where:

Y is the dependent variable, which is a binary response variable (access to credit = 1; otherwise = 0). Pi is the likelihood that Yi = 1, with values ranging from 0 to 1, and it is considered to be nonlinearly related to Z.

$$Z = \beta_0 + \beta_i X_i \quad \ldots(2)$$

where:

X_i is a set of independent variables

β_0 is the intercept which is a constant

β_i is the coefficient of the identified variables influencing access to credit

X_1 = Age of the catfish farmers (years)

X_2 = Years of education

X_3 = Marital status (married = 1, otherwise = 0)

X_4 = House-hold size (number)

X_5 = Farming experience (in years)

X_6 = pond size (m^2)

X_7 = Interest rate (naira)

e = Error term

Ordinary Least Squares Model Specification

The effect of loan access on farmer net farm income was examined using an ordinary least squares model.

The specifications are as follows:

$$Y_i = a + \beta_{i1}X_1 + \beta_{i2}X_2 + \beta_{i3}X_3 + \beta_{i4}X_4 + \beta_{i5}X_5 + \beta_{i6}X_6 + \beta_{i7}X_7 + \varepsilon_i \quad \ldots(3)$$

where:

Y= Net farm income (₦)

X_1 = Age (years)

X_2 = Gender (Male = 1, 0 otherwise)

X_3 = Household size (number)

X_4 = Years of farming experience (years)

X_5 = Level of education (years)

X_6 = Number of ponds (number)

X_7 = Access to credit (access = 1, 0 otherwise)

ε_i = Error term

RESULTS AND DISCUSSIONS

Socio-economic Characteristics of the Respondents

The majority of respondents (27.5%) were between the ages of 36 and 45, with an average age of 42 years, according to the descriptive analysis of their socioeconomic characteristics (Table 1).

This means that the majority of the responders were adults in their prime working years, which will benefit their catfish business. This findings is similar to that of [7] which found that the mean age is about 45 years.The majority of farmers (75%) were men, according to Table 1. This aligns with the findings of [4]. The bulk of the respondents (60%) were found to be married. This aligns with the findings of [15] and [3]. The average household size of the respondents was six people, which is consistent with the findings of

[16]. Additionally, the majority of farmers (71.3%) have a university degree, suggesting that they are literate. These results concurred with those of [18]. The results also showed that most farmers (70%) have been raising fish for an average of five years.

This result shows that the respondents had prior expertise with catfish production**.**

Table 1. Distribution of Respondents by Socio-economic Characteristics

Variables	Frequency	Percentage (%)	Mean
Age			42.0
≤25	6	7.5	
26 -35	21	26.3	
36 – 45	22	27.5	
46 – 55	21	26.3	
Over 55	10	12.5	
Gender			
Male	60	75	
Female	20	25	
Marital Status			
Single			
Married	19	23.8	
Divorced	48	60.0	
Separated	1	1.3	
Widow	5	6.3	
	7	8.8	
Years of Education			
Tertiary			
Secondary	57	71.2	
Primary school	13	16.3	
	10	12.5	
Household Size			
≤3			6
4-6	13	16.3	
≥7	56	70.1	
	11	13.8	
Farming Experience			
≤ 5			5
6-10	56	70	
11-15	14	17.5	
≥ 16	8	10	
	2	2.5	
Access to Credit			
Yes			
No	71	88.75	
	9	11.25	
Primary Occupation			
Farming	20	24.1	
Business/entrepreneur	46	57.5	
Government jobs	14	17.5	
Type of pond			
Earthen	26	32.5	
Concrete	31	38.8	
Plastic	17	21.3	
Flow-through	4	5	
Re-circulatory	2	2.5	
Pond Size (m^2)			300
<200	24	30	
200 – 400	30	37.6	
>400	26	32.5	

Source: Field Survey, 2023.

This contradicts the results of [21], who discovered that most farmers had only seven years or fewer of farming experience.

Additionally, Table 1 shows that the overwhelming majority of farmers (88.75%) had access to credit, suggesting that when farmers have credit, they can invest in new technologies and equipment that boost productivity and profits. This is in line with what [6]found. The majority of respondents (37.6%) had ponds that ranged in size from 200 to 400 m^2, with an average of 300 m^2, according to the results. Additionally, the majority of respondents (38.8%) used concrete ponds.

Sources and Amount of Credit Obtained

The respondents' distribution by source and credit amount is displayed in Table 2. Findings indicate that the average credit secured was ₦578,388.

Table 2. Distribution of Respondents by Sources and Amount of Credit Obtained

Variables	Frequency	Percentage (%)	Mean
Sources of Credit			
Formal	19	23.8	
Informal	31	38.7	
Both	30	37.5	
Total		100	
Amount of Credit (₦)			578,388
≤ 100,000			
101,000-300,000	22	27.5	
301,000-500,000	37	46.3	
≥500,000	8	10	
Total	13	16.3	
	80	100	

Source: Field Survey, 2023.

It can be established that the small amount of credit available to Nigerian farmers when compared with global requirements has a significant impact on farmer productivity because farmers require credit to expand their level of production as well as to purchase feed, pay labor costs, and cover other production expenses [1]. This disagrees with the findings of [7] which observed that the credit that was acquired was between ₦30,000 and ₦50,000. Additionally, the results indicated that 38.7% of farmers obtained credit through informal channels, 23.8% through formal channels, and approximately 37.5% through a combination of formal and informal channels.

This runs counter to the results of [25], who discovered that 73.7%, 22.1%, and 4.2% used informal, formal, and both sources, respectively.

Analysis of the Determinants of Access to Credit

The logit regression model estimates for the variables affecting the finance availability of catfish farmers are displayed in Table 3. The findings found that household size, years of agricultural experience, and interest rate all had a substantial influence on farmers' access to loans. Farmers' access to financing was significantly boosted by household size ($p < 0.01$). According to the findings, for every unit increase in household size, farmers have a 0.064 higher chance of receiving a loan. Years of farming experience had a positive and significant impact on farmers' access to financing ($p < 0.05$).

Table 3. Estimates of Logit Regression Model on the Determinants of Access to Credit

Variable	Coefficient	Standard error	P-value
Constant	21.309***	14530.639	0.000
Age	-0.730	1.762	0.172
Years of Education	-0.380	1.327	0.082
Marital Status	1.220	1.566	0.607
Household Size	0.064***	1.563	0.002
Years of Farming Experience	0.448**	1.402	0.041
Pond Size	-2.205	1.269	3.023
Interest Rate	-21.462***	14530.639	0.000
Log likelihood	0.724		
Prob>chi^2 = 0.0000			
Pseudo R^2 = 0.7246			

Source: Field Survey, 2023

* significant at the 10% level, ** significant at the 5% level, and *** significant at the 1% level.

Catfish farmers' years of agricultural experience boost their chances of obtaining financing by 0.448. This is in line with research by [27] and [10], which found that farmers' access to funding was significantly impacted by their level of agricultural competence. Interest rates significantly ($p < 0.01$) impacted farmers' ability to obtain credit. This suggests that for every unit increase in interest rates, the probability of farmers obtaining financing would drop by 21.462. This supports the conclusion by [24] that farmers' access to financing was significantly impacted by interest rate age.

Effect of Credit Access on the Net Farm Income of Catfish Farmers

Table 4 displayed the findings of the ordinary least squares regression model for the influence of loan access on catfish producers' net farm incomes. The results showed that the number of ponds, household size, gender, and financing availability all significantly affected the net farm income of catfish producers. While household size and the number of ponds were positively and significantly correlated (5% and 10%), gender and credit availability were positively and significantly correlated ($p < 0.01$). This indicates that the number of ponds the farmers own, their household size, and their access to financing all increase their net farm income. Additionally, a farmer's net farm income may be significantly impacted by their gender. The included factors explained 62% of the observed variation in farmers' net farm income, according to the coefficient of determination (R^2), which was 0.62. The F-ratio of 8.79 indicated that the entire model was significant at 1%.

Table 4. Estimates of the Ordinary Least Squares Regression Model on the Effect of Credit Access on the Net farm Income

Variable	Coefficient	Standard Error	P-value
Constant	36834.58**	18657.85	0.049
Age	-2274.167	24017.67	0.925
Gender	3917.349***	913.8885	0.000
Household size	41721.99 **	21190.88	0.050
Years of experience	454.8227	5436.78	0.933
Level of education	11407.66	9883.371	0.249
No of ponds	2351.187*	1294.929	0.070
Access to credit	13355.41***	4364.276	0.002
	R^2 = 0.621	F-ratio = 8.79***	

Source: Field Survey, 2023.

* significant at 10% ** significant at 5% *** significant at 1% level.

Access to credit significantly increased net farm revenue for catfish farmers ($p < 0.01$). This implies that net income would increase by 13,355.41 for every unit increase in credit

access. This is consistent with the findings of [17] and [10], who discovered that farmers' net farm income was significantly positively influenced by access to credit.

CONCLUSIONS

In Akure South, Ondo State, Nigeria, the study examined the variables affecting catfish farmers' access to financing.

According to the study, the majority of catfish farmers in the study region had access to financing, albeit in small amounts, which had no effect on or improved the performance of catfish production there. The majority of the catfish farmers (75%) were men, and their average age fell within the economically productive age range, favoring agriculture, according to the socioeconomic features of the farmers. The majority of catfish farmers had little experience growing catfish, were married, and had tertiary education.

The average credit amount got was ₦578,388, which is regarded quite low. Most (38.7%) of farmers acquired credit from informal sources, while approximately 37.5% acquired credit from both official and informal sources. The data also showed that interest rates, years of agricultural expertise, and household size all significantly influenced farmers' ability to obtain loans. The findings also demonstrated that the net farm revenue of catfish farmers was significantly impacted by gender, household size, number of ponds, and access to financing. However, the study indicates that access to credit has a beneficial influence on catfish farmers' net income, indicating that credit can assist catfish farmers in investing in their businesses and increasing production. In light of the study's findings, the following recommendations are made to improve credit access for catfish producers in the study area: The government should make an effort to make financing available to catfish farmers, and farmers should apply for loans to help them raise their production scale and income. This means that the financing made accessible by the government to the catfish producing firm should be raised in order for the business to have a greater influence on the nation's economic growth and fish production.

The government should encourage women to participate in catfish production by empowering them and providing them with access to loans, just like male farmers. The government should develop microfinance organizations to target farmers who need credit to increase productivity. To encourage farmers to accept loans from formal sources, credit providers should ensure that loan applications are processed quickly and that loans are disbursed to successful applicants without delay. In order to lower their interest rates and make it easier for businesses that produce catfish to obtain credit, the government ought to support additional microcredit organizations.

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INFLUENCE OF HYBRID AND CLIMATE CONDITIONS ON THE PRODUCTIVITY OF SUNFLOWER HYBRIDS IN SUCCESSIVE CROPPING, IN THE SOUTHEASTERN AREA OF ROMANIA

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Abstract

Sunflower is a versatile crop, highly adaptable to changing weather conditions and capable of extracting moisture and nutrients from the soil in depth thanks to its unique root system. The aim of this study was to follow the behavior of sunflower hybrids of different origins, in successive cultivation, in the pedoclimatic conditions of 2024. In this study, aspects regarding the productivity of the hybrids, their degree of capitalization or adaptation to pedoclimatic conditions, as well as quality indices such as MMB and MH were presented. For stable production, shared risk and a maximized profit in the long term, it is preferable to cultivate at least two hybrids. In the south-eastern area of the country where water deficit is frequent, the hybrid 'ES Belfis' is recommended to be cultivated on the largest share of the farm surface, because MMB is high and has a good capacity to compensate for stress, showing stability in difficult years.

Key words: *successional crop, hybrids, quality indices, productivity, climate change*

INTRODUCTION

In the Romanian economy, Agriculture is a strategic sector. It has a share of 5.2% of the Gross Domestic Product and 23% of the population is involved in this field, which places Romania on the first place in the European Union [1, 5, 3].

This relief and its climate ranked Romania on the 6th place in the European Union in terms of arable land per capita, with nearly 0.41 ha of arable land, a value higher than many countries in the European Union, such as Italy (0.11 ha/inhabitant), Germany (0.14 ha/inhabitant), where the EU 27 average is 0.212 ha/inhabitant [4, 7]. Sunflower is cultivated for seeds and eye.

The seeds are either consumed as such, but mainly dried, salted and roasted by humans. The oil extracted from seeds is used in salads and for cooks, and in industry for cosmetics, paints [15] and lubricants. Also, the seeds are ingredients in various mixtures for birds feeding. The leaves are an excellent fodder for livestock and the flowers are decorative plants [13,14,15]. Sunflower is an important oil crop which provides more than 13% of the total amount of oil produced globally [20].

Romania has a high potential for producing biofuels in general, but mainly for biodiesel, because of the important surface cultivated with oil crops, the possibility to extend this surface in the uncultivated areas and biomass production potential. The main crops suitable to produce biodiesel are sunflower, rape and soy bean [16]. The sunflower presents one of the most profitable crops for agriculture, which determines significant growth of the sown areas and increased market demands regarding the created hybrids. The breeding of competitive commercial sunflower hybrids for

the European seed market is achievable by diversifying the sunflower germplasm [6].

For increasing oil seeds production in the EU, it is very important to grow yield mainly in case of sunflower and rape and also to increase cultivated surface with soybean [15].

The forecast for the year 2024 is that Romania will cultivate 2,015 thousand with oleaginous plants, of which sunflower 77.3 %, rape 13.2% and soybean 10.3% [17]. Agriculture performance in terms of yield is low in Romania because of farm structure, dominated by small sized farms, the majority being subsistence and semi-subsistence farms [18].

Climate factors are considered of high risk for agriculture, taking into account the monthly, annual and multiannual deviations of temperature and precipitations from the climatological norms [2]. Any deviation in thermal, rainfalls regime, wind and air humidity from the optimal requirements,

along each phenological stage could affect yield and harvest, farmers' income and profit [19]. Successive cropping involves growing two or more different crops on the same land in the same agricultural year. This choice optimizes the use of land and resources.

An efficient option can be to grow sunflowers after corn. The sunflower root system can utilize the remaining nutrients and improve the soil structure affected by the corn roots, which are more superficial. The sunflower (*Helianthus annuus*) is an impressive annual plant, known primarily for its large, yellow inflorescence, which follows the sun throughout the day – a phenomenon called heliotropism, more pronounced in the young stages of the plant. Its origins come from North America, but it has been acclimatized and cultivated throughout the world, including in the area of Călărași County, where climatic conditions are favorable. Cultivated in succession, sunflower has several important advantages, but also some less advantageous aspects that should be remembered.

1. It has a valuable root system. After a crop with shallower roots, such as some grasses or even corn (which has a more extensive but different root system), the sunflower's taproot can loosen the soil deeply. This increases soil aeration and drainage, creating a favorable environment for the next crop.

2. Leverages nutrients from deep in the soil. Sunflowers can access nutrients that were not utilized by the previous crop, especially if it has a shallow root system. This can reduce the need for fertilization for the next crop.

3. It has ground cover potential. Sowing sunflowers early enough after harvesting the previous crop can provide rapid ground cover. This helps reduce erosion but also reduces the number of weeds.

4. The rotation can be diversified. Growing sunflower as a succession crop can contribute to the diversification of the rotation, an important element for managing diseases and pests specific to other crops.

As less advantageous aspects are:

1. Although it takes up nutrients from deep within, sunflower is a nutrient-consuming crop, especially potassium. It is necessary to check the soil's nutrient supply level or ensure a level of fertilization so that the soil is not depleted for the next crop.

2. If not harvested properly, sunflower seeds left in the field can become a problem weed for the succeeding crop, especially if specific herbicides are not used.

The cost of establishing a sunflower succeeding crop is relatively low, 2,050 lei per hectare for the main inputs (seed, treatments, diesel). This technology requires minimal soil work, the objective being to conserve water in the soil, taking into account the period of crop establishment. Being a successive crop, direct seeding or minimal soil cultivation is frequently used, reducing diesel and mechanization costs. The costs, including inputs and mechanical work, are lower compared to the costs of a main crop, of about 4,500-5,000 lei, thus maximizing the final profit, in the event that climatic conditions help the success of the crop. The farmers must adapt crop technologies to diminish the negative impact of climate change on yield and the extreme meteorological phenomena [9,10, 19].

MATERIALS AND METHODS

The analysis was carried out in the Baragan Plain, south-eastern Romania, The soil is a

chernozem one. The area cultivated with sunflower was 1 ha for each hybrid. The preceding crop was wheat, harvested on June 25. The sowing of the succesive crop was carried out on July 1st. The harvesting was carried out on November 26, for the successive culture. In this study, quality indices such as hectoliter mass and thousand-grain mass were monitored, as well as productions obtained. In addition to the water accumulated from precipitation, an irrigation rate of 300 mm was administered during the flowering period. Sunflower hybrids are classified according to the vegetation period (FAO/days), influencing the ripening time and heat requirement. The officially recognized classification includes groups from extra-early (FAO 100-200) to late (500-600). Most hybrids cultivated in Romania are early or mid-early.

Extra-early (FAO 100-200): Very fast maturing, suitable for short season areas.

Early (FAO 200-300): Fast maturing, ideal for cooler areas or late sowing.

Mid-early (FAO 300-400): The most common group, offering a balance between productivity and maturity.

Semi-late (FAO 400-500): Longer vegetation period, high productivity in good growing conditions.

Late (FAO 500-600): Long vegetation cycle, suitable for southern areas with high heat resources. The behavior of 4 semi-early hybrids was studied: '*Vollter*', '*1046 H',* '*Conquest',* '*ES Belfis'* and a semi-late hybrid, '*Fabulo*', of different provenances. We followed the influence of earliness on the results obtained.

'*ES Belfis'* produced by Lidea, is a semi-early linoleic hybrid, with Clearfield® Plus herbicide system. It has an exceptional productive genetic potential resistance to manna, high pressure and virulent races. Genetic resistance to Orobanche race G and an oil content: 48-49%. It is a hybrid adapted for semi-intensive/intensive technology, well adapted to the local pedoclimatic context.

'1046 H' produced by Lidea, is a high-oleic hybrid with tolerance to the herbicide EXPRESS 50 SG. It has resistance to sunflower moth, high pressure and virulent races., Very good vigor at the start of vegetation. Plant height: medium, Calatidium: bent, Vigor at the start of vegetation: very good Flowering: semi-late. Harvesting semi-early.

'*Vollter*' produced by R.A.G.T., is a semi-early hybrid, with good resistance to falling and breaking, high production potential, early flowering, very good pollination. Responds very well to intensive cultivation conditions; Plant height: 160-170 cm; Calathea position: 45°; excellent oil content: 48-49%; Ragweed resistance: races A-G, hybrid recommended for all cultivation areas, including areas with a strong infestation of Ragweed (*Orobanche cumana).*

'Conquest CLP' produced by 'Biocrop' is a semi-early hybrid from the Clearfield Plus system, with high yields under intensive cultivation conditions. With excellent tolerance to diseases such as sunflower blight and impressive ecological adaptability, *Conquest CLP* ensures stability and performance even under drought or heat stress conditions. Good resistance to S*clerotinia, Phoma, Phomopsis.* Special ecological plasticity. Impressive sized heads. Very good vigor at emergence. High degree of self-pollination. Very good adaptability to environmental conditions. Impressive production peaks. High oil content, 46-52%. Curved and convex head.

'Fabulo' is a semi-late sunflower hybrid, Biocrop brand, Clearfield Plus. It has very high production potential; superior resistance to tilting and breakage; high hectoliter weight and high number of seeds per head; complex genetic package of disease resistance – *Phoma, Sclerotinia, Orobanche (OR5*); fast start in vegetation; oil content 46 – 52%; drought tolerance; ecological plasticity. We chose this last hybrid with a later earliness to compare the behavior in successive crops with the semi-early hybrids recognized as recommended.

Quality indices such as hectoliter mass and thousand-grain mass were monitored in this study. The economic value of crop and the qualitative and packaging properties are determined by hectolitre mass (HLM) and the weight of a thousand grains (WTG)15 [11].

Hectoliter mass expressed in kg/hl is a physical measure of the apparent density of cereals, expressed in kilograms per hectoliter. WTG, expressed in g, is an indicator of grain quality and size or moisture content at which mechanical damage occurs. WTG influences the optimal sowing depth, thus determining uniform emergence [12].

RESULTS AND DISCUSSIONS

Table 1. Precipitation recorded in the period 2020-2024-mm

Month	2020	2021	2022	2023	2024
I	0.8	67.0	3.4	20.0	2.1
II	30.2	8.6	14.0	5.6	0
III	4.2	15.6	5.2	28.8	0
IV	33.0	0	35.8	44.0	64.6
V	26.8	46.0	22.4	26.6	10.6
VI	101	174.6	28.8	7.0	42.4
VII	56.4	41.2	9.2	57.0	35.8
VIII	1.0	13.4	72.7	77.4	90.0
IX	29.6	6.0	50.2	25.4	116.2
X	30.4	51.2	10.4	0	26.5
XI	22.7	26.0	32.0	38.0	22.4
XII	68.6	42.8	14.2	60.0	0
Total	404.7	492.4	298.3	389.8	500.6

Source: Meteo Station SCDA Mărculești [12].

The year 2024 recorded an appropriate amount of precipitation, which determined the possibility of efficient land utilization by establishing successive crops, during the sowing period, June-July being recorded a total of precipitation of approx. 80 mm (Table 1).
The technology of successive sunflower cultivation involves establishing the crop immediately after harvesting a main crop, aiming to capitalize on residual moisture and the warm period. It requires early hybrids, rapid weeding, sowing in moist soil at a depth of 2-3 cm and intensive weed control measures. The preceding crop should be harvested early (June-July), allowing for rapid land clearance. Therefore, the best preceding crops are grasses or rapeseed. Stubble removal is carried out immediately after harvesting the previous crop to conserve water. This is followed by ploughing or disc harrowing at 22-25 cm. Immediately after harvesting the main crop, sowing was carried out, when there was still some moisture in the soil. Early or mid-early hybrids are sown, as they are best suited for successive crops. The sowing depth is 3-4 cm, to ensure uniform emergence under the conditions of high temperatures during the sowing period. A slightly higher density than that of the main crop is recommended in spring to shade the soil. As a maintenance work, weed control is very important because weeds can reduce production by up to 50%. Pre-emergence and/or post-emergence herbicides are applied for effective control. Fertilization is influenced by the level of nutrients remaining in the soil, usually phosphorus and potassium fertilizers. for fruiting. Another maintenance work is pest control. Treatments are applied depending on the type of pest and the degree of attack. In the sunflower crop, from emergence of plants to the formation of 6 leaves, the pests were formed by *Agriotes spp., Tanymecus dilaticollis Gyll*.,etc. In sunflower, the harmful entomofauna consisted of 16 species [22]. Another way to prevent pest attacks is to treat seeds before sowing. Studies carried out on corn have shown that the effectiveness of treatments varies depending on the area, hybrid. It should be noted that the effect of plant protection products is influenced by agroclimatic conditions and the genetic characteristics of each hybrid [8].
The successive crop is harvested in autumn, before frost, in certain situations it is necessary to use desiccants if the moisture content of the seeds is high. This system is recommended in irrigated areas or in regions or years with sufficient amounts of precipitation during the summer, otherwise the risk of drought may compromise production [21].

Table 2. Sum of temperatures recorded in 2020-2024, ^{0}C

Month	2020	2021	2022	2023	2024
I	45.0	103.1	72.9	172.5	64.5
II	151.3	105.3	116.6	93.0	228.2
III	270.4	151.5	121.3	242.1	264.9
IV	348.7	287.2	361.1	32.4	452.2
V	516.5	527.2	544.2	507.1	501.0
VI	641.9	613.4	665.7	643.8	746.3
VII	751.3	760.6	665.7	777.4	814.3
VIII	766.6	741.0	765.3	727.4	773.0
IX	627.9	528.3	557.5	632.3	581.0
X	478.4	366.5	424.8	515.2	394.6
XI	168.5	257.1	269.2	235.0	168.6
XII	157.5	96.4	118.6	144.0	96.9
Total	4,924.0	4,537.6	4,682.9	4,722.2	5,175.5

Source: Meteo Station SCDA Mărculești [12].

Sunflowers require a sum of active temperature degrees (above the threshold of 5◦C), ranging, on average, between 1,600◦C and 1,700◦C throughout the vegetation period. The sum of temperatures recorded between July and November exceeded this threshold, being over 2,000^{0}C (Table 2).

Production performance

The main economic indicator is the productive potential. Differences in production suggest different adaptability to soil, climate or technology.

HLM (kg/hl) indicates the density and quality of seeds.

Higher values = better filled grains, lower losses during storage.

WTG (g) – 1,000 grain weight (MMB) Reflects the size of the seeds. Important for: crop quality, calibration, sowing, but also oil content.

'Conquest' is the leader, with a big advantage over the other hybrids, 3,326 kg/ha, with about one ton more yield compared to the average of hybrids and about 1,400 kg/ha more than the average production of hybrids, the difference being significant. The hybrids ***'Fabulo' and 'Vollter'*** are poorly productive, 1,845 kg/ha-2,109 kg/ha in the 2024 pedoclimatic conditions, they do not exceed the calculated average of the productions of the 5 hybrids.

From the point of view of HLM, the Hybrids ***'Conquest' and 'Vollter'*** have dense, well-formed berries, the HLM values being 45-44.3 (Table 3.)

'1046 H' has poor grain filling (possibly water or genetic stress), having the lowest value, 38.4 kg/hl. This value did not exceed the average of the studied hybrids - 42.34 kg/hl. '*1046 H*' has small berries, WTG having the lowest value among the analyzed hybrids, 53.5 g, this having a negative impact on production. Under the studied conditions, this hybrid is not among the favorites.

The hybrid 'ES Belfis' has very large seeds which translates into good productive capacity, 78.7 g. , above the average value of the hybrids, 67.32 g.

Table 3. Quality indices and productions obtained

Hybrid	Production kg/ha	HLM kg/hl	WTG g
FABULO	1,845	42,0	68,2
VOLLTER	2,109	44.3	64.6
1046 H	2481	38.4	53.5
CONQUEST	3,326	45.0	71.6
ES BELFIS	2,542	42.0	78.7
Average	**2,460.6**	**42.34**	**67.32**

Source: own contribution

By evaluating each hybrid on 3 criteria: Production, HLM, and WTG, a performance index was established (Table 4).

Table 4. Performance categories of hybrids

Crt.no.	Hybrid	Category
1	CONQUEST	Excellent
2	ES BELFIS	Very good
3	1046 H	Good
4	VOLLTER	Mediocre
5	FABULO	Poor quality

Source: own contribution.

CONCLUSIONS

The hybrid '*Fabulo'* is poorly productive, which confirms the theory that later hybrids are not suitable for successive cultivation.

The hybrid '*Vollter*' has a good HLM, but a low level of productivity, in successive cultivation.

They are suitable only in specific niches, not as main hybrids. '*Conquest*' proved to be the most balanced hybrid, with the best productive performance, the best HLM value and the highest mmb value. the highest production. It is recommended for commercial farms with medium-intensive technology.

The hybrid '*ES Belfis'* stood out for its large seeds, good production, and average HLM. It is a good hybrid for more difficult conditions, where grain size matters.

For stable production, shared risk and maximized long-term profit, it is preferable to cultivate at least two hybrids.

In the South-Eastern area of the country where water deficit is frequent, the hybrid '*ES Belfis'* is recommended to be cultivated on the largest share of the farm's surface, because the MMB is very high and has a good capacity to compensate for stress, showing stability in difficult years.

'*Conquest*' has superior performance but is less resistant in difficult years, with water stress. Of course, irrigation of crops can enhance the productive capacity of hybrids and avoid water stress for them.

The minimum recommended technology consists of soil preparation through superficial works aimed at preserving moisture, adequate fertilization with N + P + microelements, protection with herbicides adapted to the hybrid.

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RESILIENCE OF THE LIVESTOCK SECTOR IN THE COUNTIES OF THE SOUTH MUNTENIA DEVELOPMENT REGION, ROMANIA

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Abstract

The resilience of the livestock sector at the regional level needs to be considered in the context of numerous structural changes, market fluctuations, and frequent external disruptions affecting livestock production. This paper analyses the resilience of the livestock sector in the counties of the South-Muntenia Development Region, Romania, using official statistical data on animal stocks for the period 2015–2024. Resilience is assessed through a set of quantitative indicators reflecting both system stability and adaptive capacity, including mean values, standard deviation, coefficient of variation, average and compound annual growth rate, cumulative change between the first and last year, specialization and concentration indices. The findings show clear differences in livestock resilience across animal species and counties. Cattle and pig farming are the least resilient, with long-term declines and strong fluctuations over time. By contrast, sheep farming shows high resilience, supported by external increasing live animals and meat demand in the last decade. While goat resilience is favoured by relief and climate of the South-Muntenia Region, poultry farming works better and adapts more easily in areas where production is focused and specialized. At the county level, either diversified livestock structures or farms specialization are the main resilience livestock pillars.

Key words: *livestock sector, resilience, regional agriculture, South-Muntenia, structural change, Romania*

INTRODUCTION

Over the past three decades, the livestock sector in Central and Eastern Europe has changed deeply as a result of economic transition, market opening, shifts in farm structures, and evolving agricultural policies [13].

In Romania, these changes resulted to a strong decline in traditional livestock species, accompanied by unequal adaptation across regions and farming system [2, 3, 8].

In this context, resilience has become an increasingly important concept in agricultural research, describing the ability of a sector to withstand shocks, adjust to changing conditions, and continue to function over time [9, 15].

Livestock resilience is particularly relevant at regional and sub-regional levels, given the significant differences in production and specialization structures, as well as farm size distribution [7, 10, 14]. Recent analyses underline the vulnerability of certain livestock sectors, particularly pig farming, in the face of sanitary crises and market instability [1, 4, 5, 12, 6].

In a previous study by the authors, the South Muntenia Region was identified as having considerable potential for increased livestock density, as it remains below the national average while benefiting from favourable agricultural conditions [11]. Since empirical assessments of livestock resilience at county level remain limited, for this study we considered to evaluate livestock resilience in the counties of the South-Muntenia Region by analysing long-term and recent dynamics of animal stocks and by applying a comprehensive set of stability, dynamic and structural indicators.

MATERIALS AND METHODS

The analysis used official statistical data provided by the National Institute of Statistics

of Romania on livestock numbers for five species: cattle, pigs, sheep, goats and poultry. Data are available at national level, regional level: South-Muntenia and county level for the period 2015–2024. Livestock resilience is assessed through indicators reflecting *stability*: mean for 2015-2024, standard deviation and coefficient of variation; *dynamics*: rate of average annual growth, compound annual growth rate, cumulative change; *structural positioning*: regional and county shares, concentration ratios, specialization. For the period 2015–2024, the following indicators were calculated: mean livestock stocks, standard deviation (SD); coefficient of variation (CV). For 2024, structural indicators include: share of South-Muntenia in national livestock stocks, county share in regional totals, concentration ratios (CR2, CR3), location quotients (LQ), and diversification index.

Stability indicators (2015–2024)

For each species x_t, $t = 2015, \ldots, 2024$ (n = 10):

- Mean: $\bar{x} = \frac{1}{n}\sum x_t$
- Standard deviation (sample):
$$SD = \sqrt{\frac{1}{n-1}\sum (x_t - \bar{x})^2}$$
- Coefficient of variation:
$$CV = \frac{SD}{\bar{x}} \times 100$$

Interpretation: lower CV → higher stability → higher resilience.

Dynamic indicators (2015–2024)

- Average annual growth rate (AAGR):
$AAGR = \frac{1}{n-1}\sum g_t$
- Compound annual growth rate (CAGR):
$$\text{CAGR} = \left(\frac{x_{2024}}{x_{2015}}\right)^{1/9} - 1$$
- Cumulative change:
$$\Delta_{15-24} = \frac{x_{2024} - x_{2015}}{x_{2015}} \times 100$$

(C) Structural indicators (2024)

- Regional share in national total:
$Share^{SM} = \frac{x^{SM}}{x^{RO}} \times 100$
- County share in regional total:
$$s_j = \frac{x_j}{\sum_j x_j} \times 100$$
- Concentration ratios:
$$CR2 = \sum_{top2} s_j,\ CR3 = \sum_{top3} s_j$$

Specialization and diversification (2024)

To capture counties livestock profile, we compute:

- County livestock mix share (within-county):
$$m_{ij} = \frac{x_{ij}}{\sum_i x_{ij}}$$
- Regional livestock mix share:
$$M_i = \frac{X_i}{\sum_i X_i}$$
- **Location quotient (LQ):**
$$LQ_{ij} = \frac{m_{ij}}{M_i}$$

  $LQ > 1$ indicates above-average specialization in species $i$for county j.

- **Diversification index:**
$$DIV_j = 1 - \sum_i m_{ij}^2$$

  Higher values → more diversified livestock structure (often linked to resilience).

RESULTS AND DISCUSSIONS

The analyse of the livestock resilience at the national level indicates that this switch from low to high, in relation with species, and this aspect is proved by the differences that can be seen in the coefficient of variation. In Romania, sheep have the highest resilience between species, with a CV around 2%, which indicates very high stability of livestock numbers over the analysed decade. The sheep sector was not spared by structural changes, but managed to keep its production levels. The poultry sector, which recorded coefficient of variation values above 3%, still shows relatively high stability, supported by a well-developed and integrated agri-food value chain. Goats recorded moderate variability, which was above 3%, which can be associated with the idea of relatively stable dynamics, although this sector is more sensitive to local and market conditions than sheep. Cattle show

moderate resilience, with a CV above 5%, while pigs represent the least resilient livestock sector at national level, with a high CV, which was above 15%, highlighting strong volatility and vulnerability to sanitary unwanted events (Table 1).

Table 1. Livestock resilience, stability indicators – Romania (2015–2024)

Crt. no.	*Species*	*Mean (heads)*	*St Dev*	*CV (%)*
1.	Cattle	1,921,362	105,184	5.47
2.	Pigs	3,894,442	610,584	15.68
3.	Sheep	10,156,115	211,488	2.08
4.	Goats	1,499,603	65,699	4.38
5.	Poultry	75,770,211	2,381,576	3.14

Source: NIS. Own calculation [7].

Compared with the national situation, livestock production in South Muntenia is generally less resilient and more unstable, with greater fluctuations over the last decade for most species (Table 2). Sheep are the most resilient species in the region, with very stable numbers, playing a key stabilizing role in the livestock sector. Goats display moderate resilience, with variability above 5%, remaining relatively stable overall but showing greater fluctuations than at the national level. Poultry production in South Muntenia changes considerable over time because it is concentrated in a few places and is sensitive to major shocks, this being reflected by its high CV, which is above 7.33%.

Table 2. Livestock resilience indicators, stability indicators – South Muntenia (2015-2024)

Crt. no.	*Species*	*Mean (heads)*	*St Dev*	*CV (%)*
1.	Cattle	204,691	23,472	11.47
2.	Pigs	593,952	179,237	30.18
3.	Sheep	972,148	33,316	3.43
4.	Goats	260,861	15,088	5.78
5.	Poultry	18,814,140	1,378,926	7.33

Source: NIS, own calculation [7].

Cattle show significantly lower resilience than nationally, with a CV above 11%, indicating important structural pressures and reduced stability in the region. Pigs are by far the least resilient species, with an extremely high CV which is above 30%, reflecting high instability and a structural fragility of the pig livestock in South Muntenia.

The dynamic indicators show major differences related with the resilience of livestock species in Romania over the 2015–2024 period. Sheep represent the only livestock species with positive dynamics, as indicated by a positive AAGR of 0.71%, CAGR of 0.70%, and a cumulative increase of 6.46% (Table 3).

Table 3. Livestock resilience, dynamic indicators – Romania (2015–2024)

Crt. no.	*Species*	*AAGR %*	*CAGR %*	*Δ 2015-2025 %*
1.	Cattle	-1.60	-1.60	-13.53
2.	Pigs	- 4.42	-4,49	-33.88
3.	Sheep	0.71	0.70	6.46
4.	Goats	-0.05	-0.11	-0.98
5.	Poultry	-0.25	-0.32	-2.84

Source: NIS. Own calculation [7].

The dynamic indicators highlight a weaker and more polarized resilience profile in South Muntenia compared to the national average. Sheep show the strongest resilience in the region, with positive growth rates: AAGR of 1.15%, CAGR of 1.07% and a cumulative increase of 10% over the period (Table 4). The higher growth rates relative to the national level indicate a stronger regional specialization and adaptive capacity of sheep farming in South Muntenia.

Table 4. Livestock resilience, dynamic indicators – Muntenia (2015-2024)

No. crt.	*Species*	*AAGR %*	*CAGR %*	*Δ 2015-2025 %*
1.	Cattle	-3.32	-3.34	-26.34
2.	Pigs	- 8.33	-8,41	-54.65
3.	Sheep	1.15	1.07	10.01
4.	Goats	-1.00	-1.08	-9.27
5.	Poultry	-0.23	-0.75	-6.58

Source: NIS, own calculation [7].

As can be noticed in the Table 5, South-Muntenia gained a strategic role in poultry farming (around 25% from total at national level) and holds a significant share of national goat stocks (above 16% from total), while its contribution to cattle and sheep production remains relatively at a low level (bellow 10%),

consistent with the structural decline that can be observed during the whole analysed period.

Table 5. Share of South – Muntenia Region in national livestock in 2024

No. crt.	Species	Romania *(heads)*	South Muntenia *(head*	Share of region (%)
1.	Cattle	1,809,402	178,009	9.8
2.	Pigs	3,257,466	401,468	12.3
3.	Sheep	10,443,350	1,029,232	9.9
4.	Goats	1,426,103	233,047	16.3
5.	Poultry	76,415,724	19,116,225	25

Source: NIS [7].

Argeș and Prahova hold the largest shares of cattle stocks in the region, making them the main centres of cattle production in South Muntenia (Table 6). Teleorman is the main county for sheep and goat farming, accounting for a large share of regional sheep stocks and more than one third of goats. Poultry production is concentrated in Giurgiu and Călărași, which together account for a substantial part of regional poultry stocks. For most species, the three largest counties account for more than half of regional livestock stocks, indicating a strong concentration of production.

Table 6. County share in regional livestock stocks – selected species (2024, %)

County	Cattle	Pigs	Sheep	Goats	Poultry
Argeș	24.9	22.4	21.1	13.6	12.0
Călărași	11.0	17.3	11.6	10.8	20.1
Dâmbovița	10.4	9.4	5.0	10.3	14.4
Giurgiu	8.3	9.0	6.9	6.7	20.8
Ialomița	11.5	14.8	15.9	12.5	9.8
Prahova	20.6	11.8	17.8	15.0	16.6
Teleorman	13.4	15.3	21.7	31.0	6.3
South Muntenia	100	100	100	100	100

Source: NIS, own calculations [7].

All species are highly concentrated in a small number of areas (CR3 around 54–61%). This has important implications for resilience: while concentration can improve efficiency, it also means that problems in those areas can have a strong impact on the whole system. The highest CR2 level is recorded for goats, while the highest CR3 level is associated with the sheep.

The lowest level of CR2 is recorded for poultry, while the lowest level of CR 3 is associated with pigs (Table 7).

Table 7. Concentration ratios CR2 and CR3 species in South Muntenia (2024)

No. crt.	Species	CR2	CR3
1.	Cattle	45.47	58.87
2.	Pigs	39.69	54.98
3.	Sheep	42.8	60.56
4.	Goats	46.06	59.65
5.	Poultry	40.91	57.54

Source: NIS, own calculation [7]

The strong focus on goats and sheep in Teleorman is confirmed by very high location quotient values. Giurgiu and Călărași show a poultry specialization profile (LQ>1 for poultry), combined with low diversification, indicating that resilience in these counties is driven mainly by specialization (Table 8).
Argeș and Ialomița show multi-species specialization (several LQs>1), meaning their resilience comes from having several livestock species. The Diversification Index highlights also substantial differences in the structural composition of livestock systems across counties in the South Muntenia Region. Counties with low DIV values, such as Giurgiu: 0.065, Dâmbovița: 0.089 and Călărași: 0.110, shows a high degree of specialization, largely driven by the dominance of poultry production.

Table 8. Location Quotients (LQ) and Diversification Index (DIV) by county (2024)

County	Cattle LQ	Pigs LQ	Sheep LQ	Goats LQ	Poultry LQ	DIV
Argeș	1.95	1.75	1.65	1.07	0.94	0.258
Călărași	0.56	0.89	0.59	0.56	1.03	0.110
Dâmbovița	0.76	0.68	0.37	0.75	1.05	0.089
Giurgiu	0.42	0.46	0.35	0.34	1.06	0.065
Ialomița	1.12	1.44	1.55	1.22	0.96	0.231
Prahova	1.24	0.71	1.07	0.91	1.00	0.163
Teleorman	1.77	2.02	2.87	4.11	0.83	0.400

Source: NIS, own calculations [7].

CONCLUSIONS

At the national livestock resilience is driven mainly by small ruminants and poultry, while pig farming remains structurally unstable. In

summary, South Muntenia amplifies national vulnerabilities: while sheep continue to act as a stabilizing component, cattle and pig farming show markedly higher volatility, and poultry resilience is conditional on specialization and scale. At county level patterns support a resilience typology: diversification-based resilience (e.g., Argeș, Ialomița, partly Prahova); specialization-based resilience (Giurgiu, Călărași—poultry concentration) and fragile adaptive structures (counties where cattle/pigs decline is not fully compensated).

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TRENDS IN THE INTEGRATION OF DIGITALIZATION IN APRICOT PLANT PROTECTION IN THE ROMANIAN PLAIN

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Abstract

Digital agriculture and precision agriculture represent essential strategic directions for the sustainable development of modern fruit growing. This review paper analyzes integrated digital approaches used in plant protection, with a particular focus on apricot orchards (Prunus armeniaca L.) located in the Romanian Plain. The study synthesizes recent research results regarding the use of unmanned aerial vehicles (UAVs), remote sensing technologies, artificial intelligence algorithms, decision support information systems, and digitally assisted biological control solutions. The literature analysis highlights the advantages of real-time monitoring, site-specific application of phytosanitary treatments, and the reduction of environmental impact. At the same time, current limitations and future perspectives for the implementation of these technologies under the specific pedoclimatic conditions of southern Romania are discussed. In conclusion, the integration of digital technologies into plant protection offers significant opportunities for optimizing phytosanitary management in apricot orchards by improving decision-making processes and reducing environmental impact.

Key words**:** *UAV, plant protection, digital technologies, precision horticulture, phytosanitary monitoring*

INTRODUCTION

Biological and economic particularities of apricot cultivation

Modern fruit growing faces major challenges generated by climate change, the increasing frequency of extreme weather events, pressure on natural resources, and the need to reduce negative environmental impacts. In this context, the concepts of precision agriculture and, more recently, digital agriculture have become indispensable pillars of sustainable agricultural management, aiming to optimize production processes through the use of digital technologies and real-time data [22]. The scientific literature highlights that most research efforts have focused on field crops or other fruit tree species, while there is a noticeable lack of comprehensive syntheses addressing apricot orchards and the specific agroclimatic conditions of the Romanian Plain [22]

Therefore, the present paper aims to provide a review-based analysis of the main integrated digital approaches used in plant protection, with a focus on apricot orchards in the Romanian Plain, emphasizing the current state of research, the advantages and limitations of existing solutions, and future development directions from the perspective of modern agricultural management.

Plant protection is a key component of orchard management, directly influencing productivity, fruit quality, and economic sustainability. In the case of apricot, a species particularly sensitive to diseases, pests, and abiotic stress factors, the implementation of effective protection strategies is essential, especially in the Romanian Plain, where climate variability intensifies phytosanitary risks [23]. One of the oldest species cultivated is apricot fruit tree (*Prunus armeniaca* L.) .

The apricot fruits have been used as food and for medicinal purposes,also. Studies on the performance of apricot cultivars in the Bucharest area reveal significant variability in vegetative growth and productivity depending on cultivation technology, highlighting the need for differentiated and adaptive orchard management [23].

Conventional phytosanitary protection approaches, based on uniform application of chemical treatments, present major limitations related to efficiency, costs, and environmental impact. In this context, the digitalization of agriculture and the development of precision agriculture offer innovative solutions for crop monitoring and optimization of phytosanitary interventions [26]; [22].

Digital technologies, particularly UAVs, enable the rapid acquisition of high spatial resolution data and their integration into intelligent decision support systems. The rapid development of UAV technology, supported by advances in sensor technology, artificial intelligence, and image processing, has led to the expansion of their applications in fruit growing.

In addition to monitoring, UAVs are also used for the application of phytosanitary treatments. UAVs have a precise distribution of products for plant protection or biological control agents. Drones, used in biological control, have the ability to ensure the uniform and efficient dissemination of beneficial entomofauna, as evidenced by research conducted, but also by reducing chemical inputs and environmental impact [30]. It is necessary that application parameters be properly managed to minimize the effect of pollution, as shown by studies on spray drift[28].

In fruit growing, particularly in apricot orchards, the adoption of integrated digital approaches for plant protection remains limited, despite their considerable potential demonstrated at the international level.

Prunus armeniaca L., has many cultivated varieties original from Central Asia, where it has been cultivated for long time. From this region, apricot gradually spread both eastward and westward, becoming a fruit tree species of major importance in numerous temperate regions [11].

Table 1. Changes in apricot cultivated area and production in Romania and Europe (2022-2024)

Area	Indicator	Crop	Year	Unit	Value
RO	Harvested area	Apricot	2022	ha	1,960.0
	Production			t	23,500.0
	Harvested area		2023	ha	2,030.0
	Production			t	24,550.0
	Harvested area		2024	ha	2,020.0
	Production			t	22,910.0
EU	Harvested area		2022	ha	104,249.0
	Production			t	850,310.0
	Harvested area		2023	ha	99,944.0
	Production			t	776,793.5
	Harvested area		2024	ha	99,807.0
	Production			t	865,554.8

Source: FAOSTAT

In Romania, the area cultivated with apricot remained relatively stable during the analyzed period, amounting to 1,960 ha in 2022, increasing slightly to 2,030 ha in 2023, and subsequently recording a minor decrease to 2,020 ha in 2024. Apricot production showed a different trend, reaching 23,500 t in 2022, increasing to 24,550 t in 2023, and then declining to 22,910 t in 2024, possibly as a result of the influence of unfavorable climatic conditions.

At the level of the European Union, the harvested area showed a slightly decreasing trend, declining from 104,249 ha in 2022 to 99,944 ha in 2023 and 99,807 ha in 2024. At the same time, total apricot production varied considerably, reaching 850,310 t in 2022, recording a minimum of 776,793.5 t in 2023, followed by a notable increase in 2024 to 865,554.8 t, according to the data presented in Table 1. Production variability highlights the vulnerability of the fruit-growing sector and underscores the need for digital monitoring

and decision-support systems.
Currently, the geographical distribution of cultivated apricot extends between 50° north and 35° south latitudes, reflecting the species' high adaptability to diverse pedoclimatic conditions [13]. It is a climacteric fruit with a very limited postharvest storage life, primarily determined by its high respiration rate and intense ethylene production, factors that accelerate the ripening process and lead to rapid deterioration of fruit quality [25]. The interaction between physical and chemical characteristics such as appearance, texture, taste, and aroma, give fruits quality, the nutritional value, chemical composition, mechanical properties [15].



Photo 1. Apricot fruits
Source: pixabay.com [31].

Due to their rich chemical composition, apricot fruits also exhibit significant medicinal value, being recommended in conditions of physical and intellectual asthenia, anemia, insomnia, and during the convalescence period (photo 1). In addition, the consumption of apricots is recommended in the diet of children with delayed development and those affected by rickets [4]. Most apricot cultivars are self-fertile; however, there are also self-sterile cultivars that require the presence of compatible pollinizer varieties to ensure fruit set. An important aspect to mention is that all apricot varieties are characterized by early fruiting, with fruit production usually occurring from the third or fourth year after planting [16]. Increasing planting density in apricot orchards leads to a reduction in production per tree, but causes a significant increase in production per hectare, especially in the first years of fruiting, which highlights the economic advantages of intensive planting systems when they are correctly managed [10]. Apricot is strongly affected by numerous diseases, such as crown gall, gummosis, root and crown rot caused by *Phytophthora*, brown rot and shot hole disease, which cause significant reductions in production and considerable economic losses in fruit farms [1].The economic sustainability of apricot orchards can be seriously affected by Candidatus *Phytoplasma prunorum* (European stone fruit yellows-ESFY), a disease that causes high mortality and severe physiological decline of trees in the first years of fruiting [6]. Also, infection with *Monilinia laxa* causes significant changes in leaf metabolism in apricot, manifested by a reduction in the content of photosynthetic pigments and an increase in the level of phenolic compounds and the activity of antioxidant enzymes, these responses being associated with the resistance mechanisms of some varieties [17].

MATERIALS AND METHODS

This paper was carried out in the form of a literature review, with the objective of analyzing and synthesizing the main scientific research on the use of integrated digital approaches in plant protection, with a focus on relevant applications for fruit orchards and, in particular, for apricot (*Prunus armeniaca* L.) cultivation. The adopted methodology follows the general principles of systematic reviews, ensuring transparency and a thorough analysis of the relevant scientific literature. Following the selection process, 30 relevant scientific articles published in indexed peer-reviewed journals were analyzed, addressing the use of integrated digital approaches in plant protection, with applicability to fruit growing and, in particular, to apricot orchards.

Identification

The identification of scientific publications was carried out by consulting major internationally recognized databases, namely Web of Science, Scopus, ScienceDirect, MDPI, and Google Scholar. Searches were conducted for the period 2019–2026, selected to capture the most recent developments in the fields of digital agriculture and integrated plant

protection. Relevant keyword combinations were used, including "UAV," "precision agriculture," "orchard," "apricot," "plant protection," "spray drift," "decision support systems," "artificial intelligence," and "digital agriculture," both individually and in logical combinations.

Digital technologies used in orchard plant protection

Unmanned aerial vehicles (UAVs) have become an essential tool in the monitoring of fruit orchards due to their operational flexibility, relatively low costs, and ability to provide high spatial resolution data. The scientific literature highlights the predominant use of multirotor platforms in fruit growing, as they allow low-altitude flights, high maneuverability, and detailed inspections of tree canopies [26]; [22].

[21] reported an accuracy of 96.56% for apricot crops in identifying UAV-assisted spraying areas.

Image processing and artificial intelligence

Image processing of data acquired using UAVs represents a key component of digital agriculture applied in fruit growing. In recent years, image processing algorithms and artificial intelligence–based methods have undergone significant development, enabling the automated assessment of tree health status [20]. UAVs used for orchard monitoring are primarily equipped with RGB cameras, multispectral sensors, or hyperspectral sensors. RGB cameras represent an accessible and efficient solution for assessing the general health status of trees and have been successfully used in the detection of plant stress and visible disease symptoms [3]. Calculating vegetation indices and early detection of areas affected by abiotic and biotic stress are possible with the help of multispectral sensors [12]. Indices such as the Normalized Difference Vegetation Index (NDVI) are frequently used to assess plant vigor and stress. These indices enable the identification of areas affected by nutrient deficiencies, disease incidence, or water stress, thereby supporting informed phytosanitary management decisions [12]. Studies based on UAV imagery and deep learning algorithms demonstrate high accuracy in the detection of diseases and pests in fruit orchards [20] [24].

The use of UAV imagery enables the localized application of phytosanitary treatments exclusively in affected areas, contributing to the reduction of blanket spraying and to a decrease in the total quantities of pesticides applied [2]. The agricultural structure specific to Romania directly influences the adoption of modern technologies and the efficiency of agricultural input use, particularly in the context of small-scale farms [19]. From a farm management perspective, this information supports decision-making related to the planning of phytosanitary interventions, efficient resource allocation, and optimization of operational costs by transforming collected data into strategic decision support [29].

Decision support information systems

Data obtained through UAVs can be integrated into information systems that support decision-making regarding the application of phytosanitary treatments. Examples of such tools include digital systems for assessing disease and pest incidence, such as WinFolia, which allow the objective quantification of foliar symptoms [5].

Application of phytosanitary treatments and environmental impact

UAVs are increasingly used for the application of phytosanitary treatments in orchards, offering advantages such as access to hard-to-reach areas and a reduction in chemical input consumption [12]. Popescu et al. [19] indicate that, although climate change may influence phytosanitary pressure, pesticide use is primarily determined by agronomic, economic, environmental, and social factors. Comparative studies further show that, in the medium and long term, the use of UAVs can lead to increased economic profitability of agricultural holdings [14].

Spray drift

The application of phytosanitary treatments using drones fundamentally differs from spraying performed with conventional ground-based equipment. In the case of tractor-mounted sprayers, movement occurs between orchard rows, and the spray solution is distributed laterally on both sides of the tree

canopy. In contrast, drones apply the solution from top to bottom, either directly above the tree axis or through offset parallel passes. Ground-based sprayers use horizontal air currents generated by fans to transport droplets toward the target, whereas drones generate vertical air currents through the downwash effect produced by the propellers, thereby influencing the deposition pattern of the spray solution on vegetation [9].

Integrated digital approaches for apricot orchards

Apricot orchards exhibit specific biological characteristics that require the adaptation of digital technologies to the particularities of the species. Apricot is sensitive to diseases such as brown rot (*Monilinia* spp.), shot hole disease, and attacks by specific pests, while the pedoclimatic conditions of the Romanian Plain further intensify these risks [23].

From an orchard management perspective, ensuring favorable conditions for pollinator activity represents a determining factor for maximizing yield and the economic value of orchards [18].

The integration of UAVs, vegetation indices, and artificial intelligence algorithms enables differentiated orchard monitoring and the early identification of areas at phytosanitary risk. Recent studies demonstrate the potential of these technologies to adapt plant protection strategies to local conditions and to increase the efficiency of phytosanitary management in apricot orchards [22].

The scientific literature highlights a significant increase in interest in the use of UAVs for orchard monitoring and plant protection; however, comprehensive review studies specifically focused on apricot orchards remain limited [20]. Recent research indicates that UAVs represent an efficient and cost-effective alternative to conventional monitoring methods, reducing the time and costs associated with field inspections.

Challenges, limitations, and future directions

Despite the significant progress achieved in the field of digital agriculture, the scientific literature highlights a number of challenges that limit the large-scale implementation of UAV-based technologies in plant protection. Recent studies emphasize several constraints that hinder the widespread adoption and deployment of these technologies. The review by [8] indicates that issues related to standardization, model generalization, and technological inequalities continue to restrict the impact of UAVs in smart agriculture. Furthermore, in many regions, a lack of technical knowledge, high initial investment costs, and legislative constraints represent major barriers to UAV adoption at the farm level, particularly for small-and medium-sized farms. In addition, technological challenges persist at the stage of processing UAV-derived data, where the large volume and complexity of information require advanced computational resources and specialized expertise, thereby affecting response times and agricultural management decisions [27].

CONCLUSIONS

The study highlights the central role of integrated digital approaches in modernizing plant protection in apricot orchards. The integration of UAVs, advanced image processing and decision support systems offers real prospects for more efficient, precise and sustainable phytosanitary protection. The synthesized results support the need to adapt these technologies to the pedoclimatic conditions of the Romanian Plain and to promote them in fruit growing practice.

From a cost management perspective, UAV spraying allows for the optimization of operational expenses per unit area, an aspect confirmed by comparative assessments carried out in the pedoclimatic conditions of the Vlăsiei Plain [7].

The transposed results highlight the fact that the adoption of digital approaches contributes to reducing operational costs, optimizing phytosanitary decisions and increasing the economic sustainability of orchards.

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QUANTIFYING THE IMPACT OF INNOVATION COSTS ON THE PERFORMANCE OF AGRI-FOOD ENTERPRISES IN THE REPUBLIC OF MOLDOVA

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Abstract

Innovation is widely recognized as a critical driver of enhanced performance across all economic sectors, including the agri-food sector. In this context, targeted investments in innovation - particularly those aimed at improving the productivity of production factors - are increasingly vital. This study aims to assess the extent to which innovation-related costs influence the economic performance of agri-food enterprises in the Republic of Moldova. The research objectives include: (1) critically reviewing the academic literature on the role of innovation in enterprise development; (2) identifying and analyzing the methodologies used to quantify the impact of innovation on business outcomes; and (3) selecting and applying empirical methods to measure the contribution of innovation costs to economic performance in the Moldovan agri-food sector. To this end, the study employed a combination of research methods, including: a comprehensive bibliographic review, a semi-structured thematic interview with 107 agri-food enterprises, and quantitative analysis using Huber robust linear regression and Spearman rank correlation. The findings reveal a statistically significant positive correlation between innovation costs and gross profit, confirming the substantial influence of innovation costs on enterprise performance. These results support the economic rationale for increased innovation investments and provide practical guidance for managers in the agri-food sector seeking to enhance competitiveness and contribute to broader national economic and social development.

Key words: *agri-food enterprises, costs, gross profit, innovation, regression analysis*

INTRODUCTION

In today's context, where society is significantly impacted by a broad range of external factors, including adverse natural phenomena, geopolitical tensions, and financial instability, the pursuit of sustained economic growth, food security, and population well-being underscores the critical importance of the agri-food sector. At the same time, the agri-food sector of the Republic of Moldova faces multiple structural challenges. These include the lack of consistent growth trends in production value, the persistence of a substantial number of inefficient entities, the slow progression in the value of exported agri-food products, and the notable decline in their share of total exports [37]. In light of these circumstances, there is a clear need to effectively mobilize the key drivers of improved sectoral performance, among which innovation plays a pivotal role.

Current research in the field of innovation management demonstrates a convergence of views among scholars and practitioners regarding the major significance of innovations for enhancing the performance of firms and entire sectors [1, 5, 7, 8, 11, 20, 22, 31, 39, 41, 45], a significance further reinforced by the flexibility of the competitive environment. At the same time, although the impact of investments in innovation on revenues and financial performance is indisputable [2, 9, 27], assessing the efficiency of these financial commitments remains a major challenge. Rigorous measurement is nevertheless necessary both to justify investment decisions in innovation and to identify the initiatives that generate the greatest value among the multiple alternatives available. Access to clear, quantifiable, and

well-structured performance indicators enables managers to convincingly demonstrate how innovation activities translate into operational efficiency and economic returns. However, isolating the effects of investments in innovation is inherently complex, as firm performance is influenced by a combination of internal and external factors, both measurable and intangible. Despite these challenges, assessing the impact of innovation on enterprise performance remains an ongoing concern among researchers. A review of numerous scientific studies addressing this issue [1, 2, 3, 5, 6, 10, 31, 39, 45] reveals a wide range of tools employed by researchers, characterized by both operational similarities and distinctive methodological features. Among the most common approaches is the use of surveys or participant interviews for initial data collection. Within this context, proper sampling is of paramount importance, as the sample must be constructed in a way that ensures each unit in the total population has an equal probability of being included. The sampling method is random and allows results to be evaluated using probability theory, thereby enabling quantification of the sampling risk [40]. The synthesis of the data collection methods in the aforementioned studies and the composition of the samples is presented in Table 1.

Table 1. General data on initial data collection in investigations on the impact of innovations on enterprise performance

Research location (country)	Research hypothesis	Method(s) of initial data collection applied	Sample composition
China	Innovative and marketing capacity impacts the economic and social performance of enterprises	Survey	Representatives of 279 companies in the agri-food sectors, participants in an agricultural exhibition
Indonesia	The introduction of innovation has a positive effect on enterprise performance	Interview	55 managers of furniture manufacturing companies
Colombia	Innovation has a positive impact on performance	Online survey	293 representatives of large and medium-sized companies
Italy	Sustainable innovations, which aim to generate not only economic benefits but also social and environmental ones, are positively associated with organizational performance.	Survey; semi-structured interview	371 representatives of manufacturing companies
Ghana	Regardless of the type of innovation (product, process, organizational, or marketing) and the volume of resources allocated (innovation scale), the result will be an increase in economic performance.	Survey	1,526 representatives of agribusiness enterprises from all 10 regions of the country
Russian Federation	Innovation strategies have an impact on enterprise performance.	Observation; systematization of existing statistical information	100 companies in the IT sector
Iran	Organizational learning capacity influences innovations within enterprises.	Survey	173 managers and employees from 18 ceramic tile manufacturing companies

Source: Developed by the authors based on [1, 2, 5, 19, 31, 39, 45].

Through examining the methodologies applied by various researchers to demonstrate the relationship between innovation and enterprise performance, a wide range of methods for analysing primary data obtained from opinion surveys were identified. Among these, we distinguish the methods EFA (Exploratory Factor Analysis), CFA (Confirmatory Factor Analysis), SEM (Structural Equation Modelling), linear regression, and PLS (Partial Least Squares Regression).

The exploratory factor analysis method is used in the initial stage of analysing relationships between variables without predefined hypotheses. Exploratory factor analysis is part of a family of multivariate statistical methods that seek to identify the smallest number of hypothetical structures (also known as factors, dimensions, latent variables, synthetic variables, or internal attributes) that can explain, in a weighted manner, the observed covariance among a set of measured variables (also called observed variables, manifest

variables, effect indicators, reflective indicators, or surface attributes). In other words, it is used to identify common factors that explain the order and structure among measured variables [43].

Confirmatory factor analysis (CFA) is described as a type of measurement model, a type of analysis that belongs to the SEM (Structural Equation Modelling) family. However, what distinguishes CFA from a SEM model is that CFA focuses on the relationships between indicators and latent variables, while SEM includes structural or causal paths between latent variables. CFA can be a standalone analysis or a component or preliminary stage of a SEM analysis [21].

Structural Equation modelling (SEM) combines elements of regression, thus providing a powerful tool for modelling complex relationships between variables. SEM models consist of two interdependent components: a measurement model and a structural model. The measurement model specifies how latent constructs are indicated by their observed indicators, describes the measurement properties of these indicators (reliability and validity), and is analogous to CFA. The structural model specifies causal relationships among latent variables, describes their direct and indirect effects, and allocates explained and unexplained variance of dependent constructs [24].

Linear regression is the most classical method used to determine and model the relationship between variables. Although econometric techniques have become increasingly sophisticated, regression analysis, in one form or another, continues to be an important tool in empirical studies. Linear regression is also important as a reference point for other techniques - typically, the failure of the conditions justifying the application of linear regression leads to the development of alternative methods. Moreover, many more complex techniques often include elements or modifications of linear regression [3].

The Partial Least Squares (PLS) regression method combines the advantages of principal component analysis, canonical correlation analysis, and linear regression. PLS projects predictive and observed variables into a new space by finding pairs of weighting vectors that maximize the covariance between the two projections [44]. The studies reviewed above (summarized in Table 1) show the use of different data processing methods or, in most cases, combinations of two or more methods. For example, the objective of analyzing the influence of innovation and marketing capacity on the economic and social performance of 279 agri-food companies in China was achieved through the combination of SEM and CFA methods. The results demonstrated that the more innovative a company is, the higher its economic and social performance [44].

To evaluate the effects of innovation on the performance of enterprises in Indonesia, the PLS method was used, which demonstrated the positive impact of innovation on enterprise performance, confirming the method's relevance [19].

In Colombia, a study aimed at assessing the relationship between organizational performance and business sustainability, as well as examining how these are moderated by innovation processes, processed initial data by combining EFA, CFA, and SEM. The results confirmed the hypothesis that innovation positively affects performance and that innovations reducing environmentally harmful processes not only help companies increase profits but also provide them with an advantage in the social dimension [5].

The study conducted in Italy aimed to demonstrate that sustainable innovations, which seek to produce not only economic but also social and environmental benefits, are positively associated with organizational performance. Data analysis combined linear regression, EFA, and cluster analysis (grouping cases based on similarities). Similar to the previous study, sustainable innovations were found to enhance the economic and social performance of enterprises [1].

In Ghana, the largest sample studied, initial data processing combined EFA and SEM methods. The results confirmed the hypothesis that regardless of the type of innovation used by a company, it will increase performance and

substantially contribute to the growth of gross profit [31].

Data obtained by observation and systematization of existing statistical information in the Russian Federation investigation were analyzed using linear regression, demonstrating that innovation strategies enhance enterprise performance [2].

In Iran, a study aimed at measuring how organizational learning capacity influences the implementation of new innovations and their effect on performance processed initial data using SEM. The results showed that the more a company is oriented toward corporate culture and improving organizational learning capacity, the more innovative and high-performing it will be [39].

Based on the above, we deduce the existence of various analytical tools that allow modeling relationships between two or more variables. However, when selecting an analysis method, it is necessary to evaluate its strengths and weaknesses. Among the strengths, we can mention the reliability offered by CFA and EFA and the fact that they can ensure accurate measurement of analyzed variables, provided that correct and rigorous sampling is conducted to increase result precision. As mentioned earlier, PLS and SEM methods allow exploration of complex relationships between variables, enabling the identification of key factors that increase performance. At the same time, they can identify the effects of several types of independent variables on the dependent variable. However, developing such a model that is valid and reliable requires a large number of observations, which often poses a practical challenge. Limiting the number of respondents could lead to erroneous results regarding the influence of one or more variables on performance.

Another aspect to consider is that the analytical models presented above can be difficult to interpret, which could be a barrier to their application by researchers and especially by company managers when trying to implement a tool to measure the impact of innovations on enterprise performance.

MATERIALS AND METHODS

In order to achieve the research objective of quantifying the impact of innovation-related costs on the performance of agri-food enterprises in the Republic of Moldova, the robust Huber linear regression method and Spearman's rank correlation method were selected. This choice is justified by the absence of a fully functional dependence between investments in innovation and enterprise performance. Therefore, a stochastic relationship is observed between innovation investments and gross profit, which serves as a generalized indicator of economic efficiency and thus qualifies as an important criterion for evaluating performance. Gross profit was chosen because it best reflects the positive results of the costs incurred, encompassing the largest share of innovation-directed costs made by the studied enterprises. Similar approaches have been adopted by other researchers, such as Mai et al. [26] and Simone et al. [35].

The primary data - referring to the amounts invested in innovation and the gross profit obtained by enterprises during the 2021–2022 period were collected through a semi-structured thematic interview conducted by telephone between July 2023 and April 2024. The interview involved a sample of 107 agri-food enterprises with more than nine employees. The representativeness coefficient of the sample is presented in Table.2.

Table 2. Sample representativeness coefficient

Type of enterprise (by sector)	The number of enterprises that participated in the interview	Total number of enterprises in 2022	Representativeness coefficient
Agricultural enterprises	66	5,315	0.01
Food and beverage manufacturing enterprises	41	1,156	0.035
Total	107	6,471	0.017

Source: Developed by the authors based on [29].

The sample composition by enterprise size is illustrated in Fig. 1. The data show a predominance of small enterprises (10–49 employees), followed by medium-sized enterprises (50–249 employees). Only two

large enterprises (with 250 or more employees) were included in the sample.

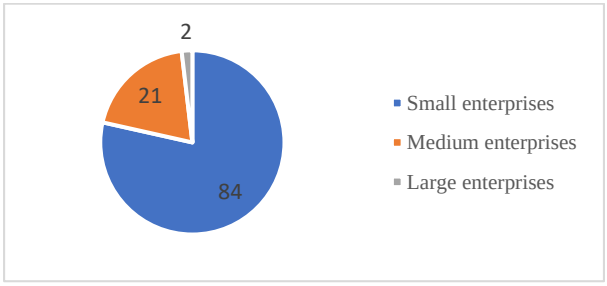


Fig. 1. Sample composition of agro-food enterprises by size
Source: Developed by the authors based on interview data.

The geographical location of the examined enterprises can be identified based on Fig. 2. Thus, we observe a predominance of enterprises from the Central Zone in both samples, as well as representation from the other geographical zones within each sample.

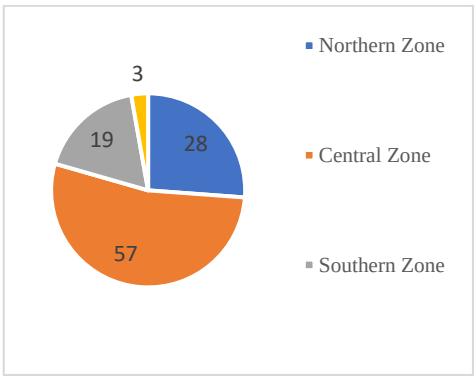


Fig. 2. Geographical distribution of agro-food enterprises in the sample
Source: Developed by the authors based on interview data

To ensure the accuracy of the responses during the interviews, it was necessary to explain to respondents the nature of innovation activities and the various types of innovation. These were categorized according to the typology proposed by the Organization for Economic Co-operation and Development (OECD), which distinguishes between product, process, organizational, and marketing innovations. This same classification is also used in the Statistical Survey No. 1 – INOV of the National Bureau of Statistics of the Republic of Moldova [30].

It was observed during the interviews that many respondents did not have a clear understanding of the concept of innovation. Consequently, they often did not consider their enterprise to be innovative - an explanation that aligns with the very low number of officially recorded innovative enterprises, according to national statistics.
The main limitations of the research were as follows: a) the small size of the analysed sample; b) the absence of control variables; c) the limited time horizon covered, due to difficulties related to the lack of statistical data on the innovation activity of agricultural enterprises. This is because Statistical Survey No. 1 – INOV, conducted by the National Bureau of Statistics of the Republic of Moldova, is applied only to enterprises in the industrial and service sectors; d) the selected stochastic analysis method allowed the evaluation of the cause-effect relationship between only one factor and the gross profit. In practice, the result of innovation implementation is determined by a complex of factors, with the incurred costs being a very important one, but not the only one.

RESULTS AND DISCUSSIONS

In order to select appropriate analytical methods and adjust models to the data, it is essential to examine the data itself. In this regard, the most commonly used are measures of central tendency and dispersion, namely: arithmetic mean, median, standard deviation, skewness, kurtosis, and the Shapiro-Wilk test. It is important to note that data on costs and gross profit tend to be highly skewed by their nature [18]. For this reason, a descriptive analysis was conducted on the values obtained from the interview, with the results presented in Table 3 and Fig. 3 and 4.
Analysing the data in Table 3, the following conclusions can be drawn: the median, which represents the middle value of the dataset [4, p.71], at 1,500 thousand MDL, indicates that half of the enterprises invested less than 1,500 thousand MDL, while the other half invested more. The mean, which is sensitive to extreme

values, is 3,320 thousand MDL- significantly higher than the median-suggesting a skewed distribution [4, p.78]. The standard deviation, which measures the degree of dispersion around the mean [4, p.94], is 6,291, indicating high variability. The skewness coefficient of 5.30 confirms a strong positive asymmetry, as a perfectly symmetrical distribution would have a skewness of zero [32, p.52].

Table 3. Descriptive analysis of amounts invested in innovation by agri-food enterprises

Indicators	Values
Number of valid observations (non-missing)	98
Missing values	0
Median (thousand MDL)	1,500
Mean (thousand MDL)	3,320
Standard deviation (thousand MDL)	6,291
Skewness coefficient	5.30
Standard error of skewness	0.24
Kurtosis coefficient	34.51
Standard error of kurtosis	0.48
Shapiro-Wilk statistic	0.46
p-value (Shapiro-Wilk test)	< .001
25th percentile (Q1, thousand MDL)	410
Median (Q2, thousand MDL)	1,500
75th percentile (Q3, thousand MDL)	3,825

Source: Developed by the authors based on interview data.

The kurtosis coefficient of 34.51 suggests a strongly leptokurtic distribution, indicating the presence of outliers, as shown in Fig. 3. Similarly, the Shapiro-Wilk test [34], which is sensitive to outliers, yielded a statistic of 0.46, confirming the non-normality of the data distribution, as illustrated in Fig .4 - especially evident at the tails of the distribution.

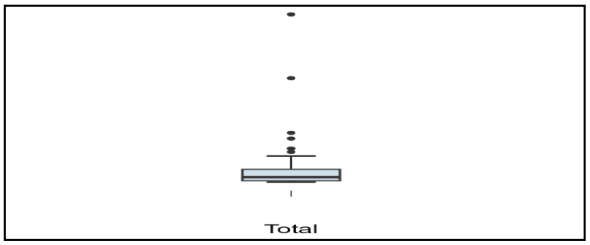


Fig. 3. Outliers in investments in innovation among agri-food enterprises
Source: Developed by the authors based on interview data.

Similarly, a descriptive analysis was carried out for the gross profit of agri-food enterprises. The results are presented in Table 4 and Fig. 5 and 6.

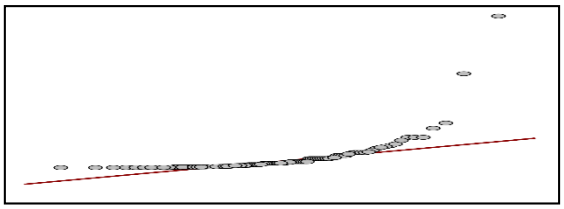


Fig. 4. Distribution of investments in innovation among agri-food enterprises
Source: Developed by the authors based on interview data.

Table 4. Descriptive analysis of gross profit among agri-food enterprises

Indicators	Values
Number of valid observations (non-missing)	98
Missing values	0
Median (thousand MDL)	3,450
Mean (thousand MDL)	7,234
Standard deviation (thousand MDL)	13,476
Skewness coefficient	3.59
Standard error of skewness	0.24
Kurtosis coefficient	17.43
Standard error of kurtosis	0.48
Shapiro-Wilk statistic	0.63
p-value (Shapiro-Wilk test)	< .001
25th percentile (Q1, thousand MDL)	1,050
Median (Q2, thousand MDL)	3,450
75th percentile (Q3, thousand MDL)	7,828

Source: Developed by the authors based on interview data.

The data in Table 4 show that the median value of gross profit indicates that half of the enterprises earned more than 3,450 thousand MDL, while the other half earned less. The mean, at 7,234 thousand MDL, is considerably higher than the median, again suggesting a positively skewed distribution. The standard deviation of 13,476 thousand MDL highlights a high degree of dispersion. The skewness coefficient of 3.59 confirms the positive asymmetry, and the kurtosis coefficient of 17.43 confirms the presence of outliers and a leptokurtic distribution, as seen in Fig. 5.

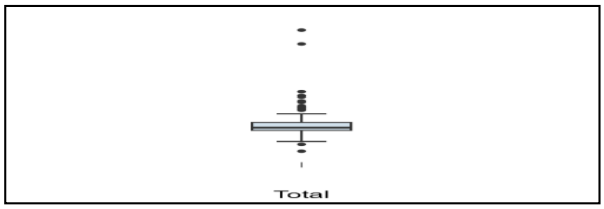


Fig. 5. Outliers in gross profit among agri-food enterprises
Source: Developed by the authors based on interview data.

The Shapiro-Wilk test result further confirms the non-normal distribution, particularly due to upper-tail deviations, illustrated in Fig. 6.

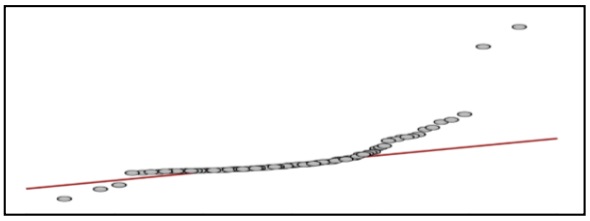


Fig. 6. Distribution of gross profit among agri-food enterprises
Source: Developed by the authors based on interview data.

The descriptive analysis confirmed the presence of outliers, a right-skewed positive distribution, and high dispersion. Since economic indicators (such as costs and gross profit) are generally non-symmetrical, it is crucial to select appropriate analytical models to produce reliable results. Outliers are extreme values that can distort statistical conclusions [42]. Statistical methods generally propose four strategies to handle outliers for accurate results [15]:

- Excluding outliers from the dataset;
- Winsorizing (replacing extreme values with less extreme ones);
- Using robust estimation methods;
- Data transformation through mathematical functions.

Among these, the most suitable option is the use of robust estimation methods [15], since removing or altering valid observations can result in the loss of essential information. Assigning zero weight to certain observations in survey statistics effectively eliminates valid data. In official statistics, this is generally avoided because survey data collected via filtered questionnaires are too valuable to discard [42]. In the present research, the outlier values reflect actual large-scale investments or profits by real enterprises. Excluding them would distort the reality observed. Additionally, before performing a regression analysis, it is necessary to determine whether a correlation exists between the variables in this case, investment in innovation and gross profit especially given the non-normality and presence of outliers. To this end, Spearman's rank correlation method was used [25]. The Spearman rank correlation coefficient (ρ) is a non-parametric measure of correlation. It is used to determine the relationship between two data sets [13, p.502]. It ranks the values of each variable instead of using raw values [33], thus reducing the impact of extreme values. Spearman's coefficient is more robust than Pearson's and measures whether both variables tend to increase or decrease together [12]. A positive correlation means high values of variable *X* (innovation costs) tend to be associated with high values of *Y* (gross profit), and vice versa. A negative correlation means high *X* values are associated with low *Y* values, and vice versa [13, p.503].

The coefficient ranges from 0 to ±1, with values closer to ±1 indicating stronger associations [33]. Interpretation of Spearman's coefficient [16]:

- $0.00 \leq r < 0.19$ – no correlation;
- $0.20 \leq r < 0.39$ – weak correlation;
- $0.40 \leq r < 0.69$ – moderate correlation;
- $0.70 \leq r < 0.89$ – strong correlation;
- $0.90 \leq r < 1.00$ – very strong correlation.

The analysis begins with the formulation of two hypotheses:

- Null hypothesis (H_0): $\rho x, y = 0$ – no correlation between variables;
- Alternative hypothesis (H_1): $\rho x, y \neq 0$ – variables are correlated.

The result of determining the Spearman correlation coefficient for the analyzed data is presented in Table 5.

Table 5. Spearman correlation coefficient between investment in innovation and gross profit

Indicator	Value
Spearman correlation coefficient	0.42
p-value	< .001

Source: Developed by the authors based on interview data

The magnitude of the coefficient - 0.42 - indicates that there is a moderate positive correlation between investments in innovation and the gross profit obtained by enterprises. However, in order to confirm that the null hypothesis can be rejected, the results of the correlation coefficient must be subjected to a statistical test to determine the significance level of the proposed mathematical-economic model. This can be done by calculating the p-value.

The p-value represents the probability of obtaining a result at least as extreme as the observed one, assuming that the null hypothesis is true. It is the smallest level of significance (α) at which the null hypothesis (H_0) would be rejected, based on the observed data. If $p \leq \alpha$, then we reject the null hypothesis at the α significance level; if $p > \alpha$, we fail to reject H_1. The smaller the p-value, the greater the likelihood that the null hypothesis will be rejected [36, p.164].

In other words, statistical significance (p) refers to the statistical testing used to determine the plausibility of a hypothesis and the probability that the result occurred by chance. Thus, data are considered statistically significant when the p-value is less than 0.05, and the confidence level is 95% [17, p. 1].

Accordingly, the p-value obtained for the Spearman correlation coefficient demonstrates that the null hypothesis can be rejected in favor of the two-tailed alternative hypothesis.

Based on these results, an advanced analysis is required to quantify not only the direction and intensity of the relationship between investments in innovation and gross profit, but also to estimate the coefficients indicating the percentage increase in profit resulting from innovation. The robust linear regression model (Huber) was chosen due to the nature of the data. As Tables 3 and 4 show, both investment and profit data are highly skewed and leptokurtic - common traits in economic data. To avoid distortion from these characteristics, robust regression methods are used. A significant advantage of Huber regression lies in its ability to generate valid relationships even in the presence of extreme values and heavy-tailed, non-normal distributions, where ordinary least squares (OLS) regression would fail [14].

Huber-type M-estimators weigh observations based on their distance from the distribution's centre. In regression, M-estimators minimize $\Sigma = r_i^2$ for OLS and $\Sigma = |r_i|$ for LAD. Huber estimators adaptively weigh residuals (r_i) based on their deviation from zero and use them to compute adjusted *Y* values [38, p.79].

In other words, Huber regression combines OLS for small residuals and LAD for large residuals (i.e., outliers) [28].

Thus, we obtain [23]:

$$\rho_{\delta(r)} = \begin{cases} \frac{r^2}{2}, & if|r| \leq \delta \\ \delta * (|r| - \frac{\delta}{2,} & if|r| > \delta \end{cases} \quad (1)$$

In other words, if the standardized residual $|r_i| \leq \delta$, the robust Huber linear equation will apply a quadratic loss function, similar to the Ordinary Least Squares (OLS) regression. Conversely, when $|r_i| > \delta$, Huber's method employs a linear loss function based on the absolute value of the residual, in line with the Least Absolute Deviations (LAD) model.

Similar to the case of correlation analysis, an essential step in the research process is the formulation of hypotheses to be tested. We therefore state the following hypotheses:

- (H_0): $\beta = 0$ - there is no relationship between innovation investments and the gross profit obtained by agri-food enterprises;
- (H_1): $\beta \neq 0$ - investments in innovation have a significant effect on the gross profit obtained by agri-food enterprises.

The results and coefficients obtained using the Huber robust linear regression are presented in Table 6 and in the estimated model equation.

The estimated model equation is as follows:

$$Y_{profit} = 1{,}578.73 + 1.43 * x_{invest} \quad (2)$$

As shown in Table 6, to describe the relationship between investments in innovation and gross profit obtained by the analysed enterprises, a sample of 98 enterprises was used. The 6 iterations indicate a stable and efficient estimation. As presented in the model equation, the estimated regression coefficient for the variable "innovation investments" is 1.43, which has the following economic interpretation: for every 1,000 MDL invested in innovation, the gross profit increases by 1,430 MDL; in other words, each MDL invested in innovation generates an increase in gross profit of 1.43 MDL.

Table 6. Results of the Huber robust regression of the relationship between investments in innovation and gross profit obtained by agri-food enterprises

Indicator				Specifications		
Dependent variable				y_profit		
Number of observations				98, un.		
Model				Robust Linear Model		
Residual degrees of freedom (Df)				96 units		
Method				IRLS (Iteratively Reweighted Least Squares)		
Norm				HuberT		
Iterations				6		
	Estimate	Standard error	Z- statistic	p Value	95% interval	
Intercept (constant)	1578.7337	552.635	2.857	0.004	495.588	2.661
x_invest	1.4317	0.078	18.355	0.001	1.279	1.585

Source: Developed by the authors based on interview data
Note: All monetary variables are expressed in thousand lei.

The obtained profitability is calculated as:

$$\frac{430}{1000} \times 100 = 43\%$$

At the same time, the Z-statistic of 18.35 with a p< 0.001 demonstrates a strong relationship between investments and gross profit, allowing us to reject the null hypothesis. The confidence interval is also positive, proving that the true effect of innovation on gross profit, with 95% confidence, lies between 1.279 and 1.585.

CONCLUSIONS

Having demonstrated the positive impact of innovations on enterprise performance, the exact quantification of this impact remains a challenge, due to the fact that performance indicators are influenced by a wide range of factors - both endogenous and exogenous, measurable and immeasurable.

The quantification of the impact of innovation costs on the performance of agri-food enterprises in the Republic of Moldova allowed the following conclusions:

a) There is a positive linear correlation between innovation costs and gross profit: as investments in innovations increase, the gross profit of enterprises correspondingly increases;

b) Innovation costs have a substantial impact on gross profit. Specifically, the regression coefficient obtained for investments in innovation, amounting to 1.43, indicates a strong relationship between the amounts invested in innovation (examined as the factorial indicator) and gross profit (examined as the result indicator). This coefficient shows that for every 1,000 MDL invested in innovation, a profit of 1,430 MDL is generated, which corresponds to a profitability of 43%;

c) The $p < 0.001$ associated with the estimated regression coefficient demonstrates that the model is statistically significant at the 0.1% level. Based on this, hypothesis H_1 is confirmed, according to which investments in innovation have a significant effect on the gross profit obtained by the analyzed enterprises.

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CHANGES IN THE BALANCE OF HUMUS IN THE SOIL OF FIVE-FIELD CROP ROTATION DEPENDING ON FERTILIZER SYSTEMS

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Abstract

Studies conducted on deep, medium-loamy typical chernozem within a long-term five-field crop rotation have shown that the removal of all by-products from the fields (soybean, winter wheat, sunflower, spring barley, and grain corn), regardless of the fertilisation system, leads to a negative humus balance ranging from 551 to 1305 kg/ha. When only wheat and barley straw is removed, the humus balance also remains negative across all experimental variants, but at significantly lower levels—ranging from 179 to 277 kg/ha. In contrast, when all by-products of the crops in rotation are used as organic fertiliser, the humus balance becomes positive, amounting to 8–398 kg/ha. The main source of humus formation in the soil is the crop residues of cultivated plants in the rotation. Through their humification, 1.66 times more humus is formed compared to that derived from the by-products of the three main crops. According to the index of agricultural ecologisation and the applied rates of organic fertilisers, the rotation variant in which by-products are used as organic fertiliser and 16 t/ha of manure + $N_{112}P_{100}K_{86}$ is applied qualifies as having an intensive level of agricultural ecologisation. The productivity of the crop rotation in which all crop by-products are removed from the fields is 11–13% lower than that of the rotation where by-products are used as organic fertiliser in three fields.

Key words**:** *crop rotation, soil, humus, balance, fertilisers, yield, dry matter, root residues, post-harvest residues*

INTRODUCTION

Soil fertility and balance cannot be maintained without the presence of organic matter and the addition of new amounts of plant residues or chemical and organic fertilizers, as plants extract significant amounts of nutrients from the soil each year. Therefore, manure application can be considered a good source of increasing potential soil fertility [3].

Soil organic matter comprises humus (on average 85%), plant residues (10%), and soil flora and fauna (5%) [22]. In chernozem soils, 95–98% of nitrogen, nearly 60% of phosphorus, and 80% of sulphur are concentrated in humus [23]. Between 50–60% of the nitrogen removed with the biomass of agricultural crops originates from humus that is, nitrogen compounds formed as a result of humus mineralisation (the remaining nitrogen is supplied by fertilisers, precipitation, plant residues, and biological nitrogen fixation) [20]. In mineral soils, most of the humus is associated with inorganic materials, particularly clays, and these interactions influence both organic and inorganic components. The binding of organic molecules to minerals is commonly studied using adsorption isotherms, where the amount of sorbed organic compound is plotted against its equilibrium concentration remaining in solution. The content of organic matter in soils depends on the availability of organic substrates to the "hungry" microbial population [16].

In natural phytocoenoses, unlike agrocenoses, the issue of organic matter deficiency in the soil does not arise: here, the processes of organic matter synthesis consistently prevail over its decomposition. Humus deficiency in

the soil remains one of the predominant problems in agricultural production. This is primarily due to the high proportion (65–70%) of crop by-products being removed from the fields, the increasing intensity of mineralisation processes in soils, and other pathways of organic matter loss (such as erosion, deflation, and leaching), along with the high concentration of row crops and the near-total absence of perennial grasses [17, 18].

The main strategies for compensating humus content in the soil include the use of all types of organic fertilisers, crop by-products, and green manure; the cultivation of perennial grasses; reducing the proportion of row crops in crop rotations; and minimising mechanical soil tillage [9]. Plant residues can compensate for 24–40% of soil humus losses. Therefore, the incorporation of crop by-products and green manure into humus-restoring processes is of great importance. Moreover, the use of crop by-products, particularly straw, as organic fertiliser has significant ecological value [8, 19].

There are two fundamental approaches to increasing the soil's organic matter content: one is by enhancing the supply of organic inputs into the soil, and the other is by limiting the processes that lead to organic matter depletion. The level of organic carbon retained in soil is determined by the balance between incoming carbon—derived from plant residues not removed during harvest and ongoing organic conversions—and carbon losses, primarily resulting from microbial decomposition of organic compounds and the subsequent release of carbon dioxide into the air. Organic inputs that return to the soil—whether directly as plant residues or indirectly through manure comprise a diverse range of organic substances. As a result, organic matter in soils serves not only as a vital carbon source supporting biological and chemical processes but also functions as a reservoir for carbon storage. However, tillage practices can diminish the amount of organic carbon present in the soil, which contributes to soil degradation and may lead to a decline in its overall fertility and productive capacity [14].

Understanding how agricultural practices influence soil characteristics is crucial for ensuring the long-term sustainability of soil resources and maintaining ecosystem integrity. The content of organic compounds (0.34%–1.34%) recorded under various land-use types was significantly lower than the threshold required to meet the needs of most agricultural crops, indicating that the structural stability of the soil may be compromised. Consequently, such soils are at greater risk of low fertility and water erosion [7].

As reported by Shepherd et al., the light fraction of soil organic matter plays a key role in shaping soil structure, and noticeable improvements in structural stability occur when fresh organic residues are consistently incorporated into the soil. Therefore, the enhancement of soil's physical condition depends less on the specific farming system employed and more on the volume and quality of organic inputs returned to the soil [25].

Leah T. [13] notes that various locally available organic by-products such as farmyard manure, sewage sludge, wine production residues, distillery effluents, cereal stubble, fermented straw, and similar materials can be effectively utilised to restore and replenish soil organic matter. The use of organic wastes in agricultural practice as fertilisers contributes to maintaining a balanced cycle of carbon and nutrients. Each tonne of organic waste applied as fertiliser replenishes soil humus reserves by 85–100 kg/ha, supplies 8–9 kg/ha of nitrogen, stimulates the increase of productive potential, and improves soil fertility.

The application of fertilizers is a common practice aimed at sustaining or improving crop yields. Over extended periods, consistent fertilization not only boosts crop production but also promotes the accumulation of organic matter in the soil, resulting in enhanced biological activity relative to soils left without fertilization. Long-term fertilizer application has, in many cases, resulted in increased water-stable aggregation, porosity, infiltration capacity, and hydraulic conductivity, as well as reduced bulk density. Fertilizer addition may

also exert physico-chemical effects that influence soil aggregation [10, 21].

Returning straw to the soil is the primary method of managing agricultural crop residues. However, the commonly used practice of straw return often has numerous negative effects on soil fertility levels and the improvement of crop yields [11].

The increased input and improved quality of organic matter entering the soil through the application of winter wheat straw, both alone and in combination with green manure, created more favourable conditions for the development of soil microflora and significantly improved the biological status of the studied soil. According to the findings [24], the application of nitrogen-based fertilizers did not produce any statistically significant changes in the biological characteristics of the studied soils.

As reported by M. Caraman et al. [4], the use of organic fertilizers led to significant improvements in the microbiological and biochemical status of the soil, including a tenfold rise in populations of beneficial microorganisms, an increase in organic matter content ranging from 48.02% to 114.81%, and a rise in humus levels between 10.56% and 15.14%. These changes contributed to enhanced physiological development of plants by 7.69%–10.53%, as well as increases in maize grain yield by 5.98%–17.45% and straw production in comparison with the control treatment.

Long-term application of mineral fertilisers (NPK) without the addition of organic matter may accelerate humus mineralisation and lead to soil quality deterioration, with a range of negative consequences such as nitrogen leaching, increased availability of toxic elements to plants, and reduced energy supply for soil microorganisms. The use of organic fertilisers (such as manure and cattle dung) supports long-term stable crop yields while maintaining optimal soil quality through sustainable long-term management involving surface-active substances. Principal component analysis is a useful tool for assessing changes in soil quality [15].

In China, combining organic amendments with fertilizers led to a substantial increase in the yields of three principal crops wheat, corn, and rice by an average of 29% compared to using organic amendments alone, and by 8% relative to fertilizers applied without organics. Higher nutrient management gains in crop yield under the combined application were observed in the order: wheat (53%) > corn (40%) > rice (8%). Significant and positive temporal trends in nutrient management with organics + fertilisers in wheat and corn yield suggest enhanced resilience of cropping systems. The addition of organic matter, either alone or in combination with fertilisers, improved both the organic matter content and nutrient management compared to the sole application of fertilisers. Despite differences in crop type or land use, the combined use of organics and fertilisers proved to be the most effective approach for increasing food production, enhancing soil organic matter, and improving the sustainability of agroecosystems [31].

In the Left-Bank Forest-Steppe of Ukraine, the continuous application of straw as fertiliser (with a compensatory nitrogen dose) along with mineral fertilisers over a 10-year crop rotation led to an increase in humus content in the arable layer of typical medium loam chernozem by 0.23–0.25%, and humus reserves by 8 t/ha [26]. The application of 40 t/ha of manure + $N_{110}P_{90}K_{90}$ and 20 t/ha of manure + 4 t/ha of straw + N_{40}+ $N_{110}P_{90}K_{90}$ increased the humus content by 25% and 20% respectively, compared to unfertilised plots. The combined incorporation of straw and green manure proved to be an effective measure for restoring soil humus content [1].

Studies conducted by M. Tkachenko et al. in a winter wheat agrocenoses revealed that shallow tillage using a disc harrow combined with resource-saving minimised mineral fertilisation increased the humus content by 0.04% in the 0–15 cm soil layer and by 0.03% in the 15–30 cm layer compared to inversion tillage. High levels of hydrolytic acidity (1.61–2.92 mol/m³/100 g of soil) were observed at all mineral fertiliser rates under inversion tillage [28].

When mineral fertilisers were applied alone at a rate of $N_{46}P_{51}K_{59}$ within a ten-field grain-row crop rotation under adequate moisture conditions, humus losses of 0.09% and 0.03% were observed in the arable and subarable horizons of typical leached chernozem soils, respectively. However, applying 12 t/ha of manure in combination with $N_{46}P_{51}K_{59}$ helped stabilise these humus levels [29].

After completing four crop rotation cycles (40 years) in typical low-humus chernozem soils, the humus content in the arable layer was 4.59% under the treatment with 8.3 t/ha of manure combined with $N_{29.3}P_{45}K_{36.7}$, and 4.72% when 16.7 t/ha of manure was applied alongside the same mineral fertiliser rates. In contrast, fallow plots showed a higher humus content of 5.20%. Additionally, acidification of the soil solution was recorded [31].

At the Poltava State Agricultural Research Station (Ukraine), on typical low-humus heavy loam chernozem, long-term field experiments (1993–2015) demonstrated enhanced soil humus restoration in crop rotations with the annual application of 10 t/ha of manure + $N_{53}P_{60}K_{60}$, combined with the use of all crop residues as organic fertiliser, alongside the obligatory application of a compensatory dose of mineral nitrogen (10 kg of active nitrogen per tonne of straw or stalks) [33].

It has been established that for simple and enhanced restoration of soil humus in typical low-humus chernozem, the annual manure application rate should be 10–15 t/ha, respectively. When manure is partially replaced by crop residues, the annual manure application rate is reduced to 10–12 t/ha. At a manure rate of 6–7 t/ha, an increasing trend in humus balance and high accumulation rates were observed. However, when manure is replaced by crop residues, the rate of humus deficit growth accelerates significantly [6].

The aim of the study was to determine the effectiveness of using crop by-products and green manure for the restoration of humus content in the soil.

MATERIALS AND METHODS

The study was conducted in a five-field crop rotation system during 2020–2024 on the experimental field of Bila Tserkva National Agrarian University. The soil type was deep typical chernozem with low humus content and medium loam texture. The experiment included four fertilisation systems: 0 – no fertilisers (control); 1 – 8 t/ha of manure + $N_{76}P_{64}K_{57}$; 2 – 12 t/ha of manure + $N_{95}P_{82}K_{72}$; 3 – 16 t/ha of manure + $N_{112}P_{100}K_{86}$. In the first crop rotation variant, all crop residues were removed from the fields. In the second variant, residues were removed only from fields where winter wheat and spring barley were grown; after their harvest, white mustard was sown as a green manure (cover crop). The crop rotation included soybean, winter wheat, sunflower, spring barley and grain maize.

The experiment was conducted in three replications, arranged systematically, continuously, and sequentially across the crop rotation fields. Each sown plot covered an area of 684 m², of which 504 m² was designated for measurement purposes. The mineral fertilisers applied included ammonium nitrate, potassium salt and single superphosphate.

In calculating the humus balance, it was assumed that 60% of the nitrogen removed with the main and by-products of the crop yield originated from soil humus (the remaining share was attributed to nitrogen from organic and mineral fertilisers, as well as atmospheric deposition, plant residues and biological nitrogen fixation). The nitrogen use efficiency from soil sources by plants was estimated at 70%. When determining the amount of humus mineralised, the nitrogen content in humus was assumed to be 5%.

For the calculation of humus mineralization, specific coefficients were applied: 0.8 for typical chernozem soils, 1.8 for row crops, 1.0 for post-harvest white mustard, and 1.2 for other cultivated plants. Additionally, symbiotic nitrogen fixation by nodule bacteria was estimated to account for 50% of the total nitrogen removed through the main and by-products of soybean harvest.

Root residues were estimated according to Yeshchenko **[**32**],** while the humus balance was calculated based on the method proposed by Chesnyak **[**5**].** The humification coefficients of plant residues were as follows:

0.23 for soybean, 0.22 for spring barley, 0.20 for winter wheat and corn, 0.15 for white mustard, 0.054 for manure, and 0.20 for the by-products of row crops and soybean.

RESULTS AND DISCUSSIONS

With increasing levels of fertiliser application, both crop yield and the mass of plant residues increased. However, the rate of increase in main yield exceeded that of root biomass and post-harvest residues. In particular, compared with unfertilised plots, the application of the first, second and third fertilisation systems resulted in an increase in main yield of: 93%, 173% and 254% in soybean, while the increase in root biomass was 65%, 112% and 170%; 82%, 142% and 200% in winter wheat, with corresponding increases in root mass of 56%, 91% and 132%; 50%, 76% and 91% in white mustard (preceded by winter wheat), with 36%, 55% and 62% in root biomass; 77%, 155% and 216% in sunflower, and 57%, 110% and 161% in roots; 62%, 107% and 146% in spring barley, and 40%, 69% and 94% in root biomass; and 66%, 107% and 150% in corn (first crop rotation variant), with 37%, 61% and 93% in root mass, respectively.

Thus, for all studied crops, the increase in main yield was significantly higher than the increase in the dry mass of root residues.

Table 1. Yield of main and by-products and dry weight of root and post-harvest residues in the first variant of crop rotation

Crops	System fertilization	Yield, t/ha		Dry weight, t/ha	
		main products	by-products	root residues	post-harvest residues
Soybean	0	0.92	1.28	0.81	0.54
	1	1.78	2.60	1.34	0.75
	2	2.51	3.87	1.72	1.09
	3	3.26	5.22	2.19	1.48
Winter wheat	0	2.39	2.94	2.57	1.92
	1	4.34	5.43	4.02	2.66
	2	5.79	7.47	4.90	3.08
	3	7.17	9.61	5.96	3.47
Post-harvest white mustard for green manure	0	11.50	–	2.22	0.60
	1	17.22	–	3.01	0.78
	2	20.25	–	3.45	0.89
	3	21.93	–	3.60	0.93
Sunflower	0	1.03	1.61	1.57	0.75
	1	1.82	3.00	2.46	1.01
	2	2.63	4.55	3.30	1.32
	3	3.25	5.75	4.09	1.54
Spring barley	0	2.09	2.32	1.77	1.05
	1	3.38	3.89	2.47	1.34
	2	4.33	5.15	3.00	1.61
	3	5.14	6.37	3.44	1.82
Post-harvest white mustard for green manure	0	10.46	–	2.02	0.55
	1	14.44	–	2.50	0.66
	2	16.82	–	2.85	0.75
	3	18.30	–	3.02	0.79
Corn	0	4.31	6.47	3.61	0.99
	1	7.17	11.11	4.96	1.41
	2	8.93	14.11	5.80	1.73
	3	10.79	17.37	6.98	2.08

Source: Authors own results.

Specifically, under the first, second and third fertilisation systems, the increase in the main part of the yield in soybean exceeded the increase in root biomass by 28%, 61% and 84%; in winter wheat – by 26%, 51% and 68%; in white mustard – by 14%, 21% and 29%; in

sunflower – by 20%, 45% and 55%; in spring barley – by 22%, 38% and 52%; and in corn – by 29%, 56% and 57% (Tables 1 and 2).

A similar pattern was observed in the second crop rotation variant. This trend was evident in both root and post-harvest residues. Under the first, second and third fertilisation systems, the increase in residue mass, compared to the control, lagged behind the increase in main yield by: 51%, 64% and 79% in soybean; 41%, 78% and 113% in winter wheat; 12%, 20% and 25% in white mustard; 41%, 76% and 105% in sunflower; 28%, 43% and 57% in spring barley; and 24%, 34% and 46% in corn.

In the first crop rotation variant, an average of 4.48 t/ha of dry root mass and 1.88 t/ha of post-harvest residues were returned annually to the soil. In the second variant, these figures were higher by 11.2% and 10.6%, respectively, amounting to 4.98 and 2.08 t/ha. The total input of organic matter from plant residues to the soil was 6.36 t/ha in the first variant and 7.06 t/ha in the second.

In both the first and second crop rotation variants, the highest amount of plant residues remained after the harvest of winter wheat – 7.15 and 7.79 t/ha, respectively, while the lowest was recorded after soybean – 2.48 and 2.83 t/ha. Under sunflower and spring barley, the amount of residues was nearly the same, amounting to 4.01 and 4.54 t/ha, and 4.13 and 4.55 t/ha, respectively.

Table 2. Yield of main and by-products and dry weight of root and post-harvest residues in the second variant of crop rotation

Crops	System fertilization	Yield, t/ha		Dry weight, t/ha	
		main products	by-products	root residues	post-harvest residues
Soybean	0	1.12	1.52	0.93	0.62
	1	2.11	3.00	1.55	0.85
	2	2.96	4.44	1.98	1.24
	3	3.81	5.94	2.52	1.62
Winter wheat	0	2.73	3.28	2.89	2.15
	1	4.78	5.80	4.39	2.88
	2	6.35	7.87	5.33	3.34
	3	7.80	9.83	6.45	3.73
Post-harvest white mustard for green manure	0	12.43	–	2.41	0.61
	1	18.40	–	3.22	0.83
	2	21.63	–	3.69	0.94
	3	23.49	–	3.88	1.00
Sunflower	0	1.21	1.86	1.79	0.88
	1	2.09	3.39	2.78	1.16
	2	2.98	5.01	3.70	1.50
	3	3.69	6.38	4.59	1.76
Spring barley	0	2.37	2.52	1.96	1.15
	1	3.74	4.06	2.69	1.49
	2	4.78	5.28	3.25	1.83
	3	5.67	6.40	3.75	2.09
Post-harvest white mustard for green manure	0	11.50	–	2.21	0.58
	1	15.64	–	3.00	0.79
	2	18.17	–	3.44	0.93
	3	19.78	–	3.77	1.02
Corn	0	4.82	7.04	4.03	1.09
	1	7.90	11.85	5.50	1.53
	2	9.73	14.89	6.34	1.83
	3	11.74	18.31	7.59	2.16

Source: Authors own results.

With increasing fertiliser application rates, both yield and root residue mass of crops in crop rotations increased. At the same time, soybean, winter wheat, sunflower and spring barley exhibited a more intensive increase in main yield compared to root biomass. Thus,

under the first, second and third fertilisation systems in the second crop rotation variant, the increase in main yield of soybean, compared to the unfertilised plots, amounted to 88%, 164% and 240%, while the increase in root residues was 67%, 113% and 171%, respectively. In winter wheat, these values were 75%, 133% and 186% for main yield, and 52%, 84% and 113% for root residues. In spring barley – 58%, 102% and 139%, and 37%, 66% and 91%, respectively; in sunflower – 73%, 146% and 205%, and 55%, 107% and 156%.

Thus, under the first, second and third fertilisation systems, the increase in main yield exceeded the increase in root residue mass in soybean by 22%, 51% and 69%; in winter wheat – by 23%, 48% and 63%; in spring barley – by 21%, 36% and 48%; and in sunflower – by 17%, 40% and 47%, respectively. In corn and white mustard under the second crop rotation variant, such a pattern was not observed, and the increases in grain or green biomass and root residues did not differ significantly.

In the second crop rotation variant, the increase in post-harvest residues lagged behind the increase in main yield for all crops grown on fertilised plots, compared to unfertilised ones. It was observed that this discrepancy in growth widened with higher fertiliser rates across all crops, except for soybean. Specifically, under the first, second and third fertilisation systems, the increase in main yield in soybean exceeded the increase in post-harvest residues by 51%, 64% and 58%, respectively; in winter wheat – by 41%, 77% and 112%; in sunflower – by 38%, 72% and 99%; in spring barley – by 28%, 43% and 58%; and in corn – by 5%, 11% and 15%.

Compared with unfertilised plots, the mass of post-harvest residues increased under the first, second and third fertilisation systems by 37%, 100% and 182% in soybean; 34%, 55% and 74% in winter wheat; 35%, 75% and 106% in sunflower; 30%, 59% and 82% in spring barley; and 59%, 91% and 128% in corn.

The average dry mass of root residues in the first and second crop rotation variants amounted to 1.52 and 1.75 t/ha in soybean, 4.36 and 4.77 t/ha in winter wheat, 2.86 and 3.22 t/ha in sunflower, 2.67 and 2.91 t/ha in spring barley, and 5.34 and 5.87 t/ha in corn. The share of root residues in the total plant residue mass was 60–65% in soybean; 70–72% in winter wheat and spring barley; and 77–79% in sunflower and corn.

On unfertilised plots, the dry mass of root residues per hectare of arable land under the first, second and third fertilisation systems amounted to 2.91, 4.15, 5.00 and 5.86 t in the first crop rotation variant, and 3.24, 4.63, 5.55 and 6.51 t in the second variant. The total plant residue mass was 4.19, 5.87, 7.09 and 8.28 t for the first variant, and 4.66, 6.54, 7.87 and 9.19 t for the second variant. Under the first, second and third fertilisation systems, the increase in plant residue mass in the second crop rotation variant was 40.3%, 68.9% and 97.2%, while the increase in arable land productivity (dry matter basis) was 68.4%, 118.9% and 167.0%, compared to unfertilised variants. Thus, the lag in residue mass increase relative to the productivity growth of the crop rotation intensified with higher fertiliser rates. With increasing fertiliser rates, the ratio of main to by-product yield of crops in the rotation increased. For example, in the second crop rotation variant, under zero, first, second and third fertilisation systems, this ratio was as follows: in soybean – 1.36, 1.42, 1.50 and 1.56; in winter wheat – 1.20, 1.21, 1.24 and 1.26; in sunflower – 1.54, 1.62, 1.68 and 1.73; in spring barley – 1.07, 1.09, 1.11 and 1.13; and in corn – 1.46, 1.50, 1.53 and 1.56. It is quite difficult to determine changes in soil organic matter stocks that are associated with management practices against the background of spatial and temporal variability. In most cases, verifying these changes requires soil sampling over an extended period of time. As an alternative, potential changes in soil organic matter stocks can be assessed using humus balance models, which help to identify the need for humus reproduction in the soil [12].

Table 3. Humus balance in the arable layer (0-30 cm) of soil (in the numerator - the first variant of crop rotation, in the denominator - the second), kg/ha

Crops	System fertilization	Loss of humus					Humus was formed				Humus balance
		Nitrogen removal by the harvest	Nitrogen removal depending on crop and soil composition	Nitrogen removal through humus mineralization	Total consumption of mineralized humus	Mass of mineralized humus	From plant residues	From by-products in the second variant of crop rotation	From the green mass of white mustard	Total	
Soybean	0	65.3/ 79.5	31.3/ 38.2	15.7/ 19.1	22.4/ 27.3	448/ 546	311/ 357	304		311/ 661	-137/ +115
	1	126.4/ 149.8	60.7/ 71.9	30.3/ 36.0	43.3/ 51.4	867/ 1,028	481/ 552	600		481/ 1,152	-386/ +124
	2	178.2/ 210.2	85.5/ 100.9	42.8/ 50.5	61.1/ 72.1	1,222/ 1,443	646/ 741	888		646/ 1,629	-576/ +186
	3	231.5/ 270.5	111.1/ 129.8	55.6/ 64.9	79.4/ 92.7	1,587/ 1,854	844/ 952	1,188		844/ 2,140	-743/ +286
Winter wheat	0	83.7/ 95.6	80.4/ 91.8	40.2/ 45.9	57.4/ 65.6	1,148/ 1,311	898/ 1,008			898/ 1,008	-250/ -303
	1	151.9/ 167.3	145.8/ 160.6	72.9/ 80.3	104.2/ 114.7	2,083/ 2,294	1,336 / 1,454			1,336/ 1,454	-747/ -840
	2	202.7/ 222.3	194.6/ 213.4	97.3/ 106.7	139.0/ 152.4	2,780/ 3,049	1,596 / 1,734			1,596/ 1,734	-1,184/ -1,315
	3	251.0/ 273.0	241.0/ 262.1	120.5/ 131.1	172.1/ 187.3	3,442/ 3,746	1,886 / 2,036			1,886/ 2,036	-1,556/ -1,710
Post-harvest white mustard for green manure	0	32.2/ 34.8	25.8/ 27.8	12.9/ 13.9	18.4/ 19.9	368/ 397	423/ 453		345/ 373	768/ 826	+400/ +429
	1	48.2/ 51.5	38.6/ 41.2	19.3/ 20.6	27.5/ 29.4	551/ 589	569/ 608		517/ 552	1,086/ 1,160	+535/ +571
	2	56.7/ 60.6	45.4/ 48.5	22.7/ 24.3	32.4/ 34.7	648/ 694	651/ 695		608/ 649	1,259/ 1,344	+611/ +650
	3	61.4/ 65.8	49.1/ 52.6	24.6/ 26.3	35.1/ 37.6	702/ 751	680/ 732		658/ 705	1,338/ 1,437	+636/ +686
Sunflower	0	61.8/ 71.1	89.0/ 102.4	44.5/ 51.2	63.6/ 73.1	1,271/ 1,462	325/ 374	372		325/ 746	-946/ -716
	1	109.2/ 123.9	157.2/ 178.4	78.6/ 89.2	112.3/ 127.4	2,246/ 2,548	486/ 552	678		1,566/ 2,310	-680/ 238
	2	157.8/ 177.3	227.2/ 255.3	113.6/ 127.7	162.3/ 182.4	3,246/ 3,648	647/ 728	1,002		2,267/ 3,350	-979/ -298
	3	195.0/ 219.9	280.8/ 316.7	140.4/ 158.4	200.6/ 226.3	4,011/ 4,526	788/ 889	1,276		2,948/ 4,325	-1,063/ -201
Spring barley	0	52.3/ 60.8	50.2/ 58.4	25.1/ 29.2	35.9/ 41.7	717/ 834	620/ 684			620/ 684	-97/ -150
	1	84.5/ 95.0	81.1/ 91.2	40.6/ 45.6	57.9/ 65.1	1,159/ 1,302	838/ 920			838/ 920	-321/ -382
	2	108.3/ 121.0	104.0/ 116.2	52.0/ 58.1	74.3/ 83.0	1,485/ 1,660	1,014 / 1,118			1,014/ 1,118	-471/ -542
	3	128.5/ 143.3	123.4/ 137.6	61.7/ 68.8	88.1/ 98.3	1,762/ 1,966	1,157 / 1,285			1,157/ 1,285	-605/ -681
Post-harvest white mustard for green manure	0	29.3/ 32.2	23.4/ 25.8	11.7/ 12.9	16.7/ 18.4	335/ 368	386/ 419		314/ 345	700/ 764	+365/ +396
	1	40.4/ 43.8	32.3/ 35.0	16.2/ 17.5	23.1/ 25.0	462/ 500	467/ 569		433/ 469	900/ 1,038	+438/ +538
	2	47.1/ 51.7	37.7/ 41.4	18.8/ 20.7	26.9/ 29.6	538/ 591	540/ 656		505/ 545	1,045/ 1,201	+507/ +610
	3	51.2/ 55.4	41.0/ 44.3	20.5/ 22.2	29.3/ 31.7	585/ 634	572/ 719		549/ 593	1,121/ 1,312	+536/ +678
Corn	0	146.5/ 163.9	211.0/ 236.0	105.5/ 118.0	150.7/ 168.6	3,014/ 3,371	920/ 1,024	1,408		920/ 2,432	-2,094/ -939
	1	243.8/ 268.6	351.1/ 386.8	175.5/ 193.4	250.8/ 276.3	5,015/ 5,525	1,174 / 1,406	2,370		2,254/ 4,856	-2,761/ -669
	2	303.6/ 330.8	437.2/ 476.4	218.6/ 238.2	312.3/ 340.3	6,245/ 6,805	1,418 / 1,634	2,978		3,038/ 6,232	-3,207/ -573
	3	366.9/ 399.2	528.3/ 574.8	264.2/ 287.4	377.4/ 410.6	7,548/ 8,211	1,656 / 1,950	3,662		3,816/ 7,772	-3,732/ -439

Source: Authors own results.

Humus balancing methods are simple tools for assessing the interaction between agricultural land use and soil organic matter. Approaches to humus balancing vary significantly in their specific objectives, scope, and methodological framework. The term "humus balance" encompasses both simple models for the quantitative assessment of changes in soil organic matter or soil organic carbon, and models aimed at optimising soil performance in the arable layer by calculating the need for organic fertilisers without a quantitative estimation of changes in organic matter or organic carbon [2].

When all by-products are removed from the fields, only white mustard demonstrates a positive humus balance; for all other crops in the rotation, the humus balance is negative across all experimental variants. After corn, annual humus losses on unfertilised plots amount to 2 t/ha, whereas under the variant with 40 t/ha of manure plus $N_{150}P_{120}K_{130}$, losses increase to 3.7 t/ha (Table 3).

Under the first, second and third fertilisation systems, the proportion of humus formed from plant residues was 85.5%, 63.2%, 59.9% and 57.8%, respectively; from manure – 0%, 25.5%, 29.8% and 33.0%; and from green manure biomass – 14.5%, 11.3%, 10.3% and 9.2%.

When by-products of soybean, sunflower and corn are used as organic fertiliser, the overall humus balance in the crop rotation remains negative, amounting to 234 kg/ha under the zero fertilisation system, 179 kg/ha under the first, 256 kg/ha under the second, and 277 kg/ha under the third system. Thus, humus losses when all by-products are removed from the fields are almost four times higher than when part of them is used as organic fertiliser.

When wheat and spring barley straw is used as fertiliser, an additional amount of humus would be added to the soil as follows: under the zero fertilisation system, 131 and 111 kg/ha; under the first system, 232 and 179 kg/ha; under the second, 315 and 232 kg/ha; and under the third, 393 and 282 kg/ha, respectively.

The use of by-products from cereal grain crops as organic fertiliser would enrich the soil with humus by 242, 411, 547 and 675 kg/ha, respectively. Under these conditions, the humus balance on unfertilised plots would be positive (+8 kg/ha), while on fertilised plots it would be profitable, amounting to 232 kg/ha under the first fertilisation system, 291 kg/ha under the second, and 398 kg/ha under the third.

Under the first, second and third fertilisation systems, the proportion of humus formed from crop residues in the rotation was 60.7%, 47.0%, 44.0% and 42.2%, respectively; from manure – 0%, 16.8%, 19.5% and 21.3%; from by-products – 29.3%, 28.3%, 29.3% and 30.2%; and from the green biomass of white mustard – 10.0%, 7.9%, 7.2% and 6.3%.

The data convincingly demonstrate that the dominant source of humus formation is crop residues, whose humification generated 1.66 times more humus than that derived from the by-products of the three crops in the rotation.

If by-products of all crops in the rotation without exception are used as organic fertiliser, the proportion of humus formed from their humification will increase to 44–46%, and on fertilised plots their effectiveness may even slightly exceed that of crop residues.

Under the condition of using cereal straw as organic fertiliser, the soil would receive an additional 242 kg/ha of humus on unfertilised plots, 411 kg/ha under the first fertilisation rate, 547 kg/ha under the second, and 657 kg/ha under the third fertilisation rate.

In ecological farming, it is necessary to maintain an optimal ratio of mineral to organic fertilisers.

This is determined by the index of agricultural ecologisation, which is calculated by dividing the mass (kg/ha) of applied mineral fertilisers (active substance) by the mass (t/ha) of organic fertilisers **[**30**].**

Up to 15 kg of active substance of mineral fertilisers should be applied per tonne of organic fertiliser **[**27**].**

Under the first, second and third fertilisation systems, the amount of organic fertiliser applied to the soil was 4.39, 14.33, 19.41 and 24.05 t/ha in the first crop rotation variant, and 6.87, 18.46, 24.83 and 30.78 t/ha in the second variant.

The agricultural ecologisation coefficient was 0, 13.7, 12.8 and 12.4 when all by-products of crops were removed from the fields, and 0, 10.7, 10.0 and 9.7 when they were used as organic fertiliser in three fields.

According to the ecologisation index and the rates of applied organic fertilisers, only the plots in the second crop rotation variant receiving the highest fertiliser rate correspond to an intensive level of agricultural ecologisation; the remaining fertilised plots in both variants fall within a transitional level.

CONCLUSIONS

With increasing fertiliser application rates, the dry matter yield of the main crop products in the rotation increases at a faster rate than the mass of plant residues. On average, 6.36 t/ha of dry plant residues are returned annually to the soil when all by-products of crops are removed from the fields, and 7.06 t/ha when only cereal straw is removed.

When all by-products are removed from the fields, the humus balance in the rotation is negative on unfertilised plots and plots fertilised with 8 t/ha manure + $N_{76}P_{64}K_{57}$, 12 t/ha manure + $N_{95}P_{82}K_{72}$ and 16 t/ha manure + $N_{112}P_{100}K_{86}$, amounting to –551, 785, 1,060 and 1,305 kg/ha, respectively. When all by-products of crops in the rotation are used as organic fertiliser, the soil humus balance is positive at 8, 232, 291 and 398 kg/ha, respectively.

According to the agricultural ecologisation index and rates of organic fertiliser application, the rotation variant where by-products are used as organic fertiliser in three fields and 16 t/ha manure + $N_{112}P_{100}K_{86}$ is applied per hectare corresponds to an intensive level of agricultural ecologisation.

The productivity of the rotation with complete removal of all by-products is 11–13% lower than that of the rotation where by-products are used as organic fertiliser in three fields.

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SOIL DYNAMICS AFFECTED BY EROSION AND SOIL EROSION CONTROL MEASURES IN THE SLĂNIC RIVER BASIN, BUZĂU COUNTY, ROMANIA

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Abstract

Land erosionisone of the mostsignificantprocesses of land degradationglobally, with major effects on soilfertility, ecosystemstability, andagriculturalproductivity. In theriverbasins of thehillyarea of Buzău County, watererosionoccurs in associationwitherosioninducedbyagriculturalpracticesand land remodelling (terracing), having a significant negative impact on thesoilprofile. The purpose of thisarticleistohighlightthetrends in theevolution of thesoilcover in the Slănic River basin, affectedbywatererosionandsoilloss, as well as recommendations for thesustainableuse of sloping land.Long-termresearchcarried out at the Aldeni–Buzău SoilErosion Control Stationshowsthatagriculturalsoils are subjecttoprocesses of washingand transport of fine material fromthesoilsurface, whichcauseschanges in texture, humus content, andothernutrientsessential for plantgrowth. The soil mapping in the Buzau area was initially carried out in 2000 and then resumed in 2023. The data obtained from the pedological mapping were necessary to highlight the anthropogenic factors correlated with the climatic ones, which act in this area, respectively the efficiency of surface erosion control measures. Based on the results, an increase in humus content by 0.3% was observed in the Ap horizon of the pellic phaeosium soil, by 0.38% in typical chernozem, and by 0.73% in eroded cambic chernozem.

Key words**:** *degraded soils, water erosion, humus, erosion control, Slănic River basin*

INTRODUCTION

Human activity has a significant impact on natural erosion processes, leading to an observable increase in soil erosion rates in various landscapes [17]. Thus, each year, over 10 million hectares of agricultural land are lost due to soil degradation and erosion, significantly affecting the availability of land for food production [16].

Soil erosion is a problem and a serious threat to soil functions, such as nutrient levels, pH, water retention capacity, texture, infiltration rates, and soil organic matter, which leads to decreased land productivity and other multiple off-site effects [6].

Of the approximately 110 million hectares of arable land in the European Union, 43 million hectares are vulnerable to a single erosion factor, 15.6 million hectares to two factors, and 0.81 million hectares to three or more factors. Approximately 3.2 million hectares of arable land are vulnerable to the possible interaction of increased flooding, drought, water, and wind erosion [3].

The estimated cost of soil erosion between 1933 and 2010 was estimated at $45.5 billion per year for the European Union, $44 billion per year for the United States, with the highest figure in Brazil, where estimates for the state of Paraná (Southern Brazil) indicate a value of $242 million per year, These figures show that conservation measures must be implemented if agricultural and livestock production is to be sustainable [22].

The costs of restoring soil losses for humus removed from the soil through erosion are quite high considering that to add 1 ton of humus to the soil, it isnecessary to apply approximately 12.5 tons of manure (1 ton / 0.08 = 12.5 tons) [21].

The scientific community has responded to these erosion challenges with model-based

assessments. One model would be to reduce soil erosion by modeling the P factor, which in the European Union reaches a value of 0.97, on arable land it is 0.95. To solve this problem of soil erosion, it is proposed to cultivate protective plants in strips at the border of the plots. These agricultural practices proposed within the P factor, reduce soil erosion by 3%, with grass-covered edges having the greatest impact, reducing the risk of erosion by 57% [14].

So, water erosion reduces the global annual production of corn and wheat by 8.9 million tons and 5.6 million tons, respectively. Countries with heavy rainfall, hilly agricultural regions, and low fertilizer use are most vulnerable to water erosion, such as areas in South and Southeast Asia, sub-Saharan Africa, and South and Central America. The main factors determining the degree of water erosion are rainfall intensity, slope steepness, soil structure, and vegetation cover. Apart from rainfall, the primary factors influencing water erosion can be directly modified through field management, such as crop selection, reduced tillage intensity, crop residue cover, and terracing [5].

There are numerousplantspeciesthatmodifysoilerosion, withresearchhighlightingtheimportance of establishing crop types, such as grasslands or wheatcrops, that are goodprotectorsagainst soilerosion [7].

United Nations Organization experts warn that 90% of the Earth's surface could be at risk of erosion by 2050.

The extent and types of erosion in Romania have increased, and it is the European country with the most varied forms of water erosion due to its natural conditions. The critical erosion season is between May and August, due to heavy rainfall during the growing season. Human activity has played an important role in inducing and intensifying erosion processes, particularly through land use, crop structure, and pasture and forest management. Thus, Romania has land with a slope of more than 5%, susceptible to erosion, accounting for 26% of arable land and 75% of pastures [2].

In Romania, soil erosion rates can increase by up to 10-20 t/ha/year. Research conducted by Patriche, shows an upward trend in erosion due to precipitation for the period 2041-2060, especially in the western, southwestern, and eastern parts of the country, which is likely to increase soil erosion by an average of 1-2 t/ha/year. However, according to some forecast models, rainfall erosion is expected to decrease between 2061 and 2080 due to lower rainfall as a result of global warming. At the European level, a similar positive trend in erosion due to precipitation has been found for most of the continent, based on the HadGEM2 climate model [15].

On eroded sloping land, the cropping systems applied must keep soil losses through erosion below the permissible limit of 3 t/ha/year and provide economically efficient yields. Thus, annual soil losses through erosion between 1980 and 2006 ranged from 0.29 t/ha for perennial grasses in the second growing season to 9.97 t/ha for sunflowers. Over the last 42 years, erosion has been within the "acceptable limits" of 3 t/ha/year for perennial grasses, wheat, and peas [4].

Investigations carried out on eroded soil with a slope of 14%, on a Cambic Chernozem with a clay-loam texture, attempted to establish crop rotations and fertilization systems that could contribute to maintaining and restoring soil fertility. Thus, the cultivation of winter wheat and corn in the pea -wheat-corn-sunflower + reserve field cultivated with perennial grasses and legumes resulted in production increases of 26% (736 kg/ha) and 31% (1,364 kg/ha), respectively, compared to continuous cultivation [1].

In the European Union, water erosion of arable land is the major threat of this type of soil degradation, which brings significant damage to the environment, leading to the elimination of carbon stored in the soil, a decrease in production, erosion manifesting itself with average soil loss rates. This average soil loss rate reaches 2.46 t/ha per year, with arable land being affected in a proportion of 12.7%. In Europe, GAEC policies through the “Thematic Strategy for Soil”, have reduced the soil loss rate by an average of 9.5% and by 20% on

arable land [13]. Soil degradation by erosion in Europe, is the most widespread degradation process, affecting 23% of soils, which makes it the continent most affected by this process, according to data communicated by FAO-GLASOD [9].

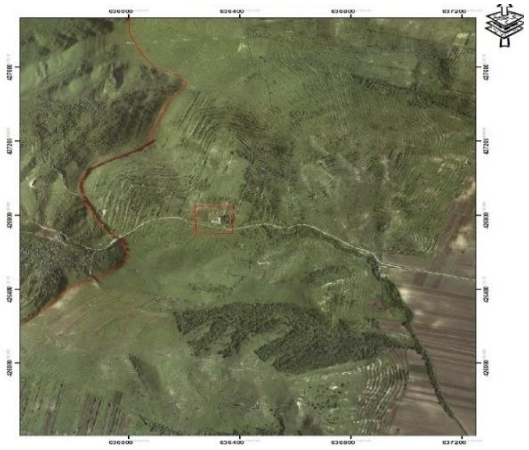
MATERIALS AND METHODS

The research is conducted in the Buzău River Basin, a river basin covering an area of 5505 km^2 and with a main course length of 302 km, the Buzau River. The main tributaries of the Buzau River, along with Slănic, are Bâsca Mare, Bâsca Chiojdului, Nişcov, Câlnău, ValeaBoului, Buzoel, and Ciulniţa.

Buzău County has a diversity of soil types, influenced by varied physical and geographical conditions and human activity. This diversity, correlated with the topography of the area, with slopes between 5 and 30%, and anthropogenic influence, affects the natural genetic evolution of the soils, which become susceptible to degradation, requiring soil cultivation techniques and measures to limit degradation adapted to each type of soil. The areahas specific local climatic characteristics, beingcharacterizedby a thermalregimewithaverageannualtemperatur esbetween 8.3-11°C. Averageannualprecipitationrangesbetween 550-650 mm, highlighted in the SubCarpathianhills. The total amount of rainfall over a 6-month period analyzed in 2023 at thestationwas 332.6 mm, sosoillosses are directlyinfluencedbythe structural characteristics of precipitation [19].

The research was carried out at the Soil Erosion Control Station located in the Valea cu Drum River basin (Map 1), where long-term research is conducted to monitor soil erosion processes and study the impact of natural and anthropogenic factors on soil degradation in the hilly area of Buzău County.

The identification of river valleys and terraces was carried out based on field research, bibliographic sources, and topographic maps. The pedological studies in the river basin aim to highlight the influence of geomorphological and climatic conditions on the dynamics of eroded soils. The research focused on the Slănic River basin, where soil profiles representative of slopes at risk of surface erosion were analyzed.



Map. 1. Location of the Erosion Control Station, Aldeni, Buzău, 45°19′8″N 26°45′24″E
Source: https://www.google.com/maps [23].

As part of these studies, soil mapping was carried out and soil samples were taken at different stages of the degradation process, and some physical (texture) and chemical (humus content) properties of the soils in the affected areas were determined.

For this study, we identified five soil profiles located in the Slănic hydrographic basin, with various anti-erosion measures, which have undergone different changes under climatic and anthropogenic influences. The physical and chemical properties of these profiles were analyzed, highlighting the changes caused by erosion but also the beneficial effects of erosion control measures, such as terracing, grassed platforms, and the construction of technological alleys.

The methods used to determine humus and soil texture were applied in accordance with the Methodology for the development of soil studies, ICPA, 1987 as follows [11]:

a. Determination of humus/organic carbon content (Walkley–Black method) consists of chemically oxidizing organic carbon in soil with a potassium dichromate ($K_2Cr_2O_7$) solution in an acidic environment (sulfuric acid, H_2SO_4). The excess of unconsumed dichromate is titrated with ammonium ferrous sulfate solution ($Fe(NH_4)_2(SO_4)_2$). The amount

of dichromate consumed is proportional to the organic carbon content.
The organic carbon content is determined from the difference between the total amount of dichromate added and the amount remaining (unconsumed), which indicates the amount of organic carbon that has been oxidized. To obtain the humus content, it is assumed that humus contains an average of 58% carbon, from which the humus is calculated according to the formula:

% Humus = % C.org. × 1.724……..…(1)
where:
- C.org. - organic carbon
- 1.724 -"Van Bemmelen factor," where soil organic with 58% carbon (100/58 = 1.724)[20].

b. The soil texture was determined by separating the mineral fractions according to size, using the sieving and pipetting method, and determining the percentage of sand, silt, and clay by size.

RESULTS AND DISCUSSIONS

Soil erosion is one of the most destructive soil degradation processes. Globally, strong and very strong erosion processes affect 300 million hectares, with 33% of soils affected by erosion worldwide, with an additional 900 million hectares moderately affected [9].
This soil degradation through erosion is favored by the position of the soils in the landscape, with surface and wind runoff being closely linked, causing the thinning or thickening of soil layers in different positions in the landscape, which will also influence crop yields [18].
The extent of climate change and extreme weather events in Romania have led to accelerating the deterioration processes that have led to the removal of the fertile layer from the surface.
In this context, we analyzed the state of degraded soils in the Slănic River basin.
The first pedological map with soil mapping was carried out in 2000 and resumed in 2024.
The soils in the studied area are classified into two classes, namely the Cernisols Class and the second being the Antrisouri Class, (according to the Romanian Soil Taxonomy System, SRTS, 2003) [12].
As the soil cover in the area is very varied, we have characterized the following three soil types from the Cernisols class [10]:
- Phaeosium, pellic, calcareous (FZ-pe-ka) - 68.95 ha,
- Typical chernozem (CZ-ti) - 26.14 ha,
- Cambic chernozem (CZ-cb) – 164.7 ha, and from the Antrisols class, we analyzed the cambic Erodosol (ER-cb), spread over an area of 141.4 ha, strongly eroded, which derives from the cambic chernozem, strongly transformed due to surface runoff, which caused a large volume of soil to be stripped from the top layer.

Pellicphaeosium (FZ-pe-ka)

The land on which these soils are found has been treated with anti-erosion measures using bench-type **agro-terraces**, and **technological alleys** have been created, which have been left grassed (pasture and hayfield), with a slope of 15-20% in this area.
Soil analyses have shown that the agro-terracing process has contributed to the conservation of physical properties, increased humus content, and improved production capacity by increasing soil fertility.
Initially, the soil had an Ap-Am-Bt_1-Bt_2-Ck profile and was slightly eroded. The agricultural work carried out on the contour line results in a downstream displacement and mixing of the soft upper horizon (Am), which gives rise to an Ap horizon on the surface. Thus, after a long period of agricultural exploitation under a managed regime, the soil profile analyzed is of the type: Ap-Am-Bt_1-Bt_2-Ck.According to the granulometric analysis, no significant changes in soil texture are noted, but the clay content decreases by 5.3% in the bioaccumulation horizon of the profile in 2023 compared to that in 2000, from 38.8% to 36.6%, without changing the clayey loam texture class (Figure 1).

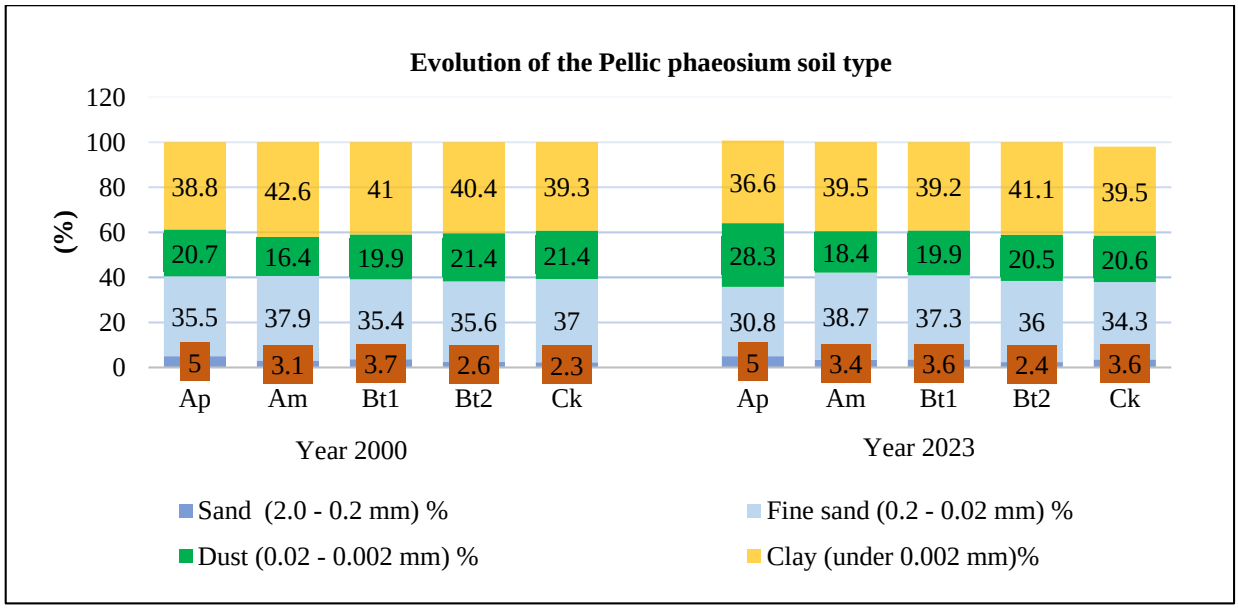


Fig. 1. Granulometric composition of pellicphaeosium, agroterracing, %
Source: Own determination.

The humus content (Figure 2) is low in the bioaccumulation horizon of the profile analyzed in 2000 (3.4%) and changes to medium values after landscaping (3.7%) due to the natural grassing of the terraces.

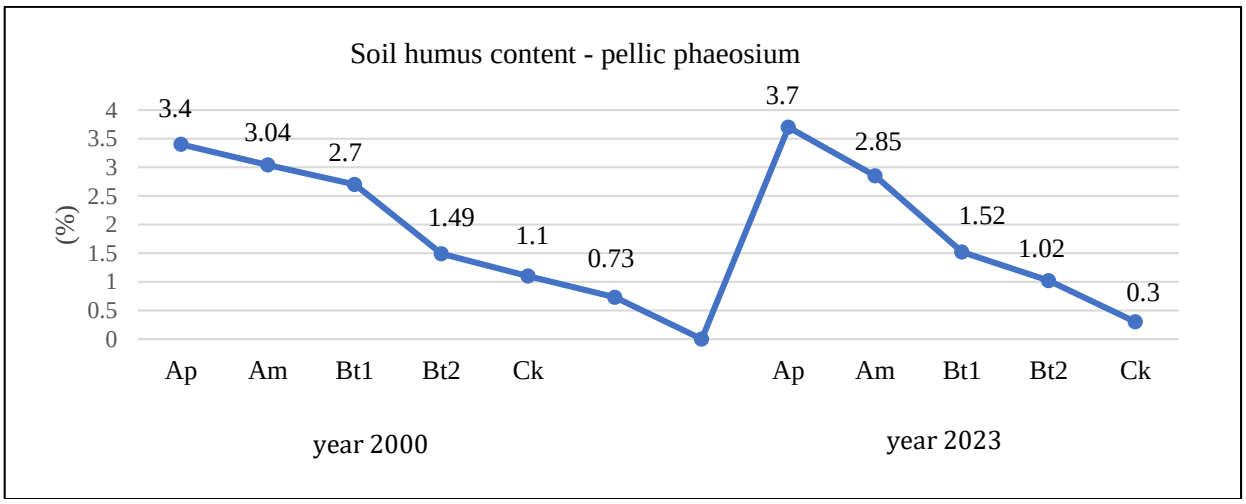


Fig. 2. Evolution of humus content – anti-erosion pellicphaeosium, %
Source: Own determination.

The conclusion is that the agro-terracing of the slope led to the conservation of the soil profile and the maintenance of relatively constant main soil fertility properties.

Typical chernozem (Am-ACk-Ck)

Here, technological alleys have been arranged, which are traffic alleys with a platform length of 3.0 m, an embankment slope height of 0.58 m, and a cut slope height of 0.58 m. and the excavation volume is equal to the filling volume of 0.4 m^3/ml, and the distance between the traffic lanes is 6 m. This development work has the advantage of modifying the water regime of the slope and reducing surface runoff, with minimal intervention on the soil profile.

The granulometric analysis of the profiles analyzed in 2000 and 2023 (Figure 3) shows that the texture is medium clay uniform across the profile and there is a 0.4% decrease in the clay fraction in the bioaccumulation horizon in the 2000 profile compared to that of 2023.

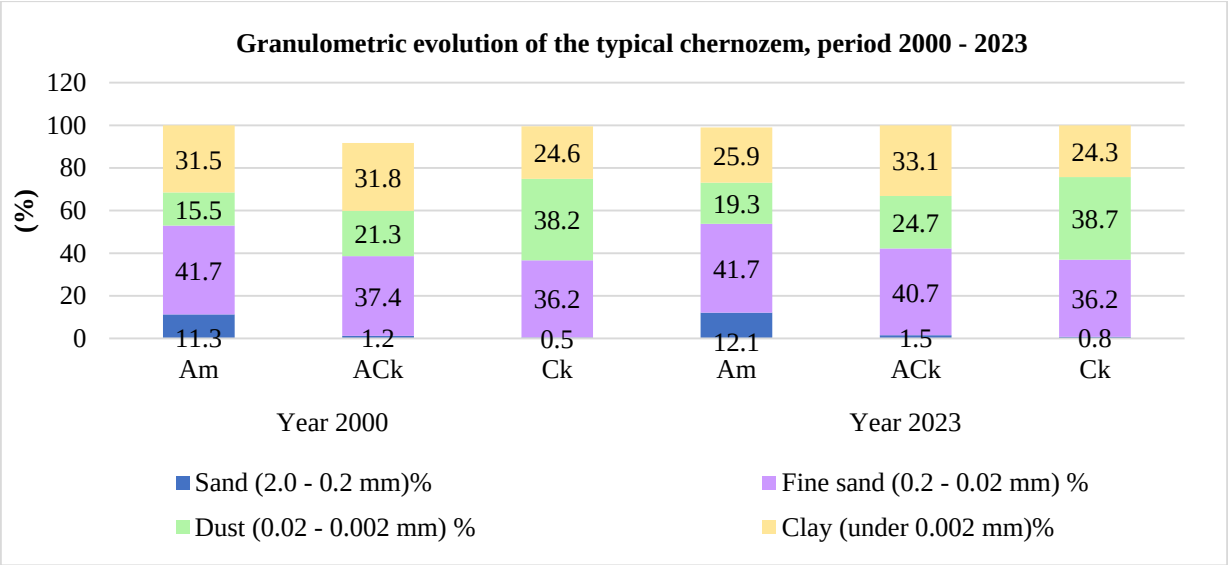


Fig. 3. Granulometric composition of typical chernozem, arranged for erosion control with technological alleys, %
Source: Own determination.

The interval between the traffic alleys was grassed and is currently used as hayfield. Following the improvement works on the typical chernozem, there was an increase in humus content of 0.38% in the bioaccumulation horizon (Am), rising from 3.79% in 2000 to 4.17% in 2023 (Figure 4).

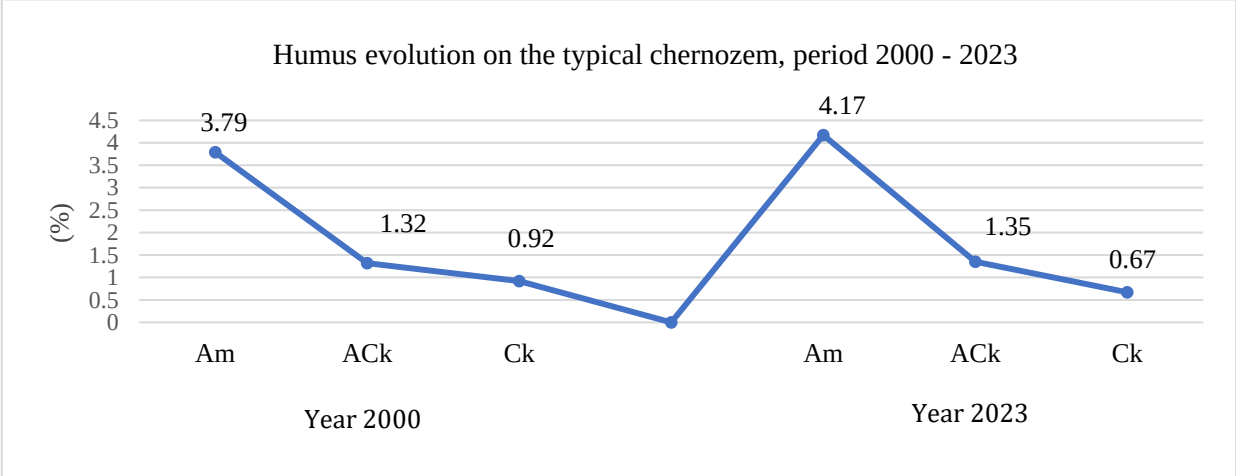


Fig. 4. Humus content in typical chernozem, arranged for anti-erosion with grassed technological alleys, %, 2000 and 2023 year
Source: Own determination.

Cambic chernozem (CZ-cb)is found on lands occupying slopes with a slope between 10% and 25%, being poorly eroded. In areas with a slope greater than 15%, terraces were constructed with the aim of reducing erosion below the maximum permitted limit, which did not require a large volume of embankments. The terraces have a platform length of 6 m, a platform slope of 5%, a slope height relative to the land elevation of 0.5 m and a reduced embankment volume of 0.5 m^3/ml. By choosing the terracing variant, the aim was to preserve the initial profile of the cambic chernozem and reduce its degradation through erosion. Following terracing, a change in the texture class was observed in the two profiles. In the case of the cambic chernozem, the clay percentage decreased by 2.7% in the surface horizon (Akp), the

erodosol appeared due to erosion at which the surface horizon Ao(Bv) is present (Figure 5).

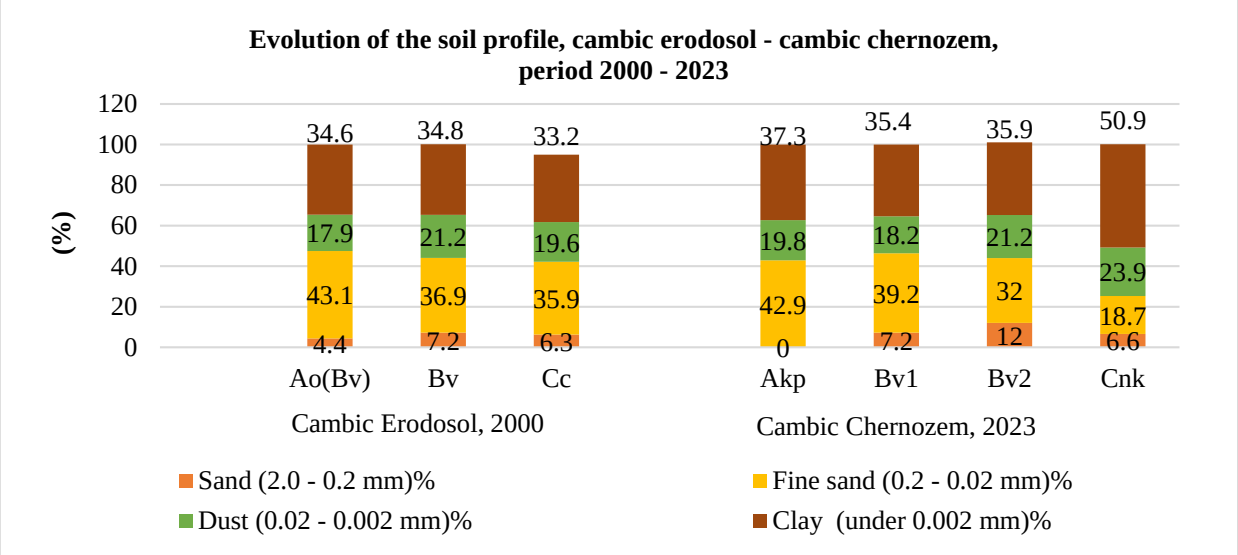


Fig. 5. Granulometric composition of cambic erodosoland cambic chernozem, terraced, %
Source: Own determination.

The bioaccumulation horizon Ao was separated from the cambic horizon Bv, with a granulometric composition corresponding to the Bv_1 horizon of the initial profile. In both profiles, the texture is medium clay loam.
Maintaining the land as grassland and hayfields led to the accumulation of a humus content of 2.04% in the upper horizon of the erodosol.
However, compared to the un-eroded cambic chernozem, this humus content is 0.97% lower than the cambic horizon from which it was formed (Figure 6). In the underlying horizon of the cambic erodosol, the humus content decreases to 0.91%, which is 0.9% lower than in the cambic chernozem profile.

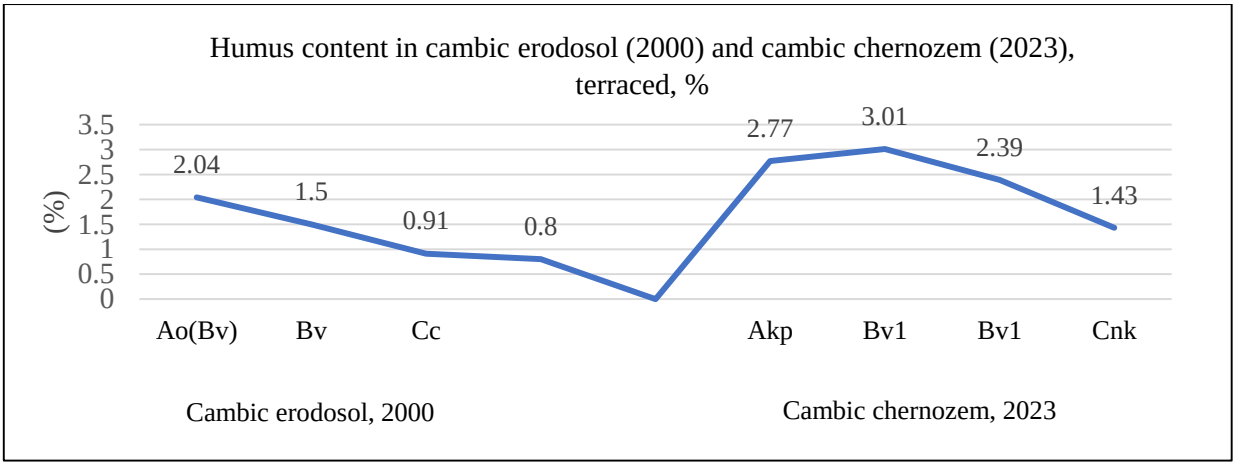


Fig. 6. Humus content in erodosol and chernozem, terraced, %
Source: Own determination.

The complex development of the hydrographic basins in the Buzău hilly area, with a view to reducing erosion degradation of agricultural land, will have to be rethought and oriented towards hydro-ameliorative works that ensure long-term soil protection after development and allow for sustainable agricultural use of the land.

Soil erosion in the Slănic River Basin is influenced by natural factors, such as heavy rainfall and steep slopes, and anthropogenic factors, such as inappropriate agricultural practices and lack of protective vegetation. These factors cause the loss of the fertile layer, a decrease in organic matter, and a reduction in the structural stability of the soil, which intensifies erosion processes and leads to land degradation. Thus, we observe that different erosion control measures are applied to each type of soil depending on the land use (Table 1).

Table 1. Soil erosion control measures applied in the Slanic River Basin

Soil profile code	Altitude	Slope	Land use	Erosion control measures
FZ-pe-ka	600 – 800 m	15 - 20 %	pasture and hayfield	bench-type agroterraces
CZ-ti	600 – 800 m	10 – 20 %	hayfield	technological alleys
CZ-cb	600 – 800 m	10 - 25 %	hayfield	bench-type agroterraces

Source: Own determination.

Economic impact on agriculture in thehillyarea of Romania

In addition to the ecological consequences, soil erosion causes considerable economic losses by reducing agricultural yields, increasing expenses for restoring soil fertility and decreasing farmers' incomes.

- The percentage of agricultural land affected by erosion is very high (over 40% of the agricultural area), affecting the productivity of land in hillyregions, including the Buzău Subcarpathia.
- Romania loses between 100 and 150 million tons of fertile soil annually due to erosion of sloping land in hilly areas, which represents an irreversible loss of natural resources for agriculture and reduces the productive potential of agricultural land [8].
- In hillyareas, the loss of fertile soil leads to decreased productivity, increased production costs (fertilizers, anti-erosion works) and loss of income for farmers, which affects agricultural competitiveness and the socio-economic sustainability of rural communities.

Agro-ecological management, oriented towards ecology, has an impact on the maintenance and significant increase of soil fertility, on the rational management of natural resources, as well as on the optimization of agro-landscapes and productions obtained in areas affected by erosion.

As a result of the anti-erosion measures initiated in the Slanic river basin area, high agricultural yields are obtained, even under moderate input conditions, when they are managed jointly (Table 2).

Table 2. The effect of soil erosion control by maintaining grassy soil at a depth of 0–10 cm on eroded cambic chernozem, during the period 2000 – 2023in the Slanic River Basin

Soil type	Erosion degree	Land use	Anti-erosion measures	The biomass of plant residues, t/ha	Fodder production, Kg/ha
Cambic erodosol	Heavily eroded	hayfield	Without green manure	0.61	1,580
Cambic chernozem	After anti-erosion design (slightly eroded)	hayfield	Green manure	0.95	3,800

Source: Own determination.

The data presented above highlight the positive influence of anti-erosion management by grassing the land and accumulating plant mass in the superficial layer (0–10 cm) of the eroded cambic chernozem. The roots ystem of plants plays an important role in fixing soil aggregates and reducing the erosion rate of the superficial layer under the action of water flow. A large impact on reducing soil erosion on slopes is generated by the biomass left on the eroded soil.

The results show that such anti-erosion practices increase the resistance to washing and the production of fodder increases from

1,580 kg/ha on the eroded soil to 3,800 kg on the anti-erosion managed soil, by protecting the soil with fodder crops.
The economic effect is obvious, demonstrating the efficiency of these practices in restoring the fertility of eroded soils.

CONCLUSIONS

Measures to combat soil erosion in the Slanic River Basin, on land with slopes greater than 10%, through the execution of agro-terracing works on slopes, the creation of technological alleys and grassing, lead to the conservation of the soil profile and the improvement of soil fertility characteristics.
In the case of pellicphaeosium, arranged by terracing and grassed technological alleys, the granulometric analysis does not reveal any significant changes in soil texture, but there is a 5.3% decrease in clay content in the bioaccumulation horizon in 2023 compared to 2000. The humus content increases to average values from 3.4% in 2000 to 3.7%, due to the natural grassing of the terraces.
In typical chernozem, arranged with technological alleys, there is a 0.4% decrease in the clay fraction in the bioaccumulation horizon in the 2000 profile compared to that in 2004. On cambic chernozem, located on slopes with a gradient between 10% and 25%, slightly eroded, terraces were built, and here a change in texture class can be observed, with clay decreasing by 2.7% in the surface horizon from cambic chernozem to cambic erodosol. Maintaining the land as grassland and hayfields has led to the accumulation of 2.04% humus in the upper horizon of the erodosol, although the humus content is low throughout the soil profile of the cambic erodosol. The hilly area of Slanic still requires measures to combat soil erosion in order to protect and conserve the arable layer and ensure satisfactory yields.
The results of this study can be applied in planning sustainable land use and adopting local policies for soil conservation and efficient surface water management in the hilly area of Buzău.

ACKNOWLEDGEMENTS

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SUPPORTING LOW-CARBON AGRICULTURE IN ROMANIA

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Abstract

The paper is an analysis of the implementation of compensatory interventions in low-carbon agriculture in Romania, at the level of the year 2024 and is based on the data from AFIR and Excel facilities for processing. Out of the 13 identified measures and interventions, through which farmers have received compensatory payments, 10 are continued measures from NRDP 2014-2020 and 3 are interventions implemented from the current NSP 2023-2027, all these being directly or indirectly related to low-carbon agriculture. Only the 3 interventions financed from the NSP 2023-2027 were subjected to analysis, and it resulted that the largest number of beneficiaries were from areas affected by significant constraints, and the largest amounts were received by the beneficiaries of projects dedicated to animal welfare.

Key words**:** *low-carbon agriculture, agricultural policies, support to agriculture*

INTRODUCTION

In the current context of environmental concerns, related to climate change and green transition, the role of agriculture, of low-carbon agriculture in particular, is of particular importance. Low-carbon agriculture, with its regenerative and conservationist practices, starting with crop rotation and diversification, use of compost and manure instead of chemical fertilisers, the so-called agroforestry with the integration of trees in crop farming systems, digitalisation and precision farming, aims to reduce greenhouse gas emissions, to increase carbon sequestration in soil and vegetation and maintain the productivity and adaptability of agricultural and food systems.

It is unanimously accepted by scientists that "existing farming practices have led to a decrease of organic matter in soil" [11].

Low-carbon agriculture, through its practices, aims "to capitalise on the capacity of plants to absorb carbon dioxide through photosynthesis" thus contributing to carbon sequestration in soil [10]. The low-carbon agricultural practices "encompass various agricultural techniques meant to improve the storing of carbon in soil and vegetation, thus mitigating greenhouse gas emissions" [9]. Low-carbon agriculture has emerged as "an essential strategy in the pursuit of European climate neutrality" [4].

The European Union specifically refers to low-carbon agriculture as "an ecological business model" aimed to encourage farmers to improve land management practices, which leads to increased carbon sequestration in living biomass and soil [5].

The EU's Common Agricultural Policy (CAP) is the framework guiding the agricultural practices, with a focus on integrating the carbon farming methods in European agriculture. This is achieved through different mechanisms, namely eco-schemes, agro-environmental initiatives, climate-related measures, cross-compliance requirements and on farm investments [3].

Romania's agricultural policies are influenced by the EU's Common Agricultural Policy, which provides funding, targets competitiveness, food security and support for rural areas. Romania implements the EU directives, adapting them to the national context, with a focus on green transition, digitalisation and support to small farmers.

The paper analyses how national agricultural policies, more exactly Romania's National Strategic Plan 2023-2024, contributes to supporting green agriculture in Romania. The

main objective of this study is to analyse the support to low-carbon agriculture in Romania.

MATERIALS AND METHODS

To attain the purpose of this research, an analysis of the implementation of compensatory interventions related to green/low-carbon agriculture was carried out at the level of the year 2024, using official AFIR data. In the database (with over 65,500 records), 13 measures and interventions were identified through which farmers received compensatory payments, out of which 10 are continued measures from NRDP 2014-2020 and 3 are interventions implemented from the current NSP 2023-2027. Only the 3 funding interventions from the current programming period were subjected to analysis, namely DR06 – Animal welfare, DR10 – Areas affected by significant natural constraints and DR30 – Support for setting up young farmers, as they have a direct influence on low-carbon agriculture.

Through Excel-based specific processing methods, both the number of beneficiaries and the amounts received in the year 2024 for the three interventions in the NSP 2023-2027 were ranked at county level, after which the maps are made.

RESULTS AND DISCUSSIONS

The green agriculture concept, which also includes low-carbon agriculture, represents an essential strategic direction in the current green transition context at EU level. Through the European Green Deal and the Farm to Fork Strategy, EU member states are encouraged to reduce carbon emissions, improve soil quality and support circular economy in agriculture.

In Romania, green agricultural policies are reflected in the main two instruments, namely NRDP 2014–2020 and NSP 2023–2027, which bring together environmental, climate and technological innovation interventions. NRDP 2014-2020 was the main funding instrument for the sustainable development of rural areas [6], while NSP 2023–2027 has integrated these measures into a unitary framework, through eco-schemes, direct payments and investment interventions focused on innovation and digitalisation [7].

The National Strategic Plan (NSP) 2023-2027 is Romania's agricultural strategy, financed through the European Agricultural Guarantee Fund and the European Agricultural Fund for Rural Development. This strategy mainly aims to strengthen the competitiveness of the agri-food sector, to improve the management of natural resources and adapt to climate change, with a particular focus on supporting farmers and rural development. The NSP 2023-2027 has two pillars: Pillar I (funded through EAGF) – Direct payments and sectoral interventions to support the market and Pillar II (funded through EAFRD) – Rural development, including support for investments, innovation, environment and climate. The NSP 2023-2027 provides for 89 funding lines, of which 51 are types of direct payments and interventions, funded through EAGF, and 38 are rural development interventions, funded through EAFRD. The rural development interventions include 11 types of environmental and climate interventions (Fig. 1).

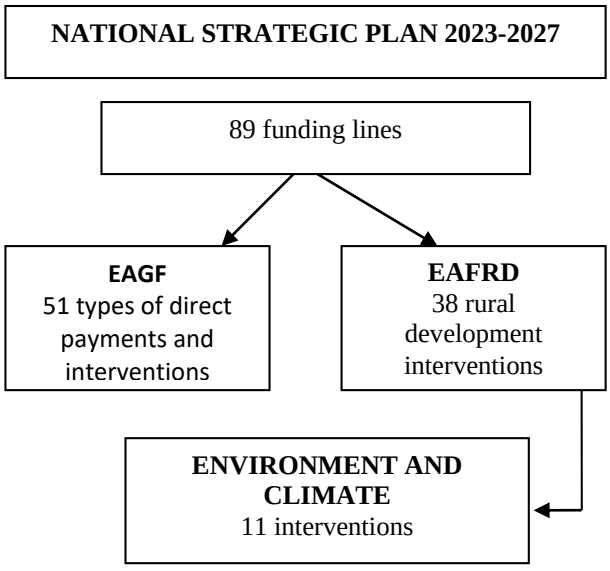


Fig. 1. National Strategic Plan 2023-2027 – funding lines
Source: adaptation after [1].

The 11 types of interventions for environment and climate worth 2.37 billion euros for the ongoing programming period are the following: DR 01 Agro-environment and

climate on permanent grassland, DR 02 Agro-environment and climate on arable land, DR 03 Agro-environment and climate – Raising livestock from local breeds in danger of abandonment, DR 04 Organic farming – conversion, DR 05 Organic farming – maintaining certification, DR 06 Animal welfare, DR 07 Silvo-environment and climate, DR 08 Afforestation – maintenance and care of afforested areas, DR 09 Areas under natural constraints – mountain areas, DR 10 Areas affected by significant natural constraints, DR 11 Areas affected by specific natural constraints.

In the year 2023, the implementation of the NSP 2023-2027 began, which was approved by the European Commission Implementing Decision no. 8783 of December 2022. The implementation of environment and climate interventions from the current programming period has been gradually introduced, the first two being DR 06 and DR 10, starting in 2023 [8], and continuing with the remaining nine interventions starting in 2024. In parallel, the implementation of the environmental and climate measures from the previous programming period continues, until the completion of ongoing commitments.

Analysis of financial interventions funded through AFIR in the year 2024

According to AFIR official data, in the year 2024 there were 65,526 beneficiaries of EAFRD payments who accessed 13 measures and interventions.

Table 1. Beneficiaries of EAFRD payments in the year 2024

Measure	Number of beneficiaries	% of total
DR06 Animal welfare	1,105	1.7
DR10 Areas affected by significant natural constraints	57,817	88.2
DR30 Support for setting up young farmers	50	0.1
M04+M05+M06+M07+M08+M09+M16+M17+M19+M20	6,554	10
Total	**65,526**	**100**

Source: author's own processing based on [2] database.

The 10 measures for which funding from NRDP 2014-2020 continues in the current period are M04, M05, M06, M07, M08, M09, M16, M17 and M20; the 3 interventions from the NSP 2023-2027 are DR 06 and DR 10 initiated in 2023, and DR 30 that has been implemented since 2024 (Table 1).

In the year 2024, most projects received funding within intervention DR10 – Areas affected by significant natural constraints, accounting for over 88% of the total number of projects. It is worth noting that 10% of the total number of projects funded in 2024 was under measures still ongoing from the previous programming period. The total value of funding received by beneficiaries in 2024 was over 276 million euros. Analysing the 3 interventions in the NSP 2023-2027, it can be noticed that the largest amounts were received by the beneficiaries who submitted projects under intervention DR 06 – Animal welfare, worth over 99 million euros in total and represented 36.2% of total amounts received by beneficiaries in the year 2024. A significant percentage is also represented by the amounts received by the beneficiaries who have submitted projects under the NRDP 2014-2020 measures, which are still being paid.

Table 2. Amounts received by EAFRD beneficiaries in the year 2024

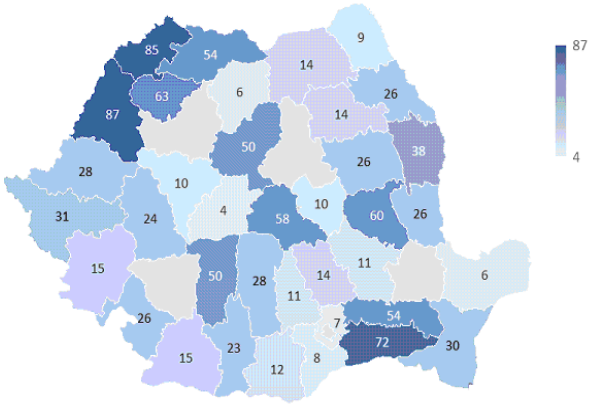
Measure	EAFRD amount euros	% of total
DR-06 Animal welfare	99,958,218.9	36.2
DR-10 Areas affected by significant natural constraints	13,147,858.1	4.8
DR-30 Support for setting up young farmers	2,624,512.6	0.9
M04+M05+M06+M07+M08+M09+M16+M17+M19+M20	160,703,237.5	58.1
Total	**276,433,827.1**	100.0

Source: author's own processing based on [2] database.

In 2024, out of the total number of environmental and climate compensatory support interventions from NSP 2023-2027, two interventions were accessed, namely DR 06 – Animal welfare and DR 10 – Areas with natural constraints or other specific constraints, both of which directly contribute to maintaining a low level of greenhouse gas emissions from agriculture and forestry, to

strengthening the degree of carbon sequestration on agricultural and forest lands and to adapting to the effects of climate change (Table 2). Intervention DR 30 – Support for setting up young farmers is not included in the specific environmental and climate support interventions, but the support provided under this intervention contributes to promoting an environmentally friendly agriculture and mainly to promoting organic farming and environment protection, as young farmers are much more involved and have better in-depth knowledge in green agriculture and environment protection.

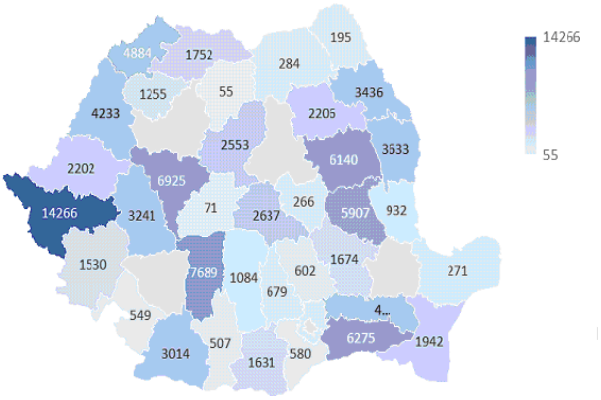
As regards the intervention DR 06 – Animal welfare, in four counties, namely Brăila, Cluj, Gorj and Harghita, plus Bucharest Municipality, there were no beneficiaries in the year 2024. Most beneficiaries of funds allocated under this intervention were noticed in Bihor (87), Satu Mare (85) and Călărași (72) counties, while the least numerous were in Bistrița-Năsăud (6), Tulcea (6) and Sibiu (4) counties (Map 1).



Map 1. Number of beneficiaries of DR 06 – Animal welfare, in the year 2024 (Number)
Source: author's own processing based on [2] database.

The ranking is different if we take into consideration the value of projects financed with the support of the DR 06 intervention. The largest amount was received by the beneficiaries from Timiș county (14.3 million euros), followed at a considerable distance by the beneficiaries from Vâlcea (7.8 million euros), Alba (6.9 million euros) and Călărași (6.2 million euros) counties (Map 2).

The explanation is that in all four counties there are large-sized livestock farming operators. For instance, in Timiș county, the largest amount, of about 11.7 million euros, was received by SC SMITHFIELD ROMANIA SRL, a company part of the American concern that acquired the COMTIM pig complex in 2004.



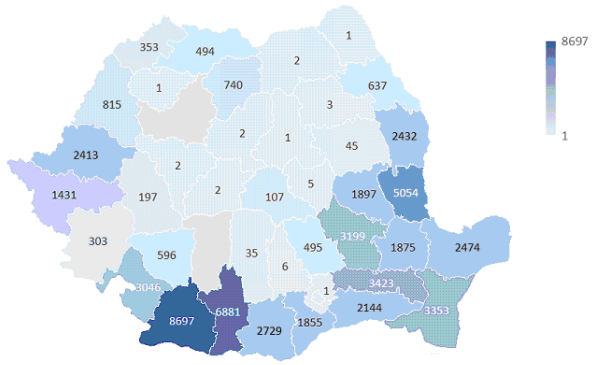
Map 2. Amounts received by the beneficiaries of DR 06 – Animal welfare, in the year 2024 (Thousand Euros)
Source: author's own processing based on [2] database

In Vâlcea county, the largest amount, approximately 3.4 million euros, was received by the company SC AVIROM POULTRY, established in 2021 and specialised in poultry farming. In Alba county, the largest amount, of approximately 6.8 million euros, was received by SC TRANSAVIA SA, a company with 100% Romanian capital, established in 1991, specialised in raising chickens and poultry meat processing. In Călărași county, there are several companies specialised in pig farming (CARMISTIN, NUTRICOM), cattle farming (SC ILYA AGRO) and poultry farming (AVICOLA CIOCANEȘTI, AVICOLA DRAGOȘ VODĂ, PUIUL REGAL, ALDIS), as well as large-sized private farms that benefited from significant funding in the year 2024. The smallest funding was received by beneficiaries from Sibiu (71 thousand euros) and Bistrița-Năsăud (55 thousand euros) counties, where the fewest projects were submitted for this intervention.

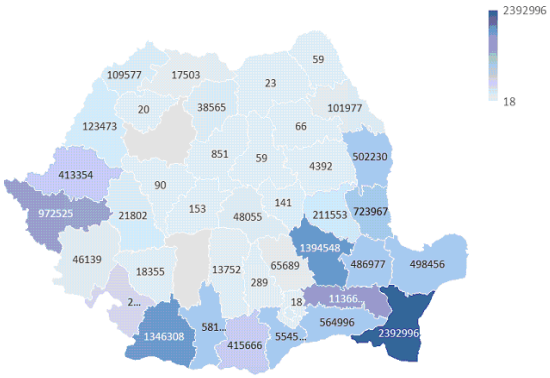
The DR 10 intervention – Areas affected by significant natural constraints has a very high number of beneficiaries, an explanation being that small amounts are granted per area. In two counties, namely Cluj and Vâlcea, there were no beneficiaries for this intervention. In terms of the number of beneficiaries of payments in the year 2024, most beneficiaries were from Dolj (8697), Olt (6881) and Galați (5054) counties, and the fewest beneficiaries were from Botoșani, Harghita, Ilfov and Sălaj counties, with 1 beneficiary each (Map 3).

The largest amounts received by the DR 10 intervention beneficiaries were in Constanța (2.4 million euros), Buzău (1.4 million euros) and Dolj (1.3 million euros), counties that overlap the map with eligible areas for environment and climate interventions. The smallest amounts were received by the beneficiaries from Suceava (23.9 euros),

Sălaj (20.79 euros) and Ilfov (18.49 euros) counties (Map 4).

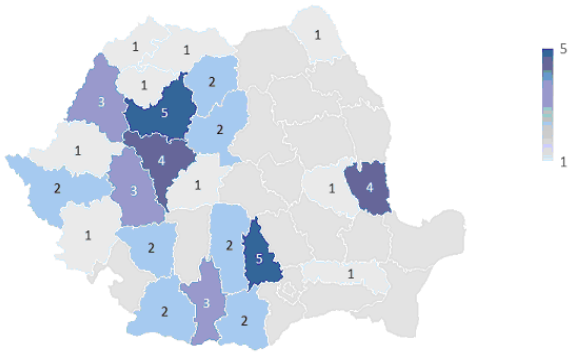


Map 3. Number of beneficiaries of DR 10 – Areas affected by significant natural constraints, in the year 2024 (Number)
Source: author's own processing based on [2] database.

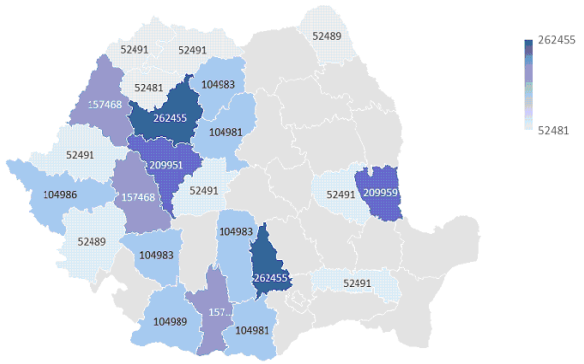


Map 4. Amounts received by the beneficiaries of DR 10 – Areas affected by significant natural constraints, in the year 2024 (Euros)
Source: author's own processing based on [2] database.

In the year 2024, in 18 counties (Bacău, Brașov, Brăila, Buzău, Călărași, Constanța, Covasna, Harghita, Iași, Ilfov, Mehedinți, Neamț, Prahova, Sibiu, Suceava, Tulcea, Vâlcea and Vaslui), there were no payments for setting up young farmers (DR30). Practically, in the eastern half of the country there were no payments for the setting up young farmers, except Galați county, with 4 beneficiaries and Botoșani, Vrancea and Ialomița counties only with 1 beneficiay each one. Most beneficiaries were from Cluj and Dâmbovița counties, with 5 beneficiaries each, and the fewest beneficiaries were found in 9 counties, with one beneficiary each (Map 5).
Because the amount allocated to support setting up each young farmer was almost identical, ranging from maximum 53,489 euros to minimum 52,491 euros, it is obvious that the largest amounts were received by the counties with the largest number of young farmers setting up in business, namely Cluj and Dâmbovița.



Map 5. Number of beneficiaries of DR 30 – Setting up young farmers, in the year 2024 (Number)
Source: author's own processing based on [2] database.



Map 6. Amounts received by the beneficiaries of DR 30 – Setting up young farmers, in the year 2024 (Euro)
Source: author's own processing based on [2] database.

CONCLUSIONS

Romania has two main agricultural policy instruments, namely the NRDP (National Rural Development Programme 2014-2020) and the NSP (National Strategic Plan 2023–2027), as essential tools in guiding the sustainable development of agriculture. Together, these programmes represent the main levers through which the state supports the transition to green agriculture, a concept that involves a balance between economic performance, protection of natural resources and well-being of future generations.
NRDP 2014-2020 laid the foundations for sustainable agriculture and introduced ecological measures that have paved the way for the NSP 2023-2027, which is more ambitious, integrates the EU climate objectives, reduced pesticide use, soil protection and transition to green technologies. While the NRDP 2014-2020 represented a first real step towards transforming Romanian agriculture into an environmentally-responsible sector, adapted to climate change, the NSP 2023-2027

takes a step forward, in line with the European objectives and policies.

Thus, in the year 2024, 13 measures and interventions, of which 10 measures from the NRDP 2014-2020 and 3 interventions from the NSP 2023-2027 were financed through AFIR, with a total amount of 276 million euros. The present paper analysed all the three interventions financed from the NSP 2023-2027 (DR 06 – Animal welfare, DR 10 – Areas affected by significant natural constraints and DR 30 – Support to setting up young farmers).

The largest amounts were received by the beneficiaries who submitted projects under the intervention DR 06 – Animal welfare, which totalled over 99 million euros and represented 36.2% of total amounts received by beneficiaries in the year 2024. For the intervention DR 06 – Animal welfare, the situation by counties highlighted that most beneficiaries of this intervention were from Bihor, Satu Mare and Călărași counties, while the least numerous beneficiaries were from Bistrița Năsăud, Tulcea and Sibiu counties. As regards the funding received under this intervention, the largest amounts were received by the beneficiaries from Timiș county, followed at a great distance by those from Vâlcea, Alba and Călărași counties. The explanation for this situation is that large-scale livestock farming operators are found in all the four counties.

For the intervention DR 10 – Areas affected by significant natural constraints, the number of beneficiaries was very high, which can be explained by the low amounts granted by area. Most beneficiaries were from Dolj, Olt and Galați counties, and the largest amounts were received by the beneficiaries from Constanța, Buzău and Dolj counties, counties that overlap the map with eligible areas for environment and climate interventions.

For the intervention DR 30 – Setting up young farmers, most beneficiaries were in Cluj and Dâmbovița counties, with 5 beneficiaries in each county, and the largest amounts were also received in these counties.

Green, low-carbon agriculture is not only an obligation derived from the EU policies, but also an opportunity for Romanian farmers who can modernise their farms and become more competitive. The two instruments, namely NRDP 2014-2020 and NSP 2023-2027 provide a basis to reach the climate objectives, but a successful transition depends on the coherent application of measures, the support provided to farmers and fostering innovation. It is only in this way that farmers can contribute to strengthening a resilient agricultural model, with low greenhouse gas emissions and positive impact upon the environment.

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AGRICULTURAL COOPERATIVES IN BULGARIA: SCENARIOS AND PERSPECTIVES FOR DEVELOPMENT

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Abstract

Agricultural cooperatives as a specific form of doing business and a social structure are part of the global economy. Since Bulgaria's accession to the EU in 2007, the Common Agricultural Policy (CAP) has shown mixed results, due to an unfair distribution of subsidies. Despite access to financing under the first and second pillars of the CAP, the income of agricultural cooperatives has been decreasing, as has their number. The issue of their financial condition and economic dimensions as a whole is on the agenda. In what direction modern cooperative structures will change and develop has been a discussion for several decades. To achieve the set goal, a linear scenario model was applied, which examines the sensitivity of key financial indicators to changes in independent variables. The model includes an analysis of the following indicators: assets, total liabilities, revenue, profit, financial autonomy ratio and total profitability ratio. Through certain assumptions for changes in independent variables, such as sales volume, debt levels, operating expenses, it is analysed how these variables affect the selected indicators. This allows to assess the impact of different scenarios on the financial condition of the cooperatives and to identify potential risks or opportunities for improving financial stability and profitability. According to the model's assessment, the business income and profit of agricultural cooperatives (on average) will continue to increase by 2030, despite expectations of a decrease in their number. The most likely scenario is an optimistic scenario, according to which the trend of increasing the amount of assets will continue, while their total liabilities will decrease, the financial autonomy ratio will increase within 20%, and their total profitability may increase twice.

Key words**:** *agricultural cooperatives, financial aspects, scenarios, development, Bulgaria*

INTRODUCTION

The cooperative business model is one of the modern examples, acting as a driving force for the association of family farms and contributing to the revitalization of rural areas. Through its organization, it creates prerequisites for the successful development of the circular and green economy in farms.

The agricultural cooperative as a specific form of doing business and social structure is part of the cooperative diversity in the world economy. Over the years of their development, cooperatives in Bulgaria have had periods of significant growth, but also of stagnation. They have developed specific models over time, based on a different subject of activity.

The evolution of cooperatives in Bulgaria reflects a complex interplay of economic, social, and political factors. The challenges they face today are multifaceted, involving both the changing landscape of European agricultural policy and internal dynamics related to governance, membership satisfaction, and financial stability [1, 9] has been a discussion for several decades. The question of how modern cooperative structures will evolve is indeed pressing, as they face increasing pressure to stay competitive while also fulfilling their broader social and community-oriented objectives.

Overall, the future of agricultural cooperatives in Bulgaria will likely involve a combination of adapting to EU policy, strengthening internal structures, engaging members more effectively, and innovating in terms of financial strategies and social impact. The challenge is balancing economic goals with the broader social objectives of cooperatives,

creating a more resilient and sustainable sector for the future.

The questions related to the development, sustainability and consolidation of modern cooperatives in Bulgaria and in particular the agricultural cooperative do not find the desired answer. In our country, scientific publications are available with a focus on the economic condition of agricultural production cooperatives under the conditions of the EU CAP [3, 4, 5, 11, 13, 15,18] etc.

[2] proposes a methodology for assessing the level of competitiveness of cooperative farms based on a survey. A factor for achieving high competitiveness is also good innovation management [19]. [13] examines the trend of key indicators such as productivity, profitability of production, profitability, net entrepreneurial income for the period 2007-2016. According to the results of the analysis, the support offered under the CAP for the period 2007 - 2013 increases the economic efficiency and profitability of production, which has a positive effect on the income of member-cooperators in agricultural cooperatives. Despite some negative trends reported, the support schemes under the CAP 2014-2020 have a positive effect on product diversification in the direction of increasing the share of protein, essential oil and fodder crops [16, 17]. At the same time, [14] report on the fundamental importance and influence of the governance structure in the agricultural cooperative when taking into account social factors and economic indicators. In this regard, [22] reveals the prerequisites for building (regional) cooperative business models for entrepreneurship [21] in agriculture. Other studies [20] include the social factor in the process of inheritance in the family farm for the sustainability of the agricultural cooperative and [6] propose an optimization model for increasing efficiency and profitability in farms. [12] provides recommendations for the future development of cooperative structures in agriculture, and [10] summarizes the potential and challenges facing cooperatives. In another study, [12] points out that some cooperatives that rent agricultural land for one year cannot establish permanent crop rotations, as well as invest in the creation of permanent crops.

Despite the existence of many publications focusing on various aspects concerning agricultural cooperatives, as well as on their financial condition for past periods, there are very limited studies outlining future financial and economic scenarios for development and sustainability, with few exceptions [17].

It is planned to forecast selected financial indicators of Bulgarian agricultural cooperatives until 2030, using a linear scenario model, which examines how these indicators react to the assumed changes in the independent variables.

MATERIALS AND METHODS

Justification for the selected financial indicators is consistent with available statistical data. Data from the Ministry of Agriculture and Food, Department of Agrostatistics, Bulgaria and Ciela Info were used. Ciela data are in absolute values and are averaged based on the number of agricultural cooperatives for the period. This combined approach aligns with both Bulgarian-specific findings and broader cooperative financial modeling literature and calculation of financial parameters (prospective projections of financial indicators). The condition for the assumptions made is that certain assumptions have been made for revenue, profit, assets and liabilities and profitability in the perspective until 2030. The selection of financial parameters is to relate to groups of indicators: resultative, derivative and impact indicators, namely:

1. Amount of assets (derivative);
2. Total liabilities (derivative);
3. Revenue (resultative);
4. Profit (resultative);
5. Financial autonomy ratio(impact);
6. Total profitability ratio(impact).

The resultative indicator profit is expressed as the difference between revenues and expenses incurred.

The financial autonomy ratio reflects the degree of financial independence of the cooperative from creditors. It is established as the ratio of equity and the total amount of

liabilities, and the value of the indicator should not be lower than 0.5.

The total profitability ratio shows the financial result from sales relative to the net amount of revenues.

The units of measurement of the selected indicators are expressed in thousands of BGN, in accordance with the adopted methodology of Ciela Norma, and the financial autonomy and total profitability ratios are presented in percentages (%).

Three scenarios are envisaged for financial and economic projections. They have been determined thanks to the expert opinion of established researchers and analysts of the cooperative business in Bulgaria - representatives of Trakia University, Stara Zagora, University of National and World Economy (UNWE), Agrarian University (AU), Plovdiv. The average values of 2020/2021 have been adopted as base years. According to the outlined framework, three separate forecasting scenarios up to 2030 have been constructed based on the NSI methodology and the EU socio-economic guidelines, as follows:

- Realistic scenario - It is built on the basis of European Union regulations. At its core, it emphasizes the socio-economic parameters of the member states;

- Optimistic scenario - Expectations project favorable socio-economic processes in the country with positive financial indicators;

-The third scenario is pessimistic. The expectations are for unfavorable socio-economic changes and negative financial trends in the country and the EU as a whole.

After selecting the financial indicators, a projection of their future values is made, on the basis of which the scenarios are evaluated. The Relative Comparative Assessment method is applied. The assessment is obtained for each indicator and for each scenario. The probability of the different scenarios is made using the method of probability measurement with covariance (PROCOV) [7]. In the model algorithm, the solution is visualized by means of a coefficient, which is taken as an evaluation scale. It is represented by a range from 0 to 1, as follows:

-from 0 - 0.2 - low score;

- 0.45 - unsatisfactory score;

-

f

f

0

The group of coefficients (Scenario likelihood) in the final matrix provides information about the probability of the scenario occurring.

RESULTS AND DISCUSSIONS

- 0.65 - satisfactory score;

- 0.8 - good score;

Information on the baseline data (Siela Norma) of the selected indicators are averaged for 2020/2021 and are presented in tabular form (Table 1). Based on them, three scenarios have been developed: realistic, optimistic and pessimistic.

In the realistics cenario, it is planned to maintain the trends to date without changes and in practice the financial indicators remain at the baseline level. It receives an overall score of 0.46, which is accepted as a satisfactory score. When building the pessimistic and optimistic scenarios, according to the assessment scale, the pessimistic scenario has an unsatisfactory score with a coefficient of 0.39, and the optimistic one - satisfactory with 0.55.

In the last three columns of Table 1, the results of the calculations of the model for the selected financial indicators parameters can be traced.

The optimistic scenario receives the highest score with a total profitability ratio of 0.74. According to the assessment, a doubling (to twenty percent) of profitability in agricultural cooperatives is expected by 2030.

The pessimistic scenario of the total profitability ratio is 0.18, which is the lowest indicator. It is expected that the total profitability will be limited to about five percent. The pessimistic scenario of the financial autonomy ratio is rated at 0.34. Based on the scores of the three scenarios for this indicator, its increase to 6% is expected. According to the model algorithm, a decrease in total liabilities is expected by an average of 20 thousand leva on an annual basis. The optimistic scenario for this indicator has the second-best score and a coefficient of 0.56. Regarding the other indicators: revenue, profit and total assets, the optimistic scenarios have

the highest score, which is an indication of expectations of an upward trend in agricultural cooperatives by 2030. Most likely, at the end of the period under review, revenue will increase by an average of 100 thousand BGN, profit by 10 thousand BGN, and assets by 50 thousand BGN.

The indicator with the lowest variation in the estimates of the three scenarios (between 0.49-0.50) is the total assets indicator. The coefficient of total profitability has the highest range, between 0.18 for the pessimistic scenario and 0.74 for the optimistic scenario.

Consolidated by indicators, the optimistic scenario has the highest score - between 0.5 and 0.74. Among the three scenarios, the pessimistic scenario scores the lowest across all indicators (0.18–0.5). The model's average score is 0.47, with breakdowns of 0.39 for pessimistic, 0.46 for realistic, and 0.55 for optimistic scenarios.

Table 1. Results of scenario assessments

Indicators	Base period 2020/ 2021	Scenarios			ISA-P	ISA-N	ISA-O
		Pessimistic	Realistic	Optimistic			
Revenue, thousand BGN	1,458.1	1,300	1,458.1	1,560	042	0.47	0.50
Profit, thousand BGN	170	150	170	180	0.41	0.4	0.50
Amount of assets, thousand BGN	1,978	1,978	1,978	2,030	0.49	0.49	0.50
Total liabilities, thousand BGN	390	420	390	370.0	0.49	0.53	0,55
Financial autonomy ratio	5	4.0	5	6.0	0.34	0.43	0.52
Total profitability ratio	0.1	0.05	0.1	0.2	0.18	0.37	0.74
					0.39	0.46	0.55
					Scenario Likelihood		**Av-0.47**

Source: own calculations based on to the methodology of Ivanov, B. (2022) [8].

The standard deviation is 0.027, indicating that the average score for each scenario falls within a narrow range around the overall mean. presented in Table 2.

Table 2. The likelihood ratio of scenarios estimates

Indicators	Confidence interval	Scenarios		
		Pessimistic	Realistic	Optimistic
Limits of the average scenario score - ISASK	0.95	0.18– 0.49	0.37 – 0.53	0.49– 0.74
The likelihood ratio of the scenarios - SLSK	0.95	0.10	0.17	0.15

Source: Own calculations based on the data from the Ministry of Agriculture and Foods "Agrostatistics" and Siela Norma Database [23].

It is assumed that the optimistic scenario will vary in the range from 0.49 to 0.74. The range of scores covered by the scenarios varies from 0.18 to 0.74, therefore the total probability of the three selected scenarios is about 47%. The most likely scenario is the realistic scenario – with a predictability of 17%. After it, respectively with 15% predictability is the optimistic scenario. The probability of the pessimistic scenario coming true is only 10%.

The results obtained through this modelling exercise are relatively encouraging for the projected trajectory of agricultural cooperative development. They suggest that the evaluated scenarios occur at the margin of the most probable future pathways. Moreover, the probability of realizing substantially better outcomes appears to be no greater than that of encountering results inferior to those projected for the realistic scenario.

CONCLUSIONS

In summary of the presented assessment of the scenarios, it can be concluded that positive

trends are expected in the financial condition of agricultural cooperatives by the end of 2030. The optimistic scenario for the selected indicators has the highest score, which means that favorable changes in the socio-economic aspect can be expected in Bulgaria, i.e. in the short and medium term, agricultural cooperatives will maintain and slightly increase their financial and economic results, as follows:

-The optimistic scenario of the total profitability ratio has the highest score, according to which the profitability of agricultural cooperatives is expected to increase almost twice on average.

-In terms of revenues, profits and the amount of assets, it is expected that they will grow at rates almost identical to the current ones.

-The total liabilities of agricultural cooperatives are expected to decrease by an average of 20 thousand. on an annual basis and a subsequent corresponding increase in the financial autonomy coefficient by 20%.

The results obtained from the application of the developed model, along with the associated scenario probabilities, can serve as a reliable tool to support decision-making by policymakers. These insights can guide the formulation of targeted policies and measures aimed at stabilizing and promoting the sustainable development of agricultural cooperatives in Bulgaria, in accordance with the principles and mechanisms of the EU Common Agricultural Policy (CAP).

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THE INFLUENCE OF GROSS VALUE ADDED AND LABOUR PRODUCTIVITY ON FACTOR INCOME IN AGRICULTURE - THE CASE OF THE CENTRAL EASTERN EUROPEAN COUNTRIES

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Abstract

The paper aimed to analyse real factor income per full-time worker in agriculture (FI) in 8 selected CEECs: Bulgaria, Croatia, Czechia, Hungary, Poland, Romania, Slovakia and Slovenia and to quantify the impact of gross value added (GVA) and labor productivity (LP) on income level. For this purpose, the data from Eurostat for the period 2015-2024 were processed using EViews10 software to determine the Pearson's correlations and multilinear regression equations, applying Ordinary Least Square Method. In 2024 vs. 2015, FI as real income per full time worker achieved an increasing trend in Bulgaria (+88.7%), Poland (+ 52.8%), Croatia (+ 25.4%), Czechia (+23.5%), Hungary (+ 13.7%), in Slovenia (+4.9%), Slovakia (+3.2%), and a decline in Romania (-15%). In 2024, GVA registered gains as follows: +93% in Poland, +86.4% in Croatia, +64% in Czechia, +46% in Slovakia, +37.5% in Romania, +29.5% in Slovenia, +26.4% in Bulgaria and +19.8% in Hungary. Also, LP increased by: +178.87% in Poland, +167% in Bulgaria, +150% in Hungary, +105 % in Croatia, +89.9% in Romania, +81.64% in Slovakia, +61.54% in Slovenia and +57.56% in Czechia. In the studied period, the highest CAGR for FI was in Bulgaria, Poland and Slovakia and the lowest one in Romania. For GVA, the larger CAGR was in Poland, Croatia and Czechia and the smallest in Hungary. For LP, the highest CAGR was found in Poland, Bulgaria and Hungary and the smallest in Czechia. The main contributors to the EU-27 FI are Poland, Romania and Hungary; for GVA: Poland, Romania and Croatia; for LP: Czechia, Hungary and Slovakia. Large positive and significant relationship between FI-GVA, FI-LP and GVA-LP were noticed in Bulgaria, Czechia, Poland. In Croatia, only for FI-GVA and GVA-LP, but moderate between FI-LP. In Hungary, the link GVA-LP is positive and strong, FI-GVA is a positive and moderate, while FI-LP is weaker. In Romania, GVA-LP positive and strong, FI-GVA is positive but weak, FI-LP is very small. Slovakia and Slovenia have positive and very strong GVA-LP and FI –LP, and a moderate FI –GVA connection. The regression analysis highlighted the existing gaps and peculiarities in agriculture of each member of the CEECs. Slovakia and Czechia have a high intercept, Slovenia and Croatia and Czechia have a high β_1 parameter, Romania has the smallest positive value and Slovakia the highest negative value. The parameter β_2 was positive in Slovakia, Poland and Bulgaria. In Bulgaria, Croatia, Czechia, Slovenia and Poland, the high R^2 shows that GVA and LP have an influence on FI, while in Hungary and Romania, the small R^2reflects that other factors like agrarian structures, subsidies, land price etc could be involved. As a conclusion, FI should be sustained by farmers' efforts to find solutions to better use the direct payments for enabling them to reimburse the capital, to cover the wages and the land lease and also to reward their own production factors.

Key words**:** *factor income-real per full-time worker, gross value added, labor productivity, CEECs*

INTRODUCTION

Agriculture belongs to the primary sector of the economy being considered a real industry branch. It has a high economic, social and environment importance as it is called to assure food security, to provide raw materials for processing industry, jobs and household income in the rural areas, to reduce poverty, to contribute to GDP and economic growth, to offer products for the domestic market and sustain international trade and also to assure a sustainable development protecting environment [46, 51].

To produce food (grains, vegetables, fruits, milk and meat) and also non-food products like fiber (cotton, silk, wool) and renewable energy, farmers must have knowledge and skills to cultivate land, sowing, and planting, fertilizing and ensuring plant protection against pests and diseases, harvesting, on one side, and also, on the other side to raise animals of various species (cattle, swine, poultry, sheep and goats, bee families etc), to assure their feeding, reproduction, health protection, milking etc and their production. For this purpose, farmers use various conventional intensive, semi-intensive and extensive technologies, organic farming system and during nowadays digitalized agricultural systems which have to be suitable to the soil and climate conditions to empower agricultural production.

Agricultural production is vital for mankind nourishing billions of people, diminishing hunger and poverty, and assuring economic growth and social development [79].

To achieve agricultural output, farm managers make huge efforts to provide suitable inputs in accordance with their business profile. Farmers dealing with crop production must have their own or leased land, ensure seeds and planting material of various crops, varieties and hybrids with a high potential yield performance, resistance to drought, diseases and pests attack, also tractors and machinery or to call for agricultural services for which they must pay. Water and fertilizers are also needed to empower production. Finally, they must harvest the obtained production using specific equipment, fuel and lubricants, and assure production storage in good conditions.

In case of the farmers dealing with animal growing, besides the inputs already mentioned, they must assure the livestock size correlated to the surface for producing forages or areas of pastures for grazing, the frozen doses for artificial insemination, medicines and treatments provided by veterinarian services, the potential milk yield or live weight goal. Sheds are necessary for animal rest and protection against cold during winter season or hard rains in other seasons. Fuel and lubricants for specific machinery for forage harvesting, transportation, preparation and distribution, and also for collecting manure are compulsory to be available in an animal farm.

The farm inputs which must be purchased by farmers involve costs, which form the so called production costs, where usually the variable costs have the highest share.

The value of agricultural output is the sum of the monetary worth of crop production, animal production and agricultural services and non-agricultural services which cannot be separated. It is

measured at basic prices, including subsidies on products and excluding taxes on products [19, 20, 21, 22].

The value of all the farm inputs: seeds and planting materials, fertilizers, pesticides, herbicides, insecticides, feedstuffs, water, veterinary medicines and treatment services, fuel and lubricants, repairs and maintenance of equipment (fixed assets are excluded) is measured at purchaser price, and form the so called “intermediary consumption”.

The difference between the output value of agricultural industry at basic price and intermediary consumption at purchaser price leads to gross value added [84, 24].

Gross value added is the economic indicator reflecting the efficiency in agriculture, because it shows how much value added was created in agriculture for one Euro spent on goods and services required by production process.

Gross value added is the starting point for determining:

-labour productivity in agriculture [61, 62, 63, 71, 76].

-the contribution to GDP of all the economic branches, summing the GVA produced in all the economic sectors [64, 67].
-net value added in agriculture, by eliminating the consumption of fixed capital from GVA, or in other words, subtracting from the output value in agricultural industry the costs of inputs plus the depreciation of fixed assets (reflecting the consumption of fixed capital) [23].
Net value added is a reference point for reflecting the position of a country in the Gross Value Chain at the global level [1, 36].
One of the most important indicators in agriculture is Factor income which reflects 'the remuneration of the production factors: land, capital and labour even though they are owned or rented or borrowed" [16]. It also shows "the capacity of the farmers to use the direct payments in such a way to be able to reimburse capital, pay the salaried workers, cover the land lease and finally to reward their own production factors" [17].
Factor income has a large variation from a country to another and even within the same farm, the reimbursement of the capital and other production factors is unequal among the internal and external factors.
The economic performance and efficiency at the EU-27 level is carried out by the contribution of each member state which varies depending on its geographical position, soil fertility and climate, number, physical and economic size of the farms, implemented technologies, fixed and capital, labour and managers level of knowledge and skills and experience in the field [75].
The Central Eastern European Countries selected in this study: Bulgaria, Croatia, Czechia, Hungary, Poland, Romania, Slovakia and Slovenia play an important role in the EU-27 agriculture, as shown in our previous research. To mention that, the Nordic CEECs: Lithuania, Latvia and Estonia also play an important role in the EU-27 agriculture, but in this research they have not been taken into consideration because of their different climate conditions compared with the group of 8 countries which was very much affected by high temperatures, long and severe droughts and low rainfalls during the analyzed decade [76].
The CEECs are passing through a deep process of agriculture transformation in the light of the EU Green Deal. Despite of the predominant small and medium sized farms, there is a trend of farm specialization and a growth both in the physical and economic size, the sustainable development goals are in the central attention, the EU financial support has stimulated investments and modernization [65, 68, 78].
However, during the last periods agriculture was affected by climate change, heat waves, long and severe droughts, fires, less precipitations, but also floods, soil erosion, environment pollution and loss of biodiversity [15].
The future tasks regard the reduction of greenhouse gas emission and carbon footprint, development of renewable energy, the implementation of adapted technologies to climate change, a more intense orientation to organic farming, measures for environment protection and biodiversity preservation to assure a sustainable development of agriculture.
Technical efficiency in agriculture depends on endowment modernization, farm structure and specialization, increased price for farm inputs and the gap between rural and urban development [9].
The analysis of the development of agriculture in each country of CEECs was made by various researchers whose results are presented below to describe the information framework.
In Bulgaria, agrarian structure is dominated by small and family farms [30, 52], but after the access into the EU structural changes and production specialization and diversification have appeared [14]. Besides a trend of concentration [8], a new orientation to organic farming has been noticed in the light of the Green Deal [2], cooperation in livestock farming is a chance for a more efficient use of the resources [4] as well as digitalization is a challenge to enhance agriculture development [96]. Agriculture must ensure not only production and high-quality products, but also it must become a sector of high profitability [54]. The higher and higher production could be a source of the intensification of agro-food trade especially with vegetables and fruits [3].
In Croatia, huge efforts are made to overcome the administrative obstacles and to achieve the policy goals in agriculture [87], to reach the self-sufficiency and assure the income growth [40] based on the harmonization of the own strategy of the country with the EU's CAP [33, 53]. Organic farming is extending creating new

opportunities for farmers to produce healthier products and increase their income and to better satisfy the needs of the modern consumer [45].

In Czechia, farmers are focused on the sustainable development of agriculture based on climate change adaptation and environment protection [7]. Agriculture is passing through a process of continuous modernization and growth [92], the price of the farm land increased reflecting the improvement in fertility and productivity [86], and as affirmed [93], the Czech agriculture has passed from "productivism to post-productivism". A special aspect is represented by social involvement and community-supported agriculture and also by the employment in agriculture of the disadvantaged people [11, 58].

In Hungary, agriculture characterized in most of cases by subsistence farming [38] is regenerating on its way to attain the Green goals [37, 89], assuring economic growth and protecting the environment quality by using less pesticides [92, 90], extending organic farming [35], focusing on the achievement of the SDGs [55] and implementing digitalization [27].

Poland has still a large number of farms, but their reduction is visible year by year [29] and the economic situation of the farms is improving [60]. However, despite that productivity is increasing there are still differences regarding modernization [6], productivity and income [13, 32] in agricultural households [34]. However, agriculture plays an important role in the economy of Poland [39, 41], being sustained by investments [42], changes in the relations of production factors [43], the aid schemes provided by state budget to support small-scale agriculture [28]. But, there are still unsolved problems concerning agriculture in the mountain areas facing with restrictive factors of various categories [95] and also the farmers' aging in small farms [85].

In Romania, agriculture is very important for food security and diminishing the import dependence [48], it is also facing huge problems and damages caused by climate change, which impose specific measures for technological adaptation and for diminishing the negative effects [50, 73, 77]. Romania is still in the top in the EU for its high number of farms and dominance of small subsistence and semi-subsistence households [65, 66], and on the last position in the EU for the low productivity [61, 62, 63].

Organic farming is increasing slowly [47] and the gap between agricultural output in the vegetal sector and animal sector is higher and higher, maintaining a continuous unbalanced ratio [74, 69],

population working in agriculture is older than 60 in a large proportion [72]. However, a good aspect is the fact that farmers apply smaller amounts of fertilizers and pesticides than in other EU countries [70] and a more and more intense accent is put on the achieving of SDGs [57]. Compared to other EU countries, agriculture contributes by a little higher percentage to GDP [64, 67].

Slovakia has an important agricultural sector in the economy [5] and after the country accession into the EU, the vegetal sector has become stronger [56]. The small farmers are supported by the CAP measures [82] because there are still regional disparities [81, 83]. Land market reflects discrepancies from a region to another [44]. The social function of agriculture must not be denied because it is a sector which could offer food, jobs, income, and economic growth for the local communities and regions of the country [91] and more than this the agricultural landscape is continuously changing [31]. In this context, the assurance of a sustainable development of agriculture imposes structural changes concerning the selection of crops which must be cultivated [49] and a higher involvement as a source of renewable energy [59].

In Slovenia, farm size is still small and farm performance is linked to subsidies [10, 12, 18], but in the Sub-Mediterranean region the socio-economic viability of farm land is more visible [88]. Organic farming is continuously extending and agri-food innovations based on intelligent agriculture empower the sustainable development of agriculture [39, 80].

In this context, the paper aimed to offer an overview on the economic performance in the CEECs based on gross value added, labor productivity and factor income real per full time worker achieved in agricultural industry during the last decade 2015-2024 using the empirical data provided by Eurostat data base and processing according to a statistical-econometrical analysis.

MATERIALS AND METHODS

The literature in the field was studied in order to create an image on the scientific background on the approached topic as provided by Google Scholar and WoS.
The primary data were picked up from Eurostat database for the interval 2015-2024 for which they were available at present.
The main indicators taken into account have been: gross value added (GVA), labour productivity and factor income, in terms of real income per fulltime worker.
The following aspects have been studied, involving illustrative representations, calculations and tabled results:
(i)Dynamics of Factor income (FI), GV and labour productivity (LP) in the 8 CEECS (2015-2024);
(ii)Compound Annual Growth Rate – CAGR for FI, GVA and LP in the 8 CEECS (2015-2024), according to the formula:

$$CAGR_{\%} = [(X_n / X_1)^{1/n} - 1] \times 100 \quad \text{.....(1)}$$

where:
X_n is the ending item of the chronological series;
X_1 is the first item of the chronological series;
N is the number of years.
(iii)The contribution of the CEECs to EU-27 FI, GVA and LP in the year 2024;
(iv)The economic efficiency (EE) in agriculture of each CEECs in terms of GVA generated by 1 Euro spent on farm inputs for the production process. The calculation is based on the formula:

$$EE = GVA/IC \quad \text{……} \quad (2)$$

where:
IC is intermediary consumption which reflects the expenditures for purchasing farm inputs for production process.
(v)Descriptive statistics for FI, GVA and LP in each CEECs (2015-2024), including mean, median, minimum and maximum value, standard deviation, skewness, kurtosis and Jarque-Bera test.
(vi)The coefficients of correlation determined using Pearson's formula between FI, GVA and LP [94].

$$r = \frac{\sum_{i=1}^{n} (x_{i-\overline{X}})(y_{i-\overline{Y}})}{\sqrt{\sum_{i=1}^{n} (x_{i-\overline{X}})2\ (y_{i-\overline{Y}})2}} \quad \text{……...} \quad (3)$$

(vii) T-test for testing the significance of the correlation coefficient based on the formula:

$$T_{calc} = r\sqrt{(\frac{n-2}{1-r^2})} = \frac{r\sqrt{n-2}}{1-r^2} \quad \text{……....(4)}$$

r = correlation coefficient
n = number of years

(viii)Multiple linear regression equations for each CEECs calculated according to the formula:

$$Y = \alpha + \beta_1 x_1 - \beta_2 x_2 + \varepsilon \text{……..} \quad (5)$$

where:
Y = the dependent variable -FI
x_1 = the independent variable 1 - GVA
x_2 = the independent variable 2 - LP
α, β_1, β_2 are the regression parameters
ε = residual variable.
The calculation is based on Ordinary Least Square (OLS) method.
The results present the parameters of the regression equations a, b and c, and also standard error, t-statistic and Probability, R squared and adjusted R squared, log likelihood, F-stat, Akaike info criterion used to identify the risk of overfitting or underfitting, Schwarz criterion to balance the goodness-of-fit against model complexity, Hannan-Quinn criterion used to identify the best model with high probability and Durbin-Watson test for autocorrelation.
Finally, the main results have been presented in brief with the conclusions.

RESULTS AND DISCUSSIONS

The dynamics of Factor Income, Gross value added and Labour productivity in the 8 CEECs

In the period 2015-2024, Factor income, in terms of real income per full time worker in agriculture increased by 88.7% in Bulgaria, 52.8% in Poland, 25.4% in Croatia, 23.5% in Czechia, 13.7% in Hungary, 4.9% in Slovenia and 3.2% in Slovakia. In Romania, FI increased from 4,131 Euro/AWU in 2015 to 6.876 Euro/AWU in 2021, the peak level, but then it started to decline to 3,509 Euro/AWU in 2024, meaning a decrease by 15.1% versus 2015 (Fig. 1).

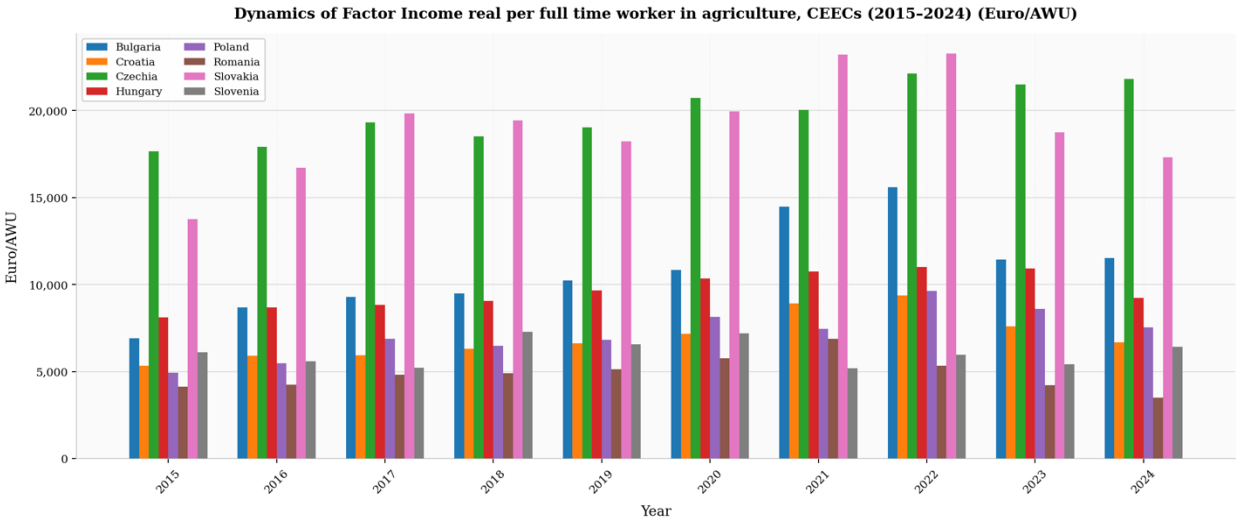


Fig. 1. Dynamics of Factor income in terms of real factor income per full-time worker in agriculture in the selected CEECs in the period 2015-2024 (Euro/AWU)
Source: Own design and calculations based on the data from Eurostat [17, 26].

GVA also increased in all CEECs as follows: by 93% in Poland, 86.4% in Croatia, 64% in Czechia, 46% in Slovakia, 37.5% in Romania, 29.5% in Slovenia, 26.4% in Bulgaria and 19.8% in Hungary. The highest GVA was carried out by Poland accounting for Euro Billion 15,169 in 2024, Romania Euro Million 101,124 in the year 2021 and Hungary Euro Million 4,136 in 2023. They are followed by Czechia, Bulgaria, Croatia, Slovakia and Slovenia (Fig. 2).

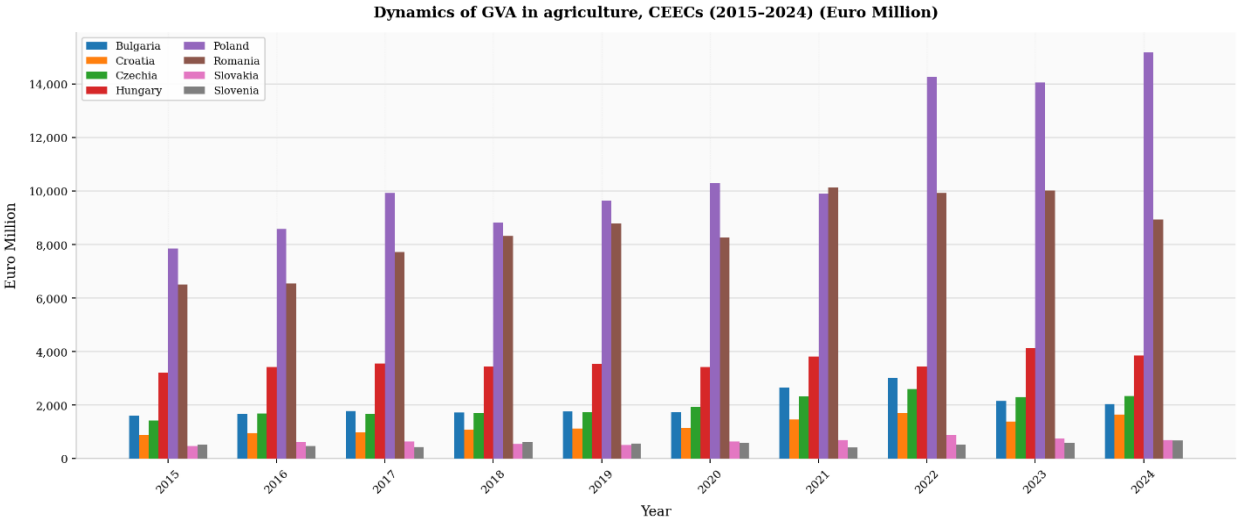


Fig. 2. Dynamics of gross value added in agriculture in the selected CEECs in the period 2015-2024 (Euro Million)
Source: Own design and calculations based on the data from Eurostat [25].

Labour productivity increased in the studied interval as follows: by 178.87% in Poland, by 167% in Bulgaria, by 150% in Hungary, by 105 % in Croatia, by 89.9% in Romania, by 81.64% in Slovakia, by 61.54% in Slovenia and by 57.56% in Czechia. This growth was determined by the growth of GVA, on one side, and by the decline in labor input, on the other side (Fig. 3).

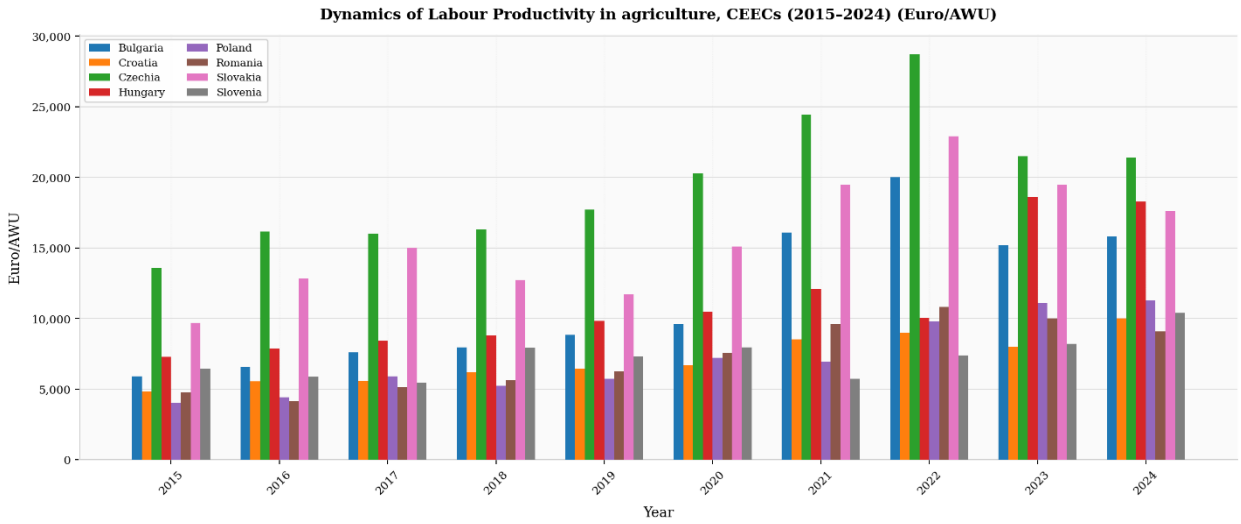


Fig. 3. Dynamics of Labour productivity in agriculture in the selected CEECs in the period 2015-2024 (Euro/AWU)
Source: Own design and calculations based on the data from Eurostat [17].

CAGR for FI, GVA and LP in the 8 CEECS (2015-2024)

The average CAGR for FI recorded the highest level in Bulgaria 5.25%, followed by Poland a (4.33%) and Slovakia (2.31%).
The lowest level was -1.62 in Romania.
Regarding the CAGR for GVA, the top level was 6.82% in Poland, followed by 6.43% in Croatia and 5.07% in Czechia.
The lowest level was 1.82 in Hungary.

Table 1. Average CAGR for FI, GVA and LP in the 8 CEECS (2015-2024) (%)

	FI	GVA	LP
Bulgaria	5.25	2.37	10.34
Croatia	2.30	6.43	7.47
Czechia	2.14	5.07	4.65
Hungary	1.29	1.82	9.63
Poland	4.33	6.82	10.80
Romania	-1.62	3.24	6.63
Slovakia	2.31	3.87	6.15
Slovenia	0.48	2.63	4.91

Source: Own calculation based on the data from Eurostat [17, 25].

For LP, the highest CAGR was 10.80% achieved by Poland, followed by 10.34% in Bulgaria and 9.63% in Hungary.
The smallest CAGR was 4.65% carried out in Czechia (Table 1).

The contribution of the CEECs to EU-27 FI, GVA and LP in the year 2024

The CEECs have a different contribution to FI, GVA and LP of the EU-27.
The highest contribution to FI is given by Poland (7.2%), followed by 2.21% from Romania and 1.60% from Hungary. The lowest contribution is allotted by Czechia (0.10%).
Regarding the contribution to GVA, Poland comes the 1st with 6.6%, being followed by 3.9% Romania and 1.7% given by Croatia.
Concerning labour productivity, the EU-a7 average level is 30.9 Euro Million per 1,000 AWU. The average of each CCEECs country does not exceed the EU-27 average.
But, we may notice that the highest LP is in Czechia (21.4), followed by Hungary (18.3) and Slovakia 17.4.
The lowest LP is in Romania's agriculture, only 5.1 Euro Million/1,000 AWU.
As can be seen, none of the CEECs do not exceed the EU- 27 average LP level (Table 2).
Figure 4 shows the comparative dynamics of FI average in the EU-27 and in each country of the selected CEECs to illustrate which country is able to exceeds this mean.

Table 2. The contribution of the CEECs to EU-27 FI, GVA and LP in the year 2024

	FI		GVA		LP	
	Euro Million	%	Euro Billion	%	Euro Million/ 1,000 AWU	%
EU-27	**154,928**	**100.0**	**228.6**	**100.0**	**30.9**	**100.00**
Bulgaria	1,335.7	0.86	2.0	0.8	15.8	51.13
Croatia	1,412.6	0.91	1.7	0.7	10.0	32.36
Czechia	1,607.4	0.10	2.3	1.0	21.4	69.25
Hungary	2,493.7	1.60	3.9	1.7	18.3	59.22
Poland	11,164.4	7.20	15.2	6.6	11.3	36.56
Romania	3,429.8	2.21	9.0	3.9	5.1	16.50
Slovakia	796.0	0.51	0.7	0.3	17.6	56.95
Slovenia	439.2	0.28	0.6	0.2	10.4	33.65

Source: Own calculation based on the data from Eurostat [17, 25].

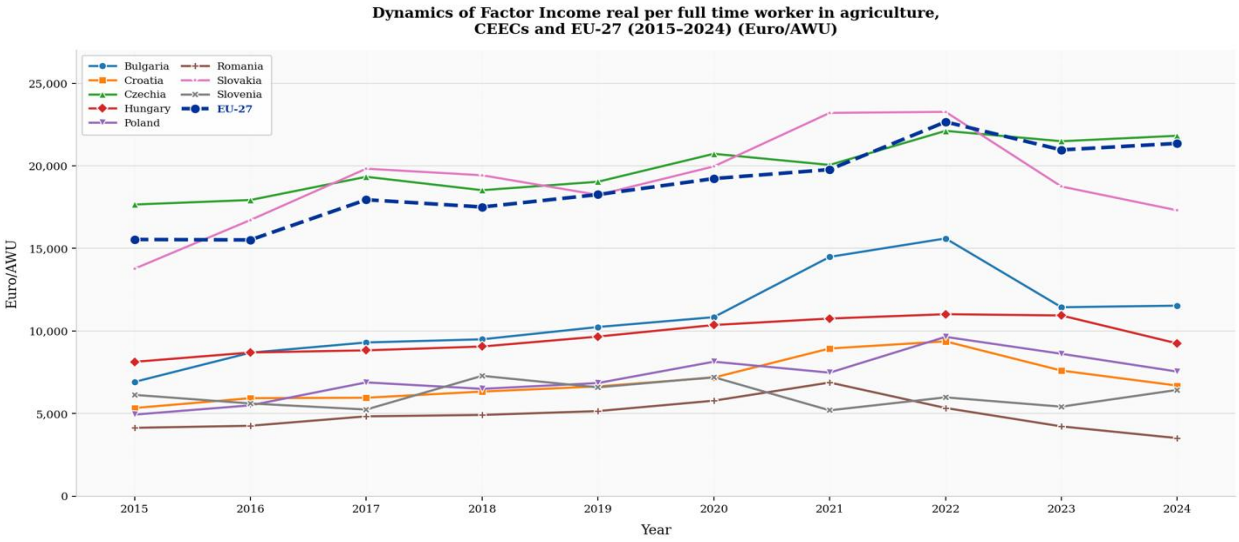


Fig. 4. The dynamics of FI real per full time worker in the EU-27 and in each country of the selected CEECs, 2015-2024 (Euro/AWU)

The economic efficiency in agriculture of each CEECs in terms of GVA generated by 1 Euro spent on farm inputs for the production process.

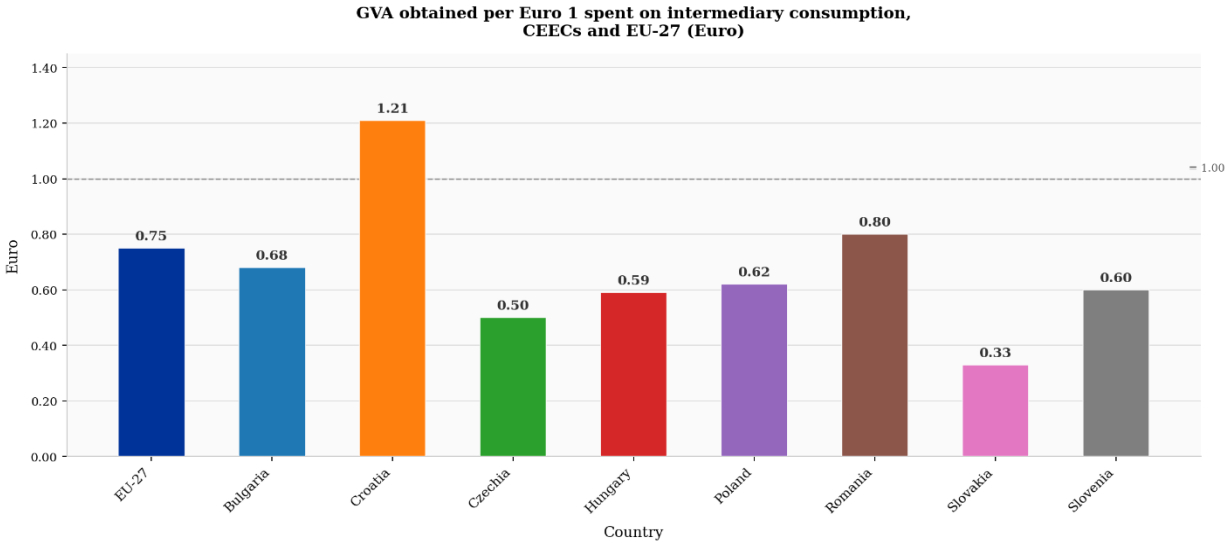


Fig. 5. The GVA/IC ratio reflecting the efficiency of Euro 1 spent on intermediary consumption
Source: Own design and calculations based on the data from Eurostat [18, 25].

At the EU-27 level, for 1 Euro spent for the inputs needed for the production process, it is produced 0.75 GVA. In the selected CEECs, in Croatia it is 1.21, the highest efficiency of agriculture. Then, are coming the following countries: Romania 0.80, Bulgaria 0.68, Poland 0.62 and Slovenia 0.60. The smallest efficiency 0.33 is achieved by Slovakia (Fig. 5).

Descriptive statistics for FI, GVA and LP in each CEECs (2015-2024)

Table 3 presents the descriptive statistics for FI, GVA and LP for each country selected in the panel of CEECs: mean, median, maximum and minimum value, standard deviation, skewness kurtosis, Jarque-Bera test and probability.

Table 3. Descriptive statistics for FI, GVA, LP (2015-2024)

Country	Descriptive statistics	FI	GVA	LP	Country	Descriptive statistics	FI	GVA	LP
Bulgaria	Mean	10,851.30	2,022.6	11,363.10	Croatia	Mean	6,995.300	1,242.5	7,087.500
	Median	10,536.00	1,780.0	9,227.500		Median	6,664.500	1,144.0	6,565.500
	Maximum	15,602.00	3,023.0	20,011.00		Maximum	9,369.000	1,717.0	10,000.00
	Minimum	6,914.00	1,620.0	5,909.000		Minimum	5,331.000	885.0	4,865.000
	Std. Dev.	2,611.965	470.1698	4,937.247		Std. Dev.	1,310.619	294.0292	1,694.858
	Skewness	0.5124	1.222887	0.4988		Skewness	0.7075	0.448701	0.3980
	Kurtosis	2.5348	3.109275	1.7640		Kurtosis	2.3624	1.794976	1.8806
	Jarque-Bera	0.5278	2.497397	1.0512		Jarque-Bera	1.0037	0.940589	0.7861
	Probability	0.7681	0.286878	0.5912		Probability	0.6054	0.624818	0.6750
Czechia	Mean	19,868.20	1,973.4	19,609.80	Hungary	Mean	9,666.200	3,587.6	11,180.20
	Median	19,693.50	1,843.5	19,003.00		Median	9,450.500	3,491.5	9,950.000
	Maximum	22,117.00	2,608.0	28,697.00		Maximum	11,013.00	4,136.0	18,600.00
	Minimum	17,656.00	1,423.0	13,582.00		Minimum	8,128.000	3,224.0	7,296.000
	Std. Dev.	1,622.896	388.0172	4,577.942		Std. Dev.	1,035.830	269.7897	4,070.716
	Skewness	0.0662	0.261518	0.6418		Skewness	0.0678	0.806676	1.1080
	Kurtosis	1.5919	1.734956	2.5689		Kurtosis	1.5742	2.760309	2.7147
	Jarque-Bera	0.8335	0.780793	0.7639		Jarque-Bera	0.8547	1.108482	2.0799
	Probability	0.6592	0.676788	0.6825		Probability	0.6522	0.574508	0.3535
Poland	Mean	7,205.400	10,850.3	7,179.700	Romania	Mean	4,898.600	8,515.5	7,313.500
	Median	7,178.500	9,917.0	6,432.500		Median	4,869.500	8,559.0	6,930.000
	Maximum	9,641.000	15,169.0	11,300.00		Maximum	6,876.000	10,124.0	10,845.00
	Minimum	4,933.000	7,848.0	4,052.000		Minimum	3,509.000	6,501.0	4,141.000
	Std. Dev.	1,406.550	2629.500	2,666.185		Std. Dev.	962.1114	1324.749	2,432.769
	Skewness	0.0392	0.657139	0.5262		Skewness	0.6299	-0.301999	0.1403
	Kurtosis	2.3798	1.846097	1.8214		Kurtosis	2.9366	1.921829	1.4763
	Jarque-Bera	0.1628	1.274507	1.0403		Jarque-Bera	0.6629	0.636361	1.0002
	Probability	0.9218	0.528743	0.5944		Probability	0.7179	0.727471	0.6065
Slovakia	Mean	19,046.40	649.3	15,656.50	Slovenia	Mean	6,104.900	539.7	7,275.800
	Median	19,087.50	646.0	15,041.50		Median	6,052.500	542.0	7,366.000
	Maximum	23,268.00	888.0	22,903.00		Maximum	7,280.000	679.0	10,400.00
	Minimum	13,768.00	474.0	9,689.000		Minimum	5,192.000	425.0	5,464.000
	Std. Dev.	2,863.039	121.373	4,137.606		Std. Dev.	762.2775	82.15575	1,483.460
	Skewness	-0.0853	0.410233	0.2969		Skewness	0.3202	0.040799	0.6844
	Kurtosis	2.6333	2.696810	2.0435		Kurtosis	1.8061	2.078543	2.9803
	Jarque-Bera	0.0682	0.318787	0.5282		Jarque-Bera	0.7648	0.356559	0.7807
	Probability	0.9665	0.852661	0.7679		Probability	0.6822	0.836709	0.6768

Source: Own calculations.

The coefficients of correlation between FI, GVA and LP

The interpretation of r value is made in accordance with the two hypothesis:

H_0- There is no correlation among the two variables, as p-value is higher than α. In this case, H_0 is accepted. The higher p-value, the more it sustains H_0.

H_1- There is a correlation between the two variables, because p-value is smaller than α, and in consequence H_0 is rejected. Between the two variables it is a relationship The smaller p-value, the more it sustains H1 (Table 4).

In case of Bulgaria, Czechia, Poland there is a large positive and significant relationship between the pairs of variables FI-GVA, FI-LP and GVA- LP for $p = 0.0001 < \alpha$, H_0 is rejected and H1 is accepted. In case of Croatia, it was found a large positive and strong relationship among FI-GVA and GVA-LP and also a moderate relationship between FI-LP for p-value < α, H_0 is rejected and H1 is accepted.

In Hungary, there are three different situations. For the pairs of variables GVA-LP, the relationship is positive and significant for p-value < α, H_0 is rejected and H1 is accepted. In case of FI-GVA, the relationship is positive but moderate, H1 is also accepted. In case of FI-LP, the correlation coefficient is below 0.5 reflecting a relatively weak positive relationship, H1 is also accepted.

In Romania, the relationship between GVA-LP is positive and very strong for p-value < α, H1 is accepted and H_0 is rejected. In case of FI-GVA, the relationship is positive but weak, H1 is also accepted. In case of FI-LP the coefficient of correlation is below 0.3 reflecting that there is no relationship between the two indicators.

In case of Slovakia, between GVA-LP is a positive and very strong relationship and between FI –LP it is also a positive and substantial connection, for p-value < α, H_0 is rejected and H1 is accepted. For the pair of variables FI –GVA it was found a positive but moderate relationship, H1 is also accepted.

In case of Slovenia, the link between GVA-LP is positive and very strong, between FI-GVA and FI-LP it is a positive but moderate connection, H1 is also accepted (Table 4).

Table 4. The coefficients of correlation among the pairs of variables by CEECs country

Country	Variables		r	P-value	t- Statistic
Bulgaria	Yx1	FI-GVA	0.9432	0.000042	8.031528
	Yx2	FI –LP	0.9256	0.000122	6.917013
	x1x2	GVA-LP	0.9164	0.000193	6.474988
Croatia	Yx1	FI-GVA	0.8078	0.004699	3.876415
	Yx2	FI –LP	0.7302	0.016487	3.022882
	x1x2	GVA-LP	0.9792	0.000001	13.651117
Czechia	Yx1	FI-GVA	0.9120	0.000236	6.288302
	Yx2	FI –LP	0.8436	0.002160	4.442645
	x1x2	GVA-LP	0.9600	0.000011	9.691984
Hungary	Yx1	FI-GVA	0.5362	0.110139	1.796509
	Yx2	FI –LP	0.4830	0.157328	1.560225
	x1x2	GVA-LP	0.9033	0.000340	5.955496
Poland	Yx1	FI-GVA	0.7919	0.006326	3.668223
	Yx2	FI –LP	0.8114	0.004377	3.926701
	x1x2	GVA-LP	0.9811	0.000001	14.327854
Romania	Yx1	FI-GVA	0.4277	0.217562	1.338378
	Yx2	FI –LP	0.2782	0.436339	0.819303
	x1x2	GVA-LP	0.9150	0.000206	6.414703
Slovakia	Yx1	FI-GVA	0.6888	0.027597	2.687653
	Yx2	FI –LP	0.7604	0.010678	3.311294
	x1x2	GVA-LP	0.9655	0.000006	10.488655
Slovenia	Yx1	FI-GVA	0.7105	0.021284	2.855930
	Yx2	FI –LP	0.5449	0.103350	1.838074
	x1x2	GVA-LP	0.9519	0.000022	8.790230

Source: Own calculations.

Multiple linear regression equations for each CEECs

The following tables present the Ordinary Least Squares (OLS) results for each of the eight CEECs for the period 2015-2024.

The three variables are:

-The dependent variable Y, FI= Factor income-real income per full-time worker (Euro/AWU)

-The independent variable X_1= GVA= Gross value added (Euro Million)

-The independent variable X_2 = LP= Labour productivity (Euro/AWU)

The model of the multiple linear regression is:

$$FI_i = \alpha + \beta_1 \cdot GVA + \beta_2 \cdot LP + \varepsilon$$

where:

FI= Factor income

α = constant

β_1 = regression parameter for GVA

β_2 = regression parameter for LP

ε = residual variable.

Table 5. Multiple linear regression equations for Factor income depending on Gross value added and Labour productivity in the eight selected CEECs

Country	Multiple linear regression equation	Country	Multiple linear regression equation
Bulgaria	FI= 1,891.143 + 3.293873 GVA+ 0.202231 LP	Croatia	FI= 2,606.255 + 10.04984 GVA-1.142558 LP
Czechia	FI= 11,845.58 + 5.447614 GVA -0.144199 LP	Hungary	FI= 2,213.345 + 2.083992 GVA-0.001797 LP
Poland	FI= 4,361.999 -0.058914 GVA + 0.485068 LP	Romania	FI= 330.5639 + 0.772515 GVA-0.274878 LP
Slovakia	FI= 14,054 – 15.76595 GVA + 0.972674 LP	Slovenia	FI= 1,106.192 + 18.96863 GVA-0.720012 LP

Source: Own calculations using EViews 10.

Table 5 presents the multiple linear regression equations for Factor income depending on Gross value added and Labour productivity in the eight selected CEECs. The detailed results of the regression analysis are shown below in Tables 6, 7, 8, 9, 10, 11, 12 and 13.

In case of Bulgaria, R squared reflects that 91.3% of the FI variation is given by GVA and LP. Factor income is statistically significant as shown by F=36.77 and p<0.001. The influence of the two factors on FI is different: while GVA has a positive significant impact (β_1= 3.293873, p= 0.0707), LP has a positive but small non-significant effect (β_2 =0.202231, p= 0.2121 (Table 6).

Table 6. Results of the regression analysis, Bulgaria

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1891.143	1751.298	1.079852	0.3160
GVA	3.293873	1.546475	2.129923	0.0707
LP	0.202231	0.147269	1.373203	0.2121
R-squared	0.913079	Mean dependent var		10851.30
Adjusted R-squared	0.888244	S.D. dependent var		2611.965
S.E. of regression	873.1779	Akaike info criterion		16.62548
Sum squared resid	5337077.	Schwarz criterion		16.71626
Log likelihood	-80.12740	Hannan-Quinn criter.		16.52590
F-statistic	36.76629	Durbin-Watson stat		0.763026
Prob(F-statistic)	0.000194			

Source: Own results using EViews 10.

In case of Croatia, 74.25% of FI variation is caused by GVA and LP, but in a different way. For FI, F-statistic is 10.08886 for p < 0.01. While GVA has a positive and significant effect on FI, β_1= 10.04984, p = 0.485, LP has a negative important impact β_2=-1.142558, p = 0.1621. Therefore, GVA if the most important factor of influence, the higher GVA, the higher FI (Table 7).

Table 7. Results of the regression analysis, Croatia

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2606.255	1090.170	2.390687	0.0481
GVA	10.04984	4.214346	2.384674	0.0485
LP	-1.142558	0.731118	-1.562755	0.1621
R-squared	0.742436	Mean dependent var		6995.300
Adjusted R-squared	0.668846	S.D. dependent var		1310.619
S.E. of regression	754.2083	Akaike info criterion		16.33254
Sum squared resid	3981811.	Schwarz criterion		16.42331
Log likelihood	-78.66270	Hannan-Quinn criter.		16.23296
F-statistic	10.08886	Durbin-Watson stat		1.375529
Prob(F-statistic)	0.008672			

Source: Own results using EViews 10.

In case of Czechia, FI is determined 84.47% of the two factors of influence and also in a

different manner like in Croatia. FI is statistically significant, F= 19.03929 for p < 0.01. The constant has a high value= 11,945.58, being statistically significant. GVA has a positive impact on FI, β_1= 5.447614, p= 0.0441, while LP has a small and non-significant negative effect, β_2=-0.144199, for p= 0.4692 (Table 8).

Table 8. Results of the regression analysis, Czechia

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	11945.58	1353.018	8.828841	0.0000
GVA	5.447614	2.223669	2.449831	0.0441
LP	-0.144199	0.188474	-0.765086	0.4692
R-squared	0.844716	Mean dependent var		19868.20
Adjusted R-squared	0.800349	S.D. dependent var		1622.896
S.E. of regression	725.1481	Akaike info criterion		16.25395
Sum squared resid	3680878.	Schwarz criterion		16.34473
Log likelihood	-78.26977	Hannan-Quinn criter.		16.15437
F-statistic	19.03929	Durbin-Watson stat		2.941498
Prob(F-statistic)	0.001476			

Source: Own results using EViews 10.

In Hungary, FI has a very small R squared reflecting that only 28.74% of its variance is determined by the two factors, GVA and LP, which means that other factors have a much higher influence. In this respect it is necessary another analysis to see if FI is influenced by agrarian structures, subsidies, land price etc. FI is non-significant, F-statistics = 1.412070, for p =0.305360.

Looking at GVA and LP, their regression parameters are very small, β_1= 2.082992, p= 0.4898, and, respectively, β_2=-0.001797, for p= 0.9927 (Table 9).

Table 9. Results of the regression analysis, Hungary

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2213.345	8387.764	0.263878	0.7995
GVA	2.082992	2.855322	0.729512	0.4894
LP	-0.001797	0.189239	-0.009494	0.9927
R-squared	0.287469	Mean dependent var		9666.200
Adjusted R-squared	0.083889	S.D. dependent var		1035.830
S.E. of regression	991.4305	Akaike info criterion		16.87950
Sum squared resid	6880541.	Schwarz criterion		16.97028
Log likelihood	-81.39750	Hannan-Quinn criter.		16.77992
F-statistic	1.412070	Durbin-Watson stat		0.873013
Prob(F-statistic)	0.305360			

Source: Own results using EViews 10.

In Poland, R squared reflects that 65.88% of the changes in FI are determined by the two independent factors**.**

FI is statistically significant, F = 6.759468, p= 0.023190. But the two factors of determination are not statistically significant: GVA has β_1= -0.058914, p= 0.9257, and LP has β_2= 0.485068 and p= 0.4464. Therefore, in Poland, GVA and LP have joined their effect on FI due to their multicollinearity reflected by their high correlation coefficient, r = 0.981 (Table 10).

In Romania, the regression equation is not statistically significant. First of all, R squared is very small, 26.15%, which reflects that other factors have a more substantial influence on FI than GVA and LP (F-statistic = 1.239840 for p = 0.345991). Among the eight CEECs countries, the model of regression equation in Romania is the weakest. GVA has the

regression parameter β_1 = 0.772515, for p= 0.2279, while LP has the parameter β_2 = −0.274878, for p= 0.4165. The dynamics of FI is slow and it is needed a more profound study to identify the stimulating factors which could improve FI. It is unanimously recognized that in Romania is the largest number of farms whose average physical size is about 4.7 ha and economic size of about Euro 4,000 per farm. Despite the agrarian structure, dominated by the subsistence farming systems, due to land fragmentation into small plots, lack of modern technical endowment and technologies, CAP subsidies are not sufficient to assure a visible beneficial effect of farm income (Table 11).

Table 10. Results of the regression analysis, Poland

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4361.999	2539.828	1.717439	0.1296
GVA	-0.058914	0.609736	-0.096623	0.9257
LP	0.485068	0.601347	0.806635	0.4464
R-squared	0.658852	Mean dependent var		7205.400
Adjusted R-squared	0.561381	S.D. dependent var		1406.550
S.E. of regression	931.5345	Akaike info criterion		16.75487
Sum squared resid	6074296.	Schwarz criterion		16.84564
Log likelihood	-80.77434	Hannan-Quinn criter.		16.65529
F-statistic	6.759468	Durbin-Watson stat		1.074983
Prob(F-statistic)	0.023190			

Source: Own results using EViews 10.

Table 11. Results of the regression analysis, Romania

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	330.5639	3013.712	0.109687	0.9157
GVA	0.772515	0.584662	1.321303	0.2279
LP	-0.274878	0.318374	-0.863381	0.4165
R-squared	0.261578	Mean dependent var		4898.600
Adjusted R-squared	0.050601	S.D. dependent var		962.1114
S.E. of regression	937.4536	Akaike info criterion		16.76754
Sum squared resid	6151734.	Schwarz criterion		16.85831
Log likelihood	-80.83768	Hannan-Quinn criter.		16.66796
F-statistic	1.239840	Durbin-Watson stat		0.843020
Prob(F-statistic)	0.345991			

Source: Own results using EViews 10.

In Slovakia, 60.84% of FI variation is determined by the two independent variables. The regression model is statistically significant, F-statistic = 5.438739, p= 0.037564.

The constant has a high value, 14,054.56, for p = 0.0292 showing that agricultural income is high in this country. GVA has a negative regression parameter, β_1 = -15.76595, for p= 4858, while LP has a small parameter β_2 = 0.972674, p= 0.1657. All these reflects that in this country both GVA and LP have a non-significant effect on FI, GVA contributing in a negative way, while LP in a positive manner. Therefore, it could be supposed that in Slovakia, the effects of GVA and LP on FI are hidden by the high collinearity explained by the correlation r = 0.966 among the two independent factors (Table 12).

In Slovenia, 68.90% of the FI variation is caused by the change of the two independent factors. The model of regression equation is statistically significant, F–Statistic = 7.755679 for p= 0.016766. GVA has a positive and substantial impact on FI, β_1 = 18.96863, for p= 0.0208, while LP has a negative regression parameter, β_2 = -0.720012, p= 0.0811 (Table 13).

Table 12. Results of the regression analysis, Slovakia

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	14054.56	5141.635	2.733480	0.0292
GVA	-15.76595	21.42731	-0.735788	0.4858
LP	0.972674	0.628555	1.547478	0.1657
R-squared	0.608446	Mean dependent var		19046.40
Adjusted R-squared	0.496573	S.D. dependent var		2863.039
S.E. of regression	2031.400	Akaike info criterion		18.31416
Sum squared resid	28886103	Schwarz criterion		18.40494
Log likelihood	-88.57082	Hannan-Quinn criter.		18.21458
F-statistic	5.438739	Durbin-Watson stat		0.652358
Prob(F-statistic)	0.037564			

Source: Own results using EViews 10.

Table 13. Results of the regression analysis, Slovenia

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1106.192	1279.729	0.864396	0.4160
GVA	18.96863	6.384439	2.971072	0.0208
LP	-0.720012	0.353578	-2.036361	0.0811
R-squared	0.689046	Mean dependent var		6104.900
Adjusted R-squared	0.600202	S.D. dependent var		762.2775
S.E. of regression	481.9850	Akaike info criterion		15.43703
Sum squared resid	1626167.	Schwarz criterion		15.52780
Log likelihood	-74.18514	Hannan-Quinn criter.		15.33745
F-statistic	7.755679	Durbin-Watson stat		1.744102
Prob(F-statistic)	0.016766			

Source: Own results using EViews 10.

CONCLUSIONS

This research was destined to present the analysis of real factor income per full-time worker in agriculture in 8 selected CEECs: Bulgaria, Croatia, Czechia, Hungary, Poland, Romania, Slovakia and Slovenia and to identify in what measure gross value added and labor productivity influences income level, based on the data provided by Eurostat for the period 2015-2024 and using statistical-econometric modeling which involved the determination of Pearson's correlations between the variables, multilinear regression equations, Ordinary Least Square Method and the assistance of EViews10 software.

The main results showed that:

-In 2024 vs. 2015, factor income, in terms of real income per full time worker in agriculture has registered an ascending trend in Bulgaria **(+**88.7%), Poland (+ 52.8%), Croatia (+ 25.4%), Czechia (+23.5%), Hungary (+ 13.7%), a slight growth in Slovenia (+4.9%) and Slovakia (+3.2%), and a decline in Romania (-15%).

-Gross value added has also an upward tendency, the gains at the end of the interval being: +93% in Poland, +86.4% in Croatia, +64% in Czechia, +46% in Slovakia, +37.5% in Romania, +29.5% in Slovenia, +26.4% in Bulgaria and +19.8% in Hungary.

-Labour productivity also went up year by year in 2024 being higher by +178.87% in Poland, +167% in Bulgaria, +150% in Hungary, +105 % in Croatia, +89.9% in Romania, +81.64% in Slovakia, +61.54% in Slovenia and +57.56% in Czechia.

-The average CAGR varied from a country to another. The highest CAGR for FI was noticed in Bulgaria, Poland and Slovakia and the lowest level in Romania. For GVA, the larger CAGR was observed in Poland, Croatia and Czechia and the smallest in Hungary. For LP, the highest CAGR was found in Poland, Bulgaria and Hungary and the smallest in Czechia.

-The CEECs have an important contribution to the EU-27 regarding these three indicators as follows: for EU FI, the main contributors are Poland, Romania and Hungary; for GVA: Poland, Romania and Croatia; for LP: Czechia, Hungary and Slovakia.
-For 1 Euro spent on farm inputs for production process, at the EU-27 level it is produced 0.75 GVA in average, but in the CEECs, the economic efficiency is smaller: Romania 0.80, Bulgaria 0.68, Poland 0.62, Slovenia 0.60 and only 0.33 in Slovakia. The only exception is Croatia, where the efficiency of 1.21 exceeds the EU-27 average by + 0.46.
-The coefficients of correlation between the pairs of variables, where Y = Factor income, the dependent variable, x_1 = GVA and x_2 = LP, have varied from a country to another reflecting the disparities which are still present in the agriculture of these countries regarding farms structure, labor force, production structure, land use and applied technologies.
-In Bulgaria, Czechia, Poland it was found a large positive and significant relationship between FI-GVA, FI-LP and GVA- LP. In Croatia, a large positive and strong relationship is between FI-GVA and GVA-LP and also a moderate relationship between FI-LP. In Hungary, between GVA-LP is positive and strong connection, but in case FI-GVA it is a positive and moderate one, while for FI-LP, the link is smaller than 0.5. In Romania, GVA-LP has a positive and very strong link, FI-GVA is positive but weak, FI-LP is small about 0.3. Slovakia has a GVA-LP positive and very strong relationship, also in case of FI –LP, and for FI –GVA a moderate connection. A similar situation is in Slovenia as well.
Comparatively analyzing the results regarding the regression equations, it could be affirmed that the econometric models are very different as a reflection the existing gaps and peculiarities in agriculture of each member of the CEECs. The intercept had a high value in case of Slovakia and Czechia, the regression parameter β_1 has a high positive value in Slovenia and Croatia and even in Czechia, while in Romania has the smallest positive value and in Slovakia the highest negative value. The parameter β_2 had positive values only in Slovakia, Poland and Bulgaria.
In Hungary and Romania, FI has a very small R squared, which means that other factors have a much higher influence than GVA and LP. In consequence, it is needed an additional analysis to establish if FI is influenced by agrarian structures, subsidies, land price etc.
In Bulgaria, Croatia, Czechia, Slovenia and Poland, the high R squared shows that the variation of FI is related to the variation of the independent factors, GVA and LP.
In some cases, it was noticed the effect of multicollinearity between GVA and LP on FI.
As a final conclusion, this study proved a large variation in factor income among the CEECs, despite that there is a slight trend of convergence and not significant. Factor income should be sustained to develop through farmers' efforts to find solutions to better use the direct payments for enabling to reimburse the capital, to cover the wages and the land lease and also to reward their own production factors.

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PRODUCTION COSTS, REVENUES, INTERMEDIARY CONSUMPTION AND GROSS VALUE ADDED IN BULGARIA AND ROMANIA'S AGRICULTURE

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Abstract

The study aimed to assess production costs (PC), incomes (I), intermediary consumption (IC), gross value added (GVA) and the GVA per Euro 1 expenses in Bulgaria and Romania, to point out the gaps and suggest solutions for a sustainable development of agriculture in the future. The period of analysis was 2015-2024 for which Eurostat provided data. The methodology included: illustrative dynamics, structural indices, comparisons, averages and standard deviations, coefficient of variation, CAGR, regression equations, tabled results. The main results are: production costs decreased by 13.8% in Bulgaria and 7.7% in Romania. In Romania, costs are 3.5 times higher than in Bulgaria. In 2024, the top costs belonged to other costs 22.2%, rents 21.5%, labour 16.4%, feeding stuffs 11.6% and fertilizers 9.7%. In Romania, the top costs are other costs 46%, feeding stuffs 14%, energy 12.5% and labour 8.7%. Total revenues decreased by 27.8% in Bulgaria and by 17.3% in Romania, the last having a 3.9 times higher income. The top source of revenue in Bulgaria and Romania is crop production. On the 2nd position, in Bulgaria are subsidies, followed by animal production and in Romania animal production and subsidies. In 2024, IC in Romania accounted for Euro Mil. 11,367, while Bulgaria Euro Mil. 2,915. GVA from agriculture increased by 26.4% in Bulgaria, while in Romania by 37.5%. In 2024, Romania had Euro Mil. 8,944 GVA, while Bulgaria Euro Mil. 2,048. GVA/IC was higher in Romania than in Bulgaria in the studied period. In 2024, Romania achieved Euro 0.79 GVA, while Bulgaria 0.73 for 1 Euro spent on IC, being close to 0.75 the EU-27 average. To improve the efficiency in agriculture: Bulgaria and Romania must obtain a higher GVA, increasing agricultural output and keeping under a rigorous control IC. Bulgaria must reduce other costs and rents, while Romania to diminish other costs. To increase income, it is required production diversification, intensification of agricultural services and non-agricultural activities. Romania needs investments in modern technologies and more qualified work force grow labour productivity. Initiatives to join the resources (land, labour, capital) must continue associative forms could be welcome to optimize production costs, delivery of agri-products across the product chain and increase agricultural output value and GVA.

Key words**:** *production costs, revenues, intermediary consumption, gross value added, agriculture, Bulgaria, Romania*

INTRODUCTION

To achieve agri-products, farm managers must assure the inputs which are required during the production process both in the vegetal and animal sector.

The main farm inputs used in agriculture are: land, biological material, fertilizers, pesticides,

labour, feedstuffs, energy, water and machinery and equipment which involves expenditures.

Land could belong to the owner or could be leased from other owners for which the farmers must conclude contracts and pay the corresponding rent or lease; soil quality depends on soil type, physical composition, texture, content of nutrients, especially humus, water and oxygen and it is very important to sustain plant development during the vegetation period and yield [31]; grasslands sustain animal growing providing forages for livestock which could directly graze the green grass from spring to autumn or benefit of hays during winter season; they also protect soil against erosion and foods risk, offer habitat for various pollinators, sequestrate carbon and represent marvelous landscapes [6].

Biological materials Plant culture needs seeds and planting material (seedlings, cuttings, tubers, bulbs, roots etc) of various varieties and hybrids with high genetic potential and quality which are very important to assure the expected yields [19]. Animal growing requests young animals of various breeds or cross-bred offspring resulting from high value genitors and which are selected at the farm level or bought from the market by farmers to invest in the future growth of animal production: milk, meat, egg etc [2].

Fertilizers play a special role in maintaining and increasing improve soil fertility grace to their content in nutrients like: Nitrogen, Phosphorus, Potassium etc and also are required for increasing production [3].

Pesticides (herbicides, insecticides, fungicides, rodenticides) are needed to protect crops against weeds, insects, fungi, rodents etc.; however, the chemical substances could pollute soil, water and air, the environment quality as a whole and for this reason they must be used carefully not to create risks of contamination and health problems; in many countries and especially in the EU, there are severe rules regarding the use of this type of substances. An alternative is to use bio-pesticides based on pheromones, microorganisms, plant extract, minerals etc which are both efficient and environmental friendly [5].

Labour is the main driver in agriculture which valorises land and fixed capital to carry out agri-products; the quality and training level of workforce impose the performance in productivity and efficiency in term of production per worker, which could increase income for the rural population and assure the success in agri-business; labour input is also an important factor of influence on labour productivity; the more workforce, the less labour productivity [8]; the less work force but of a high training level could allow the implementation of the advanced technologies like: Io T and sensors for establishing the right moment for sowing in connection with soil temperature and moisture content, precision agriculture (GPS, drones, sensors etc) for monitoring planting, growing and harvesting, automation and robotics which involves robots for planting, weeding, harvesting, storing etc, and AI tools (machine learning, big data, IoT) for optimizing farm management [4].

Feedstuffs are required in animal farming for nourishing the species and animal categories to assure their life, health, reproduction, growth and production; their content must assure the essential nutrients: proteins, fats, carbohydrates, vitamins and minerals etc according to the rations adapted to each growth purpose, animal species and category; feedstuffs are of a large variety: green grass, hay, straw, silage, roots, tubers etc [30].

Energy (fuel, electricity, solar) is essential in agriculture to put in work machinery, irrigation systems, fertilizer and pesticides spreading, climatized storing, transportation, post-harvest processing etc.; renewable energy sources are very important to reduce pollution and enhance production quality and protect environment against pollution [18].

All these farm inputs involve various costs for purchasing the corresponding products and materials in the required amounts and at the market price.

In addition, production cost could include rents, interest to loans of borrowings, taxes and other costs.

Water is compulsory for plant growing either natural from precipitations or through

irrigation systems. Also, in animal farming water maintains life and sustain production.

Machinery and equipment are necessary for enabling the farmers to prepare land, to plow, maintain crops, irrigate, harvest, transport, and store, for milking, watering, transporting feedstuffs, cooling milk, collecting eggs, sheep shearing, extracting honey etc.

Production cost depend on crop or animal species and category, on purpose for which they are raised, technology applied, the degree of mechanization, farm management and farm manager capacity to keep under a continue control production costs and find solutions to reduce them for the same expected production level, that is to ensure a high economic efficiency of his business.

Production costs must be covered by farm income, whose value is expected to be higher and assure profit for farmers to enable them to continue their business.

The revenues in agriculture come from the marketed plant and animal products, subsidies on product or other type, agricultural services run for beneficiaries and from non-agricultural secondary activities which cannot be separable such as agro-tourism.

Income in agriculture depends on a large range of factors such as: crop or animal sector, geographical position of the farm location, climate and soil fertility, farm size, specialization, labour productivity, yields, production, marketed products, market prices, off-farm incomes, policy support etc. [11].

To carry out the production process in agriculture, farmers make use of intermediary consumption which include the expenditures for assuring the farm inputs.

The agricultural output value results from summing the market value of all crops, animals and products achieved in a farm during a year. From the value of agricultural production, the expenditures for intermediary consumption are subtracted and the remaining represent the gross value added.

Gross value added is a measure of the productivity achieved by a producer, economic sector, region and economy. It is the economic indicator which reflects labour productivity, calculated dividing GVA by AWU, for example in the EU. It is also used to calculate the contribution to GDP, if from GVA there are subtracted the subsidies on products and added Taxes on products [24].

More than this in the EU, the economic efficiency in agriculture is expressed by the ratio GVA/Intermediary consumption, which reflects how much GVA was produced by Euro spent on intermediary consumption.

The main aspects regarding this research framework were approached by many authors, but because the study case regards only two countries Bulgaria and Romania, in this paper there are cited especially the ones who belong to this scientific environment.

Bulgaria is facing with new challenges and trends especially in fruit and vegetable sector regarding the cultivated areas and production in relationship with export and imports determined by the goals to align agriculture sustainable development according to the EU "Farm to Fork" strategy [1, 22].

Agriculture needs a better agrarian structure for increasing gross value added, labour productivity and farm income [27, 21].

The assessment and reduction of the use of fertilizers and pesticides are compulsory to produce healthier agri-products and maintain environment quality [28, 29].

To reduce the cost of energy in agriculture, it is an opened box to renewable energy which could enhance both agriculture and rural areas development [44].

Efficiency and productivity in agriculture depend on labour input, the volume of production and production costs [23, 25, 26].

In the light of the EU Green Deal, Bulgaria strategy is focused on farms, employed people in agriculture and location index for rural areas [42].

Subsidies are needed to sustain farmers and increase profitability [20].

The development of agriculture in the coming future must be based on digitalization which imposes a deep evaluation of its determinants and challenges to sustain a realistic implementation strategy [7].

In Romania, agricultural production was studied in close relationship with production cost in conventional but also in organic system

[9]. A comprehensive study on production cost in agriculture was made by [43].
The level and structure of production costs differ in close relationship with the economic size of the farms [10].
The cost of energy used in agriculture differs depending on crop technology and mechanization degree and the comparison between organic and conventional system could offer solutions to reduce energy and the related expenses [32].
Gross margin, as a barometer of efficiency and profitability both in crop and animal farming, highlighted the need to increase profitability by optimizing costs, especially variable costs [33].
This is proved even in beekeeping, where the apiculturists' income depends on honey production level and also on the related expenses to achieve it [34].
In dairy farming, profit is deeply linked to the amount of milk marketed to the processing industry and also to production cost per one liter of milk [35].
Labour productivity in Romania's agriculture is still small, because of the dominance of small subsistence and semi-subsistence farms where technologies applied are still traditional and labour input I still high [36].
Agricultural output is generated in a larger proportion by crop sector and in a much lower percentage by animal farming as a consequence of the continuous decline of the livestock and its production [37, 38].
Because of the largest number of agricultural holdings and their lower performance in Romania compared to other EU countries, the amount of chemicals used per hectare is much smaller, both regarding fertilizers and pesticides.
However, according to the EU Green Deal, Romania makes efforts to align its agriculture to the attain the proposed goals [39, 40]. Despite of the efforts done, there are still disparities regarding agricultural development in the territory of Romania [41].
In this context, this research aimed to analyze production costs, revenues, intermediary consumption, gross value added and efficiency in terms of GVA achieved by Euro 1 spent in Bulgaria and Romania in the period 2015-2024, based on the data provided by Eurostat and to point out the differences regarding these indicators and identify ways to better sustain agriculture development in the future.

MATERIALS AND METHODS

The study involved many updated information picked up from the specialized literature on the topic.
The studied and selected indicators have been: production costs, revenues, intermediary consumption, gross value added and economic efficiency expressed by the ratio between GVA and intermediary consumption in agriculture of two EU member states: Bulgaria and Romania.
The data were provided by Eurostat data base and regard the period 2015-2024.
The processing methods involved:
-Graphical representation of the dynamics of each indicator;
-The calculations of the mean values, standard deviations, coefficients of variation and CAGR;
-The calculation of the structure of production costs and revenues;
-The determination of the regression equations and R square for some indicators;
-The calculation of GVA/IC ratio and the determination of the graphical representation for comparing the performance achieved by the two countries.
A part of the results has been displayed in tables destined to show the differences among these countries.
The results have been correspondingly interpreted and finally, the conclusions synthetized the main ideas resulting from this research.

RESULTS AND DISCUSSIONS

Brief presentation of agriculture in Bulgaria and Romania

The selected indicators regarding agriculture in Bulgaria and Romania in the year 2024 are presented in Table 1.

Table 1. Main statistical indicators characterizing agriculture in Bulgaria and Romania in 2024

	Indicator	**MU**	**Bulgaria**	**Romania**
1	Utilized agricultural land	ha	4,419,350	12,550,330
2	Arable land	ha	3,285,180	8,481,980
3	Number of agricultural holdings	No.	107,630*	2,859,360*
4	Farm labour force	No. persons	254,910	7,352,200
5	Value of agriculture output industry at basic prices	Euro Million	4,963	20,211
6	Intermediate consumption	Euro Million	2,915	11,267
7	Gross value added of agricultural industry at basic price	Euro Million	2,048	8,944
8	Labour productivity	Euro/AWU	20,011**	10,845**
9	Agriculture factor income, real per full-time worker	Euro/AWU	11,530	3,509

*In 2023. **In 2022.
Source: Eurostat [12, 13, 14, 15, 16, 17].

Dynamics and structure of production costs in Bulgaria and Romania in 2024 versus 2015

In 2024, the value of production costs in Bulgaria was Euro Million 3,200, by 13.8% smaller than Euro Million 3,711 in the year 2015.

In Romania, production costs attained the value of Euro Million 11,405 in 2024, losing 7.7% compared to Euro Million 12, 344 in 2015. Comparatively analyzing the figures, it is easy to notice that in Romania versus Bulgaria production costs are higher, taking into account the differences exiting between the two EU member states regarding the utilized agricultural area, arable land, number of farms and agrarian structure, labour force, technologies applied, farmers managerial capacity to run their business, and business profile purpose and size.

In Bulgaria, the costs of seeds, fertilizers, labour, rents, taxes and other costs increased, while the expenditures with plant and animal protection, feeding stuffs and energy declined.

In Romania, in 2024, it was registered a substantial decline of the expenditures for seeds, fertilizers, plant and animal protection and feeding stuffs, energy, rents, taxes, while labour, interest and other costs increased (Table 2).

Table 2. The value and structure of production costs in Bulgaria and Romania in 2024 versus 2015 (real prices Euro Million)

Crt. No.	**Cost item**	**Bulgaria**			**Romania**		
		2015	2024	Absolute differences	2015	2024	Absolute differences
1	Seeds	89	115	+26	708	585	-123
2	Fertilizers	188	276	+88	595	480	-115
3	Plant and Animal protection	319	175	-144	584	446	-138
4	Feedstuffs	520	371	-149	2,525	1,596	-929
5	Energy	578	303	275	1,794	1,415	-379
6	Labour	411	523	+112	690	997	+307
7	Rents	517	691	+174	171	123	-48
8	Interest	17	23	+6	84	162	+78
9	Taxes	1	10	+9	23	15	-8
10	Other costs	1,071	713	+358	5,170	5,586	+416
	Total costs	**3,711**	**3,200**	**-511**	**12,344**	**11,405**	**-939**

Source: Own calculations based on the data from Europa.eu., 2026 [17].

In Bulgaria, in 2024, the highest expenditures are for other costs, followed by rents, labour and feeding stuffs, energy and fertilizers and this is also explained by the price growth. The cost for seeds and taxes remained relatively at the same level (Fig. 1).

Figure 2 provided an image on the production costs dynamics in Romania's agriculture in the analyzed interval. The top costs belong to other costs, followed by feedstuffs and energy. While other costs recorded almost a continuous growth, the expenditures spent on feedstuffs

and energy started to decline since 2022 to 2024.

The other costs remained relatively at a constant level, in de decreasing order being: labour, seeds, fertilizers, plant and animal protection, rents and taxes.

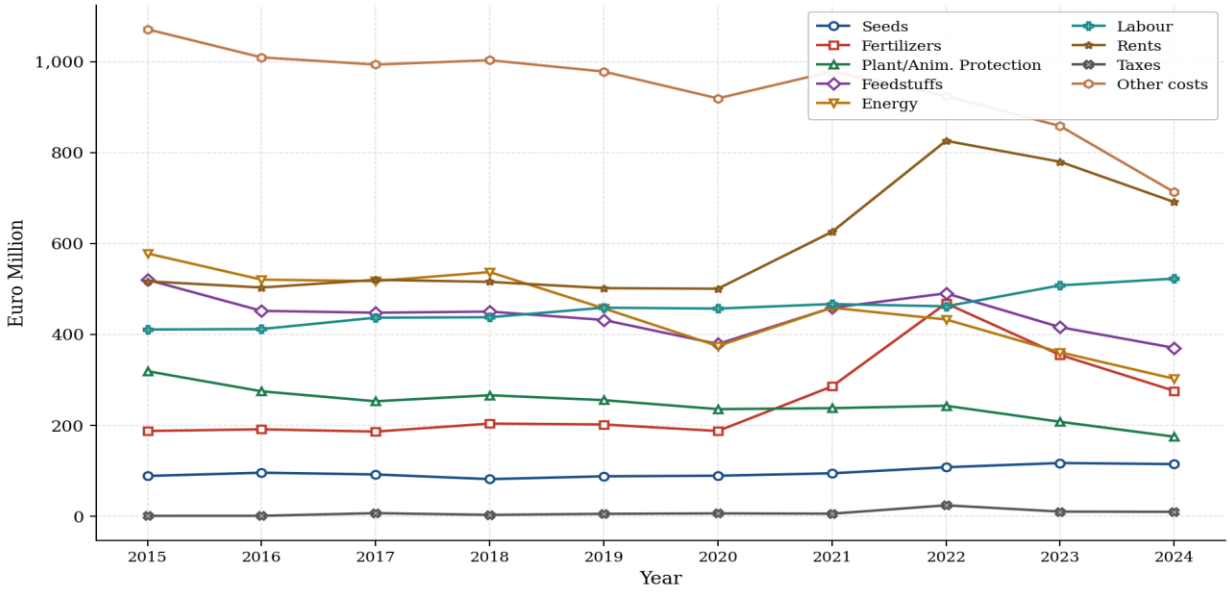


Fig. 1. Dynamics of production costs by cost item in Bulgaria, 2015-2024 (Euro Million)
Source: Own design based on the data from Europa.eu., 2026 [17].

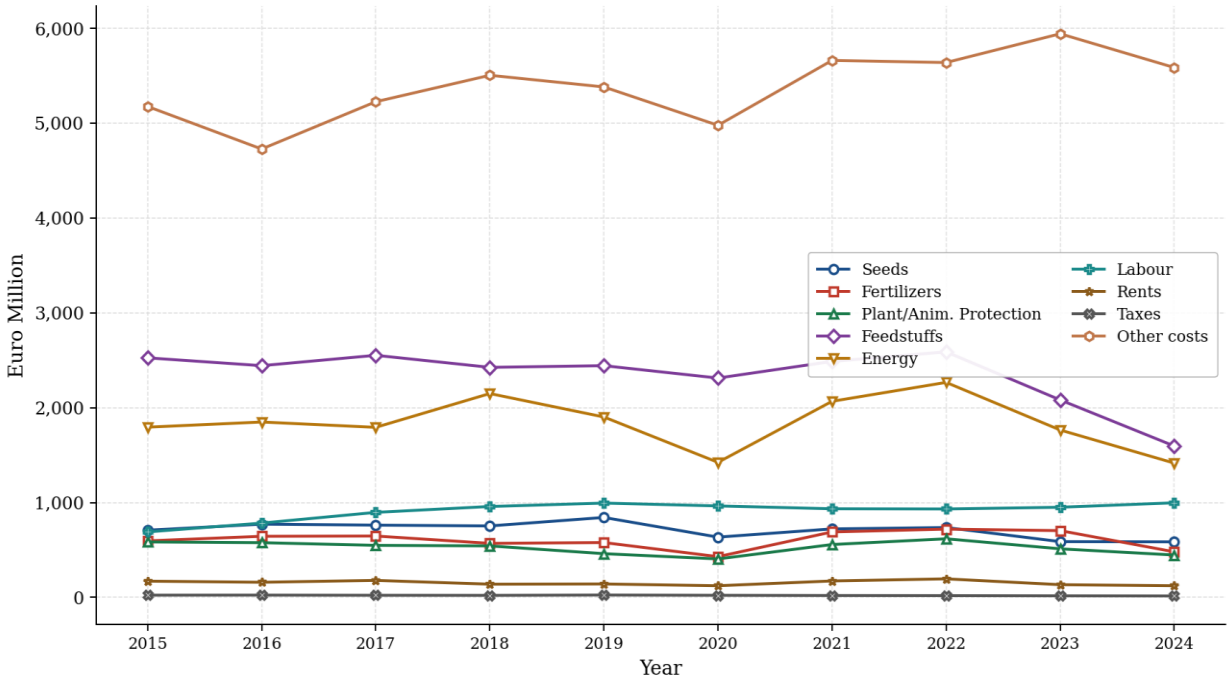


Fig. 2. Dynamics of production costs by cost item in Romania, 2015-2024 (Euro Million)
Source: Own design based on the data from Europa.eu., 2026 [17].

The production cost structure is more relevant illustrated by Fig. 3 and Fig. 4, where there are shown the shares of each item cost in total costs in the year 2024 in Bulgaria, and, respectively, in Romania.

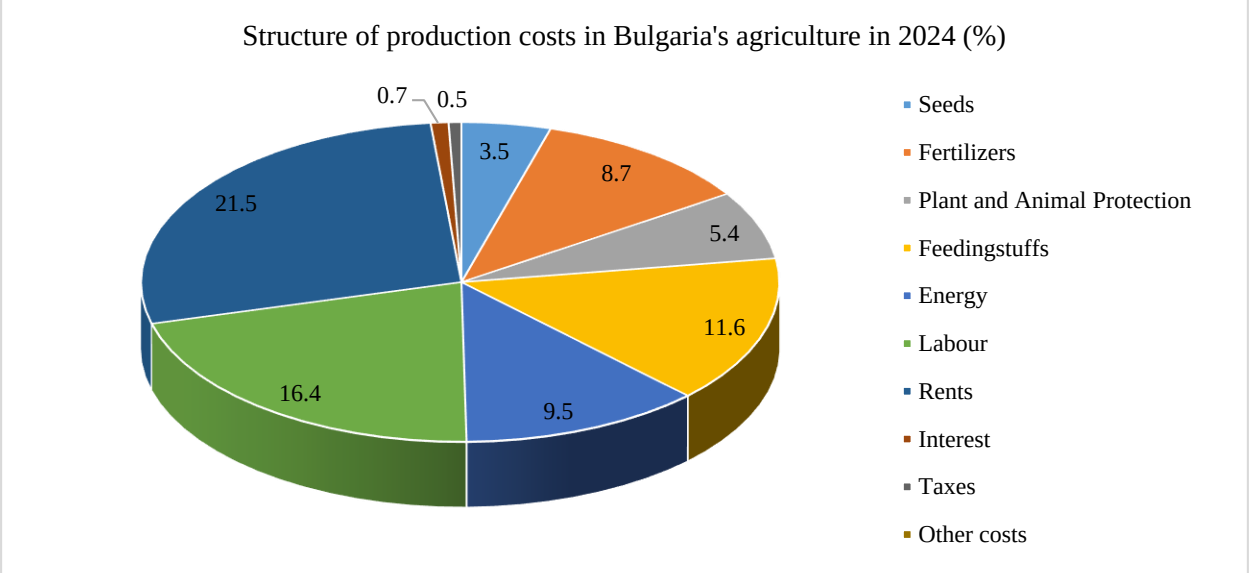


Fig. 3. Structure of production costs in Bulgaria's agriculture in 2024 (%)
Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

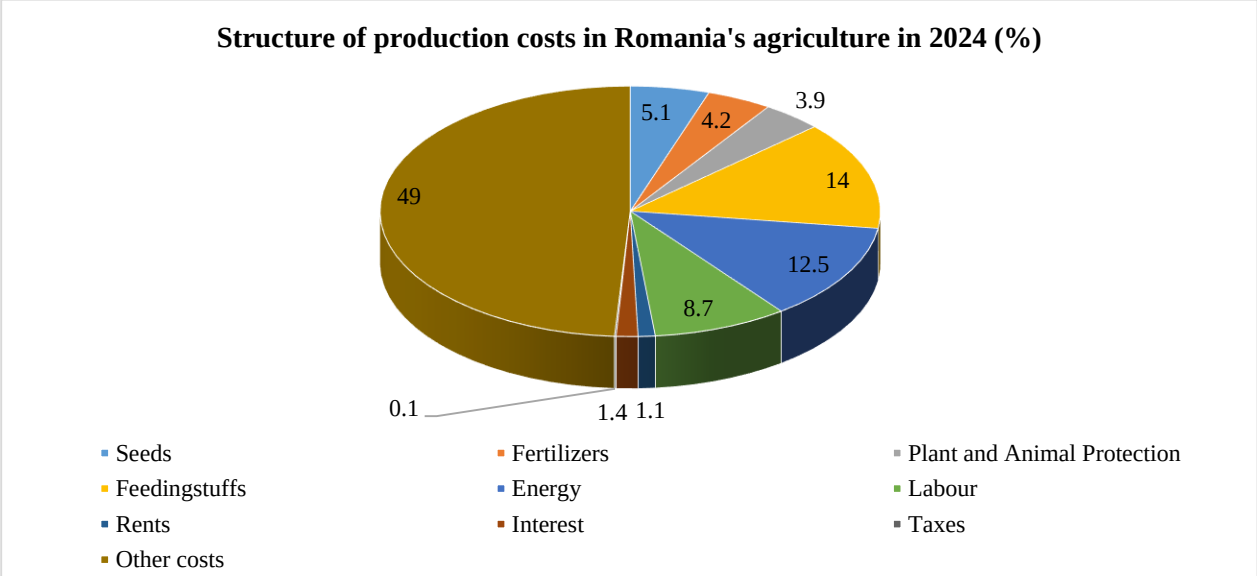


Fig. 4. Structure of production costs in Romania's agriculture in 2024 (%)
Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

If we make comparisons between the two countries, we may observe that the weights of seeds, feeding stuffs, energy, interest and other costs increased in Romania by +1.6 pp, +2.4 pp, 3 pp, 0.7 pp and 2.4 pp compared to their shares in Bulgaria (Table 3).

In the analyzed interval, the means, standard deviations, coefficients of variation and CAGR for the agricultural production costs by cost item are presented in Table 4 for Bulgaria and in Table 5 for Romania.

In case of Bulgaria, the coefficient of variation of labour reflects that the data are homogenuous and concentrated around the mean and could be considered representative.

In case of seeds, plant and animal protection, feeding stuffs, energy, the coefficient of variation is ranging between 10-20%, reflecting that the data are relatively homogenous.

A higher variation coefficient was noticed for fertilizers, rents and mainly taxes, which points out that the dispersion of the variables is considerably high, and, as a consequence, the average is not representative (Table 4).

Table 3. Comparative structure of production costs in Bulgaria and Romania in 2024

Crt. No.	Cost item	Comparative structure of production costs (%)		Differences RO –BG (pps)
		Bulgaria	Romania	
1	Seeds	3.5	5.1	+1.6
2	Fertilizers	9.7	4.2	-5.5
3	Plant and Animal protection	5.4	3.9	-1.5
4	Feeding stuffs	11.6	14.0	+2.4
5	Energy	9.5	12.5	+3.0
6	Labour	16.4	8.7	-7.7
7	Rents	21.5	1.1	-20.4
8	Interest	0.7	1.4	+0.7
9	Taxes	0.5	0.1	-0.4
10	Other costs	22.2	46.0	+24

Source: Own calculations based on the data from Europa.eu., 2026 [17].

Table 4. Mean St. Dev, CV% and CAGR% for production costs by item in Bulgaria, 2015-2024 (Euro Million)

	Mean	St. Dev.	CV%	CAGR%
1.Seeds	97.16	12.10	12.45	2.60
2.Fertilizers	254.51	94.37	37.08	3.93
3.Plant/Anim. protection	247.00	38.57	15.61	-5.82
4.Feedstuffs	441.79	45.71	10.35	-3.34
5.Energy	454.13	87.70	19.31	-6.27
6.Labour	457.40	36.49	7.98	2.44
7.Rents	598.23	125.43	20.97	2.95
8.Taxes	7.52	6.70	89.14	24.55
9.Other costs	945.02	100.28	10.61	-3.99

Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

In case of Romania, the lowest variation coefficient was identified for other costs, accounting for 6.71%, the mean being representative. But, for the most costs: seeds, fertilizers, plant and animal protection, feeding stuffs, energy, labour, rents and taxes, the variation coefficients vary between 10-20% highlighting the relative homogeneity among the data for each cost item (Table 5).

Table 5. Mean St. Dev, CV% and CAGR% for production costs by item in Romania, 2015-2024 (Euro Million)

	Mean	St. Dev.	CV%	CAGR%
1.Seeds	710.28	83.54	11.76	-1.88
2.Fertilizers	605.48	95.38	15.75	-2.13
3.Plant/Anim. protection	525.00	67.86	12.93	-2.66
4.Feedstuffs	2345.30	300.50	12.81	-4.49
5.Energy	1,842.27	278.21	15.10	-2.35
6.Labour	909.80	98.45	10.82	3.75
7.Rents	153.50	25.24	16.44	-3.25
8.Taxes	20.62	3.26	15.80	-4.32
9.Other costs	5,382.00	361.26	6.71	0.77

Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

Dynamics and structure of revenues from Bulgaria and Romania's agriculture in 2024 versus 2015

A detailed image of the agricultural revenues by type in the last year of the analyzed interval 2024, versus the 1st year, are shown in Table 6 both for Bulgaria and Romania.

In the studied period, Bulgaria performed a decline by 27.8% in agricultural income, from Euro Million 4,923 in 2015 to Euro Million 3,556 in 2024.

Analyzing the figures by each income item, we may notice that all the types of revenues decreased.

The highest level of revenue comes from crop output and then from subsidies and other revenues (Table 6).

In Romania, the agricultural revenues also decreased, but from Euro Million 16,942 in 2015 to Euro Million 14,023 in 2024, meaning a loss by 17.3%. The highest revenue is provided by crop output and on the 2nd position comes animal output. Then, other revenues and subsidies also contribute to total income. Within other revenues, the peak value belongs to non-agricultural secondary revenues which cannot be separable, like the ones offered by agri-tourism which has known a well development during the last decades.

Therefore, in case of Romania, the only revenue items which increased are other revenues and other subsidies (Table 6).

Table 6. Structure of revenues from agriculture in Bulgaria and Romania in 2024 versus 2015 (Real prices, Euro Million)

Crt. No.	Revenue item	Bulgaria			Romania		
		2015	2024	Absolute differences	2015	2024	Absolute differences
1	Crop output	2,626	1,809	-817	9,802	6,958	-2.844
2	Animal output	1,041	729	-312	4,020	3,615	-405
3	Subsidies	890	780	-110	1,577	1,594	+17
	-on product	213	79	-134	0	0	0
	-other subsidies	677	701	+24	1,577	1,594	+17
4	Other revenues	366	238	-128	1,643	1,856	+213
	-Agricultural services	248	155	-93	193	444	+251
	-Non-agricultural secondary revenues which cannot be separable	118	83	-35	1,450	1,412	-38
	Total revenues	**4.923**	**3,556**	**-1,367**	**16,942**	**14,023**	**-2.919**

Source: Own calculations based on the data from Europa.eu., 2026 [17].

Figure 5 shows the dynamics of each type of revenue in Bulgaria. The illustration offers us a clear view of each item. Crop output is in the top, but after an inflexion downward in 2020 and a short recover till 2022, crop production registered a deep decline in 2024.

On the 2nd position are subsidies, but since 2020, they registered a downward trend as well, animal output and other incomes have remained relatively stable in the analyzed interval, just a little slight decline could be observed (Figure 5).

In Romania, crop output is also the main source of income, and even in this country, since 2018 to 2020, when crop production declined due to the negative impact of climate change, a short recover till 2021 was noticed, but then the income provided by this sector has continuously decreased so that in 2024 it achieved the smallest level in the interval 2015-2024.

On the 2nd position comes animal output, but it is far away from crop output level, explained by the deep decline in livestock and animal production. On the last positions, there are subsidies and other incomes (Figure 6).

Figure 7 illustrates that in Bulgaria 53.3% of agricultural income is delivered by crop farming, 21.1% by animal farming, 18.1% by subsidies and 7.45 by other revenues.

Figure 8 describes the structure of revenues in Romania's agriculture, showing that 49.6% comes from crop production, 25.7% from animal sector, 13.3% from other revenues and 11.4% from subsidies.

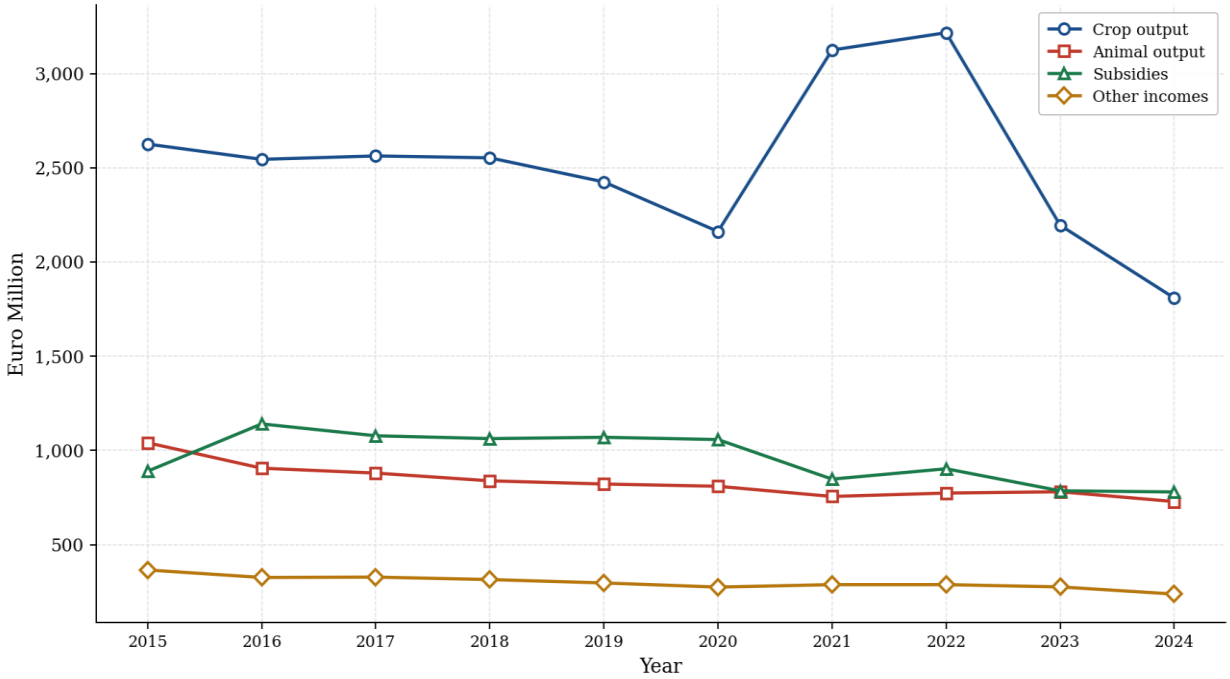


Fig. 5. Dynamics of production costs by cost item in Bulgaria, 2015-2024 (Euro Million)
Source: Own design based on the data from Europa.eu., 2026 [17].

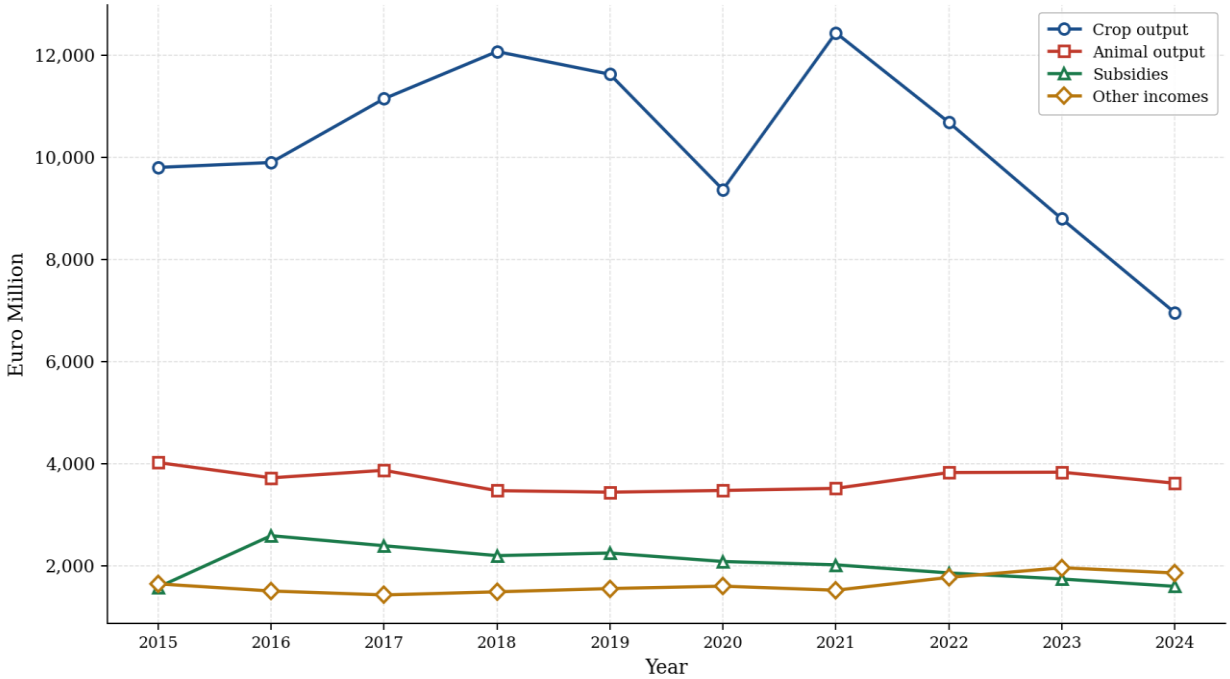


Fig. 6. Dynamics of production costs by cost item in Romania, 2015-2024 (Euro Million)
Source: Own design based on the data from Europa.eu., 2026 [17].

Table 7 presents the comparative cost structure in Bulgaria and Romania in the year 2024. In Bulgaria, crop output has a larger share in total revenue, 53.3% compared to 49.6% in Romania.

Animal output has a higher share in Romania, accounting for 25.7% versus 21.1% in Bulgaria.

Subsidies are more contributors to revenues in Bulgaria by 18.1%, while in Romania, their contribution is only 11.4%.

Other revenues are higher in Romania, with a share of 13.3%, compared to only 7.4% in Bulgaria.

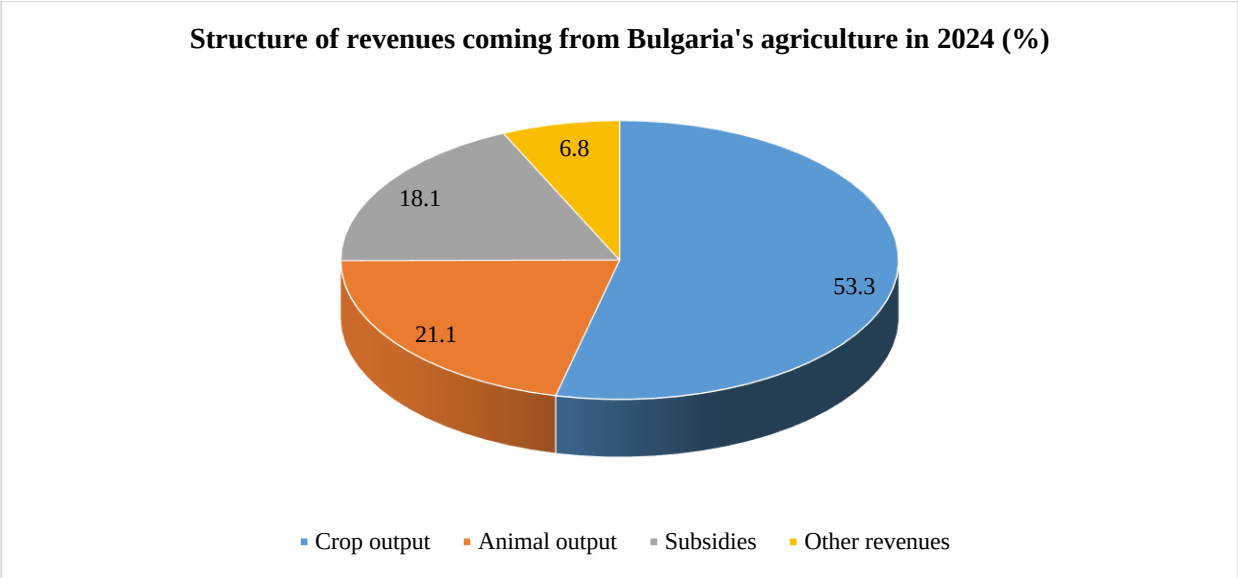


Fig. 7. Structure of revenues from agriculture in Bulgaria in 2024 (%)
Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

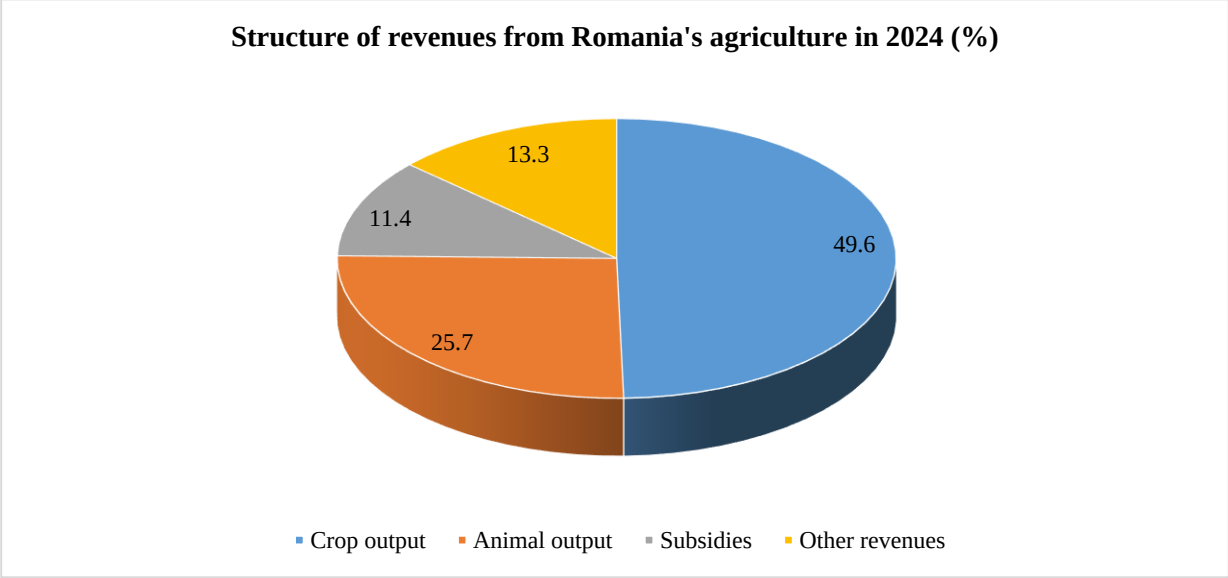


Fig. 8. Structure of revenues from agriculture in Romania in 2024 (%)
Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

Table 7. Comparative structure of revenues in Bulgaria and Romania in 2024

Crt. No.	Cost item	Comparative structure of revenues (%)		Differences RO –BG (pps)
		Bulgaria	Romania	
1	Crop output	53.3	49.6	-3.7
2	Animal output	21.1	25.7	+4.6
3	Subsidies	18.1	11.4	-6.7
4	Other revenues	7.4	13.3	-5.9

Source: Own calculations based on the data from Europa.eu., 2026 [17].

Table 8 presents the means, standard deviations, coefficients of variation and CAGR for the income items in Bulgaria's agriculture. The coefficient of variation ranged between 10-20% in case of all the income categories, reflecting a relative homogeneity among variables.

Table 8. Mean St. Dev, CV% and CAGR% for agricultural income by item in Bulgaria, 2015-2024 (Euro Million)

	Mean	St. Dev.	CV%	CAGR%
1.Crop output	2,522.00	423.60	16.80	-3.66
2.Animal output	833.80	90.93	10.91	-3.50
3.Subsidies	961.70	134.30	13.97	-1.31
4.Other incomes	299.70	35.56	11.87	-4.21

Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

Table 9 highlights that in Romania, the coefficients of variations are smaller than10% in case of animal output, the average being representative as the values of variables are concentrated around the average. But, the coefficients of variation for crop output, subsidies and other incomes vary between 10-20% pointing out that the variables are relatively homogenous.

Table 9. Mean St. Dev, CV% and CAGR% for agricultural income by item in Romania, 2015-2024 (Euro Million)

	Mean	St. Dev.	CV%	CAGR%
1.Crop output	10,278.90	1,668.69	16.23	-3.37
2.Animal output	3,677.30	203.64	5.54	-1.06
3.Subsidies	2,028.30	337.93	16.66	0.11
4.Other incomes	1,631.10	175.46	10.76	1.23

Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

Intermediary consumption in agriculture of Bulgaria and Romania

The level of this indicator has relatively increased in the both countries, being much higher in Romania than in Bulgaria.

The factors of influence are of a large variety as shown by R square value. In Romania, R square reflects that 63.57% of the intermediary consumption variation is caused by time, but probably market prices and the used amounts have a higher impact.

In case of Bulgaria, R square shows that only 58.12% of intermediary consumption is determined by time, and that in a constant manner other factors look to be more influent according to the specific conditions in the country (Fig. 9).

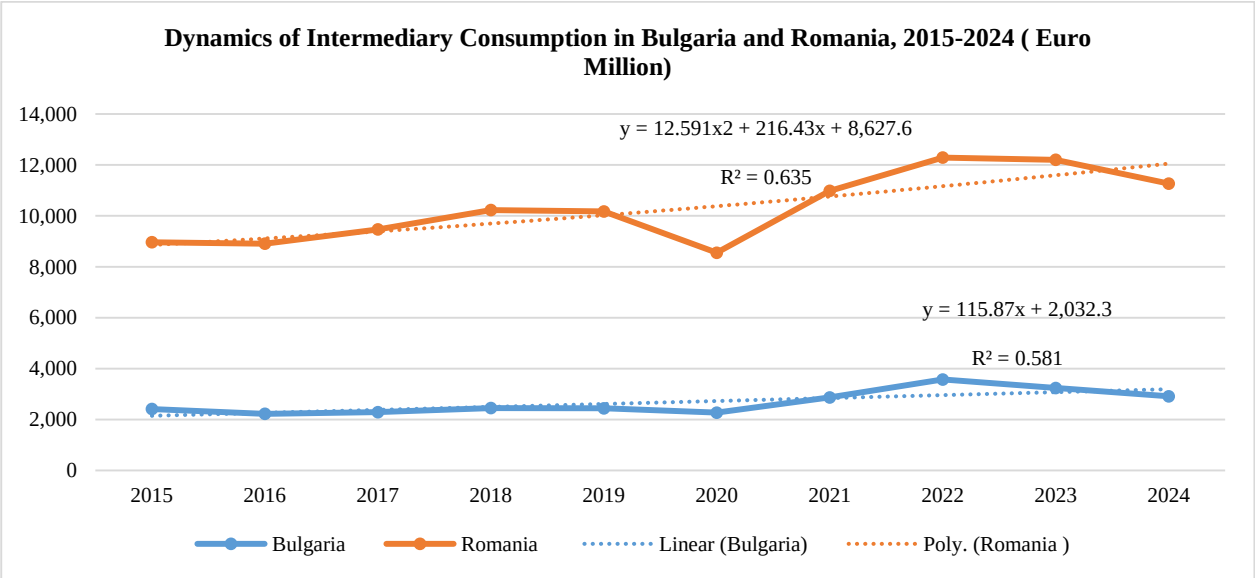


Fig. 9. Dynamics of Intermediary consumption in Bulgaria and Romania's agriculture, 2015-2024 (Euro Million)
Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

In Romania, intermediary consumption varied between Euro Million 8,964 in 2015 to Euro Million 11,267 in 2024, which means a gain of 25.69%.

In Bulgaria, the level of intermediary consumption ranged between Euro Million

2,413 in 2015 to Euro Million 2,915 in 2024, which means a gain of 20.67%.

Studying the trend line, we may notice that in Romania it was an inflexion in the year 2020, then a recover, but after 2022 the line has a downward tendency to 2024.

In case of Bulgaria, intermediary consumption had a relatively constant line till 2020, but after 2021, it recorded a peak in 2022, but then it declined to 2024.

However, in Romania intermediary consumption is 3.86 times higher than in Bulgaria's agriculture in 2024.

Gross value added in agriculture of Bulgaria and Romania

Having in mind the level of agricultural output value at basic prices and intermediary consumption at purchase price, gross value added resulted from their difference and creates a more profound image about the performance in the agricultural sector.

In the period 2015-2024, Bulgaria carried out a GVA accounting for Euro Million 2,048 in 2024, meaning by 26.41% more than Euro Million 1,620 in 2015.

In the same interval, in Romania, GVA from agriculture increased by 37.57% from Euro Million 6,501 in 2015 to Euro Million 8,944.

In Bulgaria, R square reflects that 39.7% of GVA variation is given by years and the remaining 60.3% is determined by other factors.

In Romania, R square tells us that 85.87% of GVA is caused by time and just a small part accounting for 14.12% is influenced by other factors (Fig. 10).

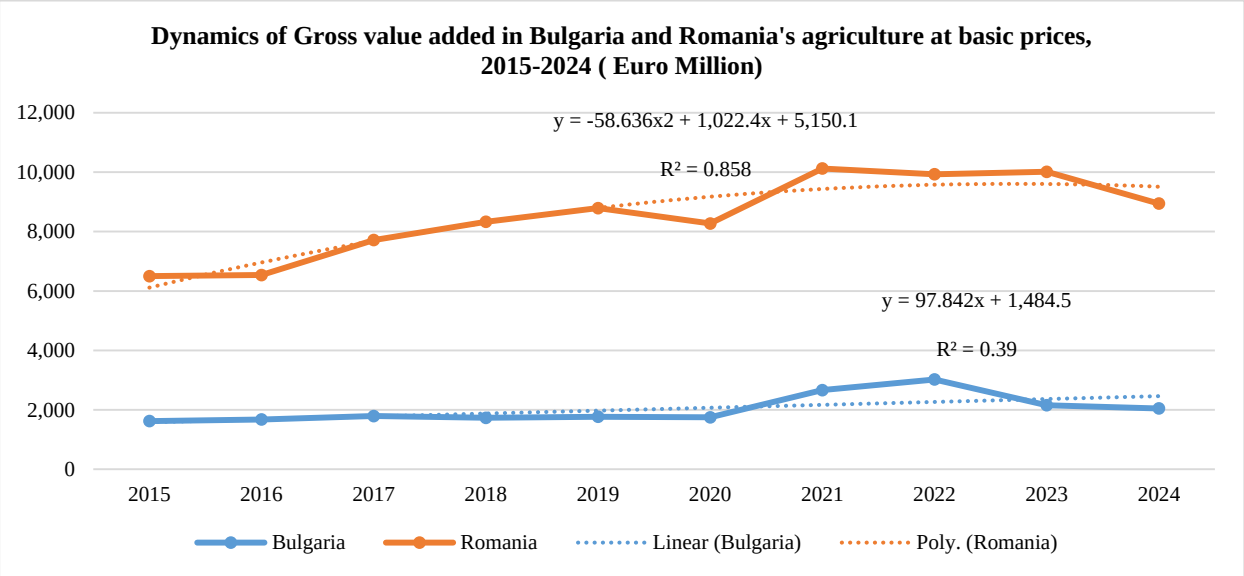


Fig. 10. Dynamics of Gross value added from agriculture in Bulgaria and Romania, at basic prices, 2015-2024 (Euro Million)

Source: Own design based and calculations based on the data from Europa.eu., 2026 [17].

Efficiency in agriculture of Bulgaria and Romania in terms of GVA achieved per Euro spent for intermediary consumption - IC

A comparative dynamics of the efficiency in agriculture expressed in the GVA value carried out per Euro one spent on farm inputs or intermediary consumption in Bulgaria and Romania is illustrated in Fig. 11.

The graphic reflects that the ratio GVA/IC is higher in Romania than in Bulgaria and, if we compare the levels got in 2024 with the EU-27 average accounting for 0.75, we may affirm that Romania exceeded a little the EU level, while Bulgaria is a little below.

However, the both countries could be considered around the EU-27 average, and this could be interpreted as an incentive to enhance their efforts to increase economic performance in their way to a sustainable development by optimizing the relationship between the factors which determine GVA and the factors which influence intermediary consumption.

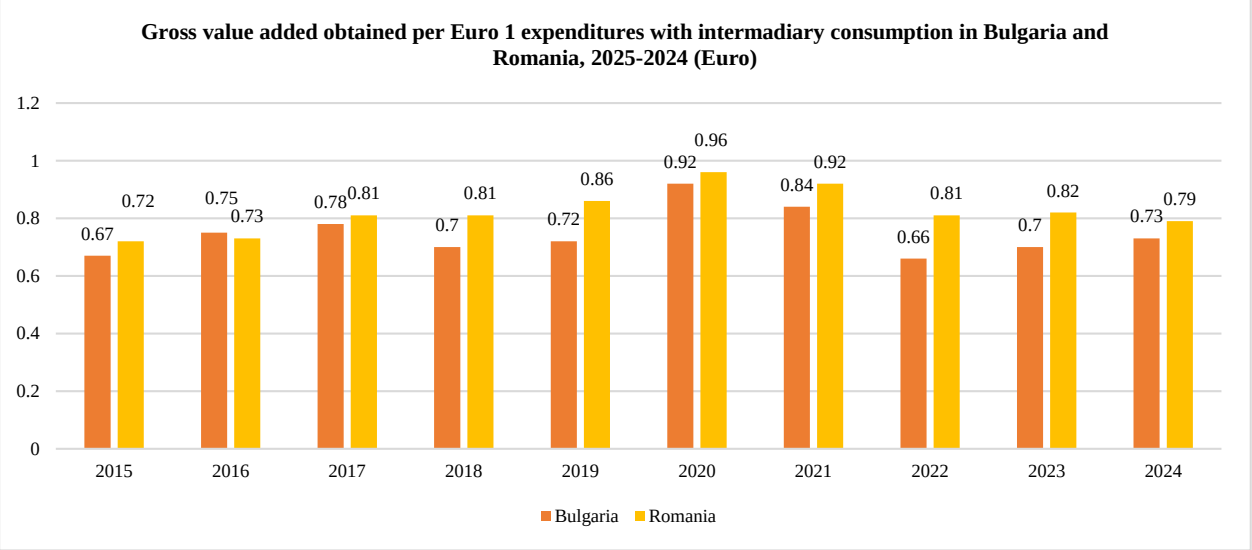


Fig. 11. Gross value added obtained in agriculture of Bulgaria and Romania per Euro 1 expenditures with intermediary consumption, 2025-2024 (Euro)
Source: Own design and calculations based on the data from Europa.eu., 2026 [17].

CONCLUSIONS

The study was destined to evaluate production costs, revenues, intermediary consumption, gross value added and efficiency in terms of GVA achieved by Euro 1 spent in Bulgaria and Romania and to highlight the existing differences regarding these indicators and identify solutions to support the sustainable development of agriculture in the future.

The research period was the last decade 2015-2024 for which Eurostat database provided data.

Even from the beginning it was presented the image of agriculture gaps between the two countries: versus Bulgaria, Romania has a 2.83 times higher utilized agricultural area, 2.58 times higher arable land, 26.5 times more farms, 28.8 times more labour force, 4.07 times higher agricultural output value, 3.8 times higher intermediary consumption, 4.3 times higher gross value added.

But, in terms of labour productivity and agriculture factor income, real per full-time worker, Romania registered a worse situation compared to Bulgaria: -45,9 % less labour productivity and – 69.6% smaller agricultural real income per full-time worker.

In the both countries, in the analyzed interval, production costs declined: by 13.8% in Bulgaria and by 7.7% in Romania. In Romania, production cost are 3.5 times higher than in Bulgaria.

While in Bulgaria, the costs of seeds, fertilizers, labour, rents, taxes and other costs increased, in Romania the expenses for seeds, fertilizers, plant and animal protection and feeding stuffs, energy, rents, taxes decreased.

In 2024, the highest share in production costs in Bulgaria is kept by other costs 22.2 %, rents 21.5%, labour 16.4%, feeding stuffs 11.6% and fertilizers 9.7%, while in Romania, it belongs to other costs 46%, feeding stuffs 14%, energy 12.5 and labour 8.7%.

The values of variation coefficients proved a relative homogeneity for the most cost items both in Bulgaria and Romania.

Versus 2015, in 2024, the total revenues from agriculture decreased in the both countries by 27.8% in Bulgaria and by 17.3% in Romania. Romania achieved a 3.9 times higher agricultural revenue than Bulgaria.

In Bulgaria, almost all the revenue categories declined, except other subsidies which increased a little. In Romania, only other subsidies, other revenues and agricultural services increased.

Both in Bulgaria and Romania, the highest contribution to agricultural income is given by crop production. But, on the 2nd position, in Bulgaria are subsidies, followed by animal production and in Romania there are animal production and subsidies.

In the both countries, most of the revenue

items had a relative homogeneity among variables as proved by the variation coefficients.

Intermediary consumption increased in the both countries, other factors having a higher influence.

In 2024, intermediary consumption in Romania accounted for Euro Million 11,367, being 3.8 times higher than in Bulgaria's agriculture, which registered Euro Million 2,915.

In the analyzed interval, GVA from agriculture increased by 26.4%, while in Romania by 37.5%.

In 2024, Romania had Euro Million 8,944 GVA, while Bulgaria Euro Million 2,048.

The ratio GVA/IC was higher in Romania than in Bulgaria in almost of the years from the studied interval. In 2024, Romania achieved 0.79, while Bulgaria 0.73 Euro GVA for 1 Euro spent on IC.

Comparing these two levels with 0.75, the average of the EU-27, we may consider that the both countries are around this mean.

Therefore, the research showed the existing differences in the agriculture of Bulgaria and Romania but regarding the efficiency in terms of GVA per Euro 1 expenditures for intermediary consumption, the both countries are at the level.

The analyses allowed to draw a few recommendations for the both countries to improve the efficiency in agriculture:

-Both Bulgaria and Romania must be focused on obtaining a higher GVA, increasing agricultural output value and keeping under a rigorous control the expenditures with the intermediary consumption;

-Bulgaria must find solutions to reduce other costs and rents, while Romania has to diminish other costs.

-The both countries have to increase the agricultural income by diversifying production both in crop and animal sector, intensifying agricultural services and non-agricultural activities which could supply additional revenues.

-Romania has a specific situation in agriculture, regarding the high labor input which has a negative influence on labour productivity. Investments in modern technologies which require less but a more qualified work force could be a good alternative to grow labor productivity.

-The large number of farms and their average small size are still among the restraining factors of the growth in agricultural production and GVA. For this reason, initiatives for joining the resources land, labour, capital by creating cooperatives or other types of associative forms could be welcome to optimize production costs, delivery of agri-products across the product chain and increase agricultural output value and GVA.

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MANAGEMENT OF DETERMINANTS OF PRODUCTION COSTS IN THE AGRICULTURAL SECTOR: A CASE STUDY OF UKRAINE

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Abstract

The purpose of the study is to model and quantify the impact of basic factors on the amount of production costs in the agricultural sector of Ukraine., as well as to substantiate directions for improving cost management efficiency based on correlation and regression analysis. The article examines the factors shaping the cost structure of agricultural enterprises using forecasting modelling. It is substantiated that the dynamics of production costs are formed under the influence of interrelated labour and production-resource factors, among which the key ones are the volume of agricultural output, average wages, employment level, and the efficiency of fixed assets utilization. It is established that the most significant positive impact on the dynamics of costs in the agricultural sector of Ukraine is exerted by production volume and average wages, whereas the return on assets produces a restraining compensatory effect. Based on the estimated model, a forecast of costs up to 2030 is carried out, which indicates the preservation of an upward growth trajectory under an inertial scenario of agricultural sector development.

Key words**:** *cost management, cost determinants, agricultural sector, production cost, economic efficiency, production processes, correlation and regression modelling*

INTRODUCTION

Under the conditions of structural changes in the economic sphere and the strengthening of internal asymmetries in the activities of the agricultural sector of Ukraine, the issue of effective regulation of production costs, which are a key determinant of financial results and competitiveness of agricultural enterprises, is gaining increased scientific and practical significance. Instability in the structure of resource provision, rising prices of material components of production, as well as asymmetry between the rates of change in costs and performance indicators generate systemic risks that lead to a decline in the economic efficiency of agricultural activity. Under such conditions, traditional approaches to accounting and analytical support for cost management prove to be insufficient for the adequate identification of the factors shaping costs and for substantiating managerial decisions. A particular complexity in this regard is associated with the multifactorial nature of costs, which is inherent in agriculture. In turn, this is determined by a complex combination of technological, organizational-production, and institutional parameters that are in constant dynamic interaction. Consequently, the absence of an integral methodological framework oriented towards the systemic management of cost determinants limits the possibilities for forming adaptive models of cost optimization

and increasing the profitability of agricultural production.

In this aspect, the problem lies not only in the quantitative reduction of costs but also in the necessity to form an economically justified mechanism for their structural transformation. Moreover, such a transformation should be carried out with due regard to the specifics of production cycles and resource constraints of agricultural enterprises, which requires in-depth scientific analysis and methodological reconsideration of existing management approaches.

In contemporary scientific research, the issue of cost management in agricultural production is considered through the prism of cost formation, optimization of resource provision, and enhancement of business performance. At the same time, priority attention is focused on identifying determinants that determine the structure of costs, analyzing their impact on financial performance indicators, and creating an appropriate methodological toolkit for controlling. The issue of regulating the cost component in the agricultural sector has been reflected in scientific research, in particular in the works of N. Antoniuk [1], I. Arakelova [2], L. Cherchyk [3], M. Dziamulych [4-13], N. Khomiuk [14], M. Khvesik [15], V. Kostiuk [16], I. Mazniev [17], A. Popescu [18-27], M. Rudenko [28-29], V. Sarioglo [30], O. Shubalyi [31-35], A. Verzun [37].

At the same time, there remains a need for a comprehensive analysis of the systemic interaction of factors influencing the costs of agricultural enterprises, which determines the necessity of developing integrated models for managing cost determinants.

In this context, this article aimed to set up an economic and statistical model for assessing the effect of key determinants on production costs in Ukraine's agriculture and also to substantiate directions for increasing cost management efficiency based on correlation and regression analysis.

MATERIALS AND METHODS

As mentioned above, to quantitatively assess the impact of determinants on the level of production costs in the agriculture of Ukraine. The data have been taken from State Statistics Service of Ukraine [36] and also from [35].

The study applied methods of correlation and regression analysis, which allow to identify the direction and strength of relationships between the dependent and independent variables. At the same time, a multifactor linear regression model of the following form was used as the basic analytical framework:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon,$$

where:

y – denotes production costs of agricultural enterprises;

x_1 – number of employed persons in agriculture;

x_2 – average monthly wage;

x_3 – volume of agricultural output;

x_4 – return on fixed assets;

β_i – model parameters;

ε – random error term.

The estimation of model parameters was carried out using the least squares method, which involves minimizing the sum of squared residuals:

$$\sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \rightarrow min$$

The quality of model approximation was evaluated using the coefficient of determination:

$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y}_i)^2}$$

In addition, the statistical significance of individual parameters was tested using the Fisher F-test and the Student t-test.

To detect multicollinearity among the independent variables, the Pearson pairwise correlation matrix was employed.

Forecasting of production costs up to 2030 was carried out on the basis of the estimated regression equation by extrapolating the trends of the explanatory variables and substituting their forecast values into the model.

RESULTS AND DISCUSSIONS

The need for targeted regulation of factors that shape production costs in the agricultural sector is due to their key role in ensuring financial stability, strengthening competitive positions, and maintaining the strategic efficiency of the functioning of agricultural enterprises. In particular, it should be noted that the high level of resource intensity of production processes in agriculture creates increased sensitivity of production costs to changes in prices of material, energy, and labour resources, which requires a systemic approach to identifying the key factors shaping costs. Managing cost determinants makes it possible to minimize their absolute level and to ensure a rational cost structure that is consistent with the technological parameters of production and the strategic development objectives of enterprises. In this context, management acts as a tool for enhancing resource efficiency and for forming an adaptive model of economic behaviour of agricultural economic entities. To analyze the composition of costs in the agricultural sector of Ukraine, we will refer to the materials presented in Figure 1.

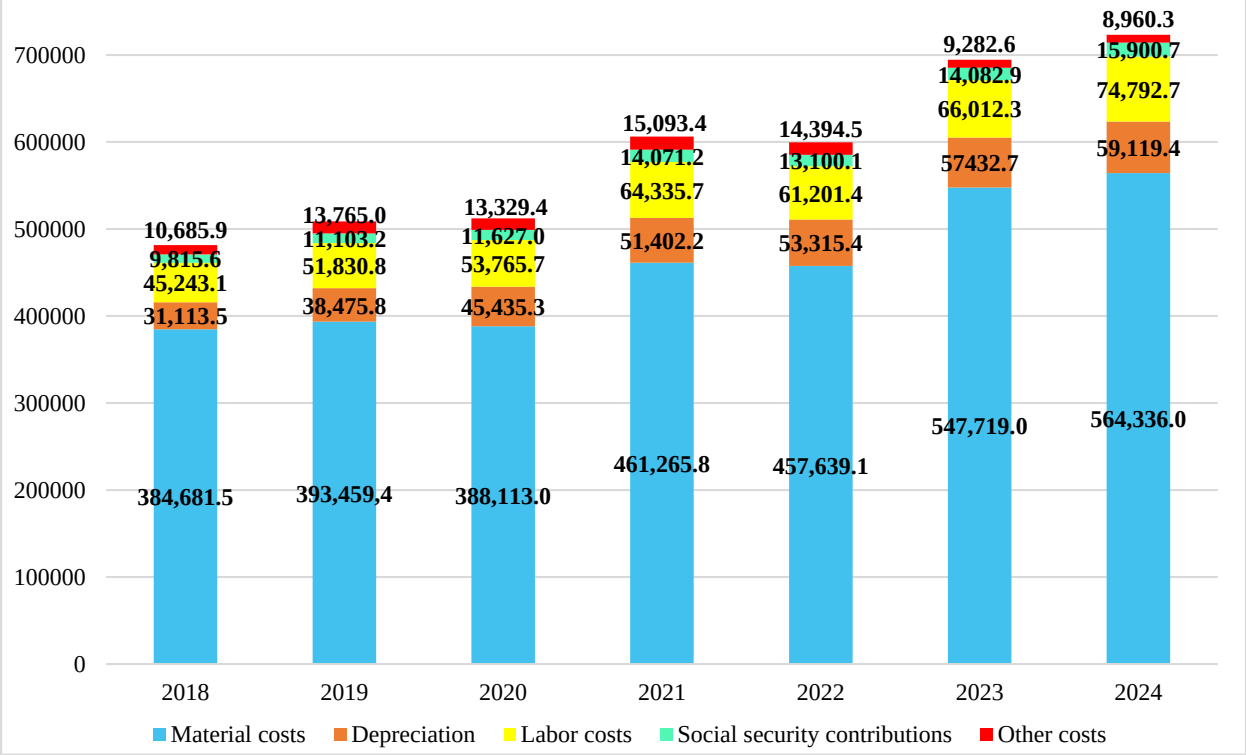


Fig. 1. Dynamics of the structure of production costs in the agricultural sector of Ukraine in 2018–2024, million UAH
Source: compiled by the authors based on [36].

The analysis of the cost structure indicates the dominance of material costs, the volume of which increased from approximately UAH 385 billion in 2018 to more than UAH 564 billion in 2024. Such dynamics reflect an increase in the resource intensity of production and a rise in the cost of material and technical components. Depreciation charges also show a steady upward trend, from UAH 31 billion to almost UAH 59 billion, which indicates growing capital intensity and the renewal of fixed assets. It should also be noted that labour costs increased from UAH 45 billion to nearly UAH 75 billion, which is a consequence of labour shortages and rising labour costs. Social contributions during the analyzed period grew more moderately, maintaining a proportional dependence on the wage fund. At the same time, fluctuations in other cost components are characterized by the absence of a stable trend, which may indicate the unsystematic nature of decision-making regarding the regulation of indirect costs. In general, the configuration of the cost structure indicates an increase in the importance of material and resource and investment components in the formation of the

cost of production, which increases the dependence of agricultural production on the parameters of resource supply and actualizes the need for comprehensive improvement of cost management mechanisms.

If we speak about the key determinants of production costs in agriculture, then, in our opinion, they should include the number of employed persons and the average level of wages of hired workers. This is determined by the fact that these elements form the basic component of the structure of variable and semi-fixed costs that are directly related to ensuring the functioning of the production process. At the same time, employment indicators reflect the scale of labor potential utilization, which is directly related to the volume of production activity and the amount of organizational costs. The level of average wages, in turn, characterizes the monetary expression of the cost of labor and determines the change in the personnel compensation fund, which is one of the most sensitive elements in the cost structure. Accordingly, it can be argued that their interaction forms not only the quantitative but also the qualitative dimension of costs, since changes in wages directly affect productivity and the efficiency of human capital utilisation in agricultural production. Therefore, let us assess the dynamics of changes in these indicators over the past few years (Figure 2).

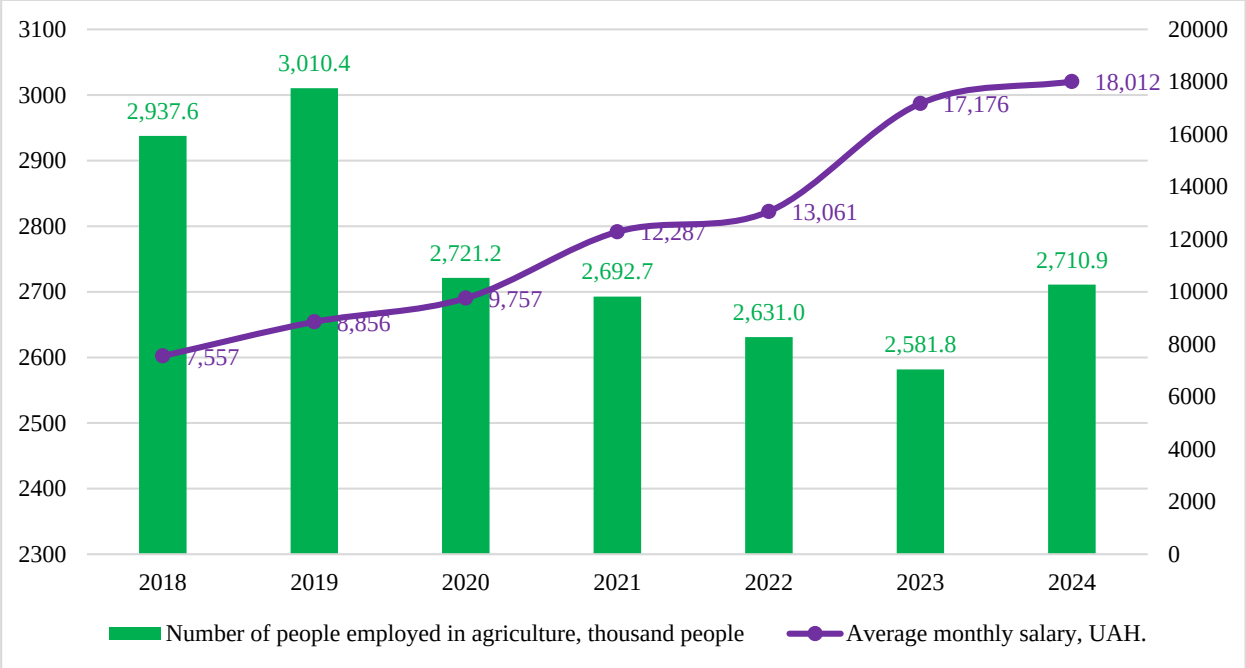


Fig. 2. Dynamics of the number of employed persons and the average level of wages in the agricultural sector of Ukraine for 2018-2024.
Source: compiled by the authors based on [36].

The results of the analysis indicate the presence of a stable divergent trajectory between employment indicators and the level of labor remuneration in the agricultural sector of Ukraine during 2018–2024. In particular, during this period the number of employed persons decreased from 2,937.6 thousand in 2018 to 2,581.8 thousand in 2023, which corresponds to a decline of 12.1%, with a slight recovery in 2024 to 2,710.9 thousand. At the same time, the average wage increased from UAH 7,557 in 2018 to UAH 18,012 in 2024, that is, by 2.38 times. Such asymmetry indicates the compensatory nature of the growth in labour costs under conditions of shrinking labour resources. From this, it can be concluded that labour shortages increase the cost of the labour factor, which is reflected in the expansion of the personnel payroll and the increasing importance of the labor component in the formation of the cost of agricultural products.

Also, in our opinion, it is advisable to take into account such factors of cost dynamics as the

scale of production and the efficiency of the use of fixed capital, since they directly determine the configuration and level of costs of agricultural business entities and set the economic prerequisites for redistribution between constant and variable cost elements. In particular, the expansion of production volumes, other things being equal, forms the manifestation of the scale effect, which leads to a reduction in the share of fixed costs per unit of output and contributes to the growth of aggregate cost efficiency. The return on assets indicator, in turn, characterizes the degree of intensity of the use of production capital and determines the level of capital intensity of the technological process. At the same time, it should be taken into account that in the agricultural sector, insufficient return on fixed assets provokes a disproportionate increase in depreciation and operating expenses. Conversely, its increase makes it possible to minimise losses from underutilisation of production capacities and to optimise the cost structure in the long run, which is especially important for agricultural production. Therefore, let us assess the changes in these indicators over the analysed period (Figure 3).

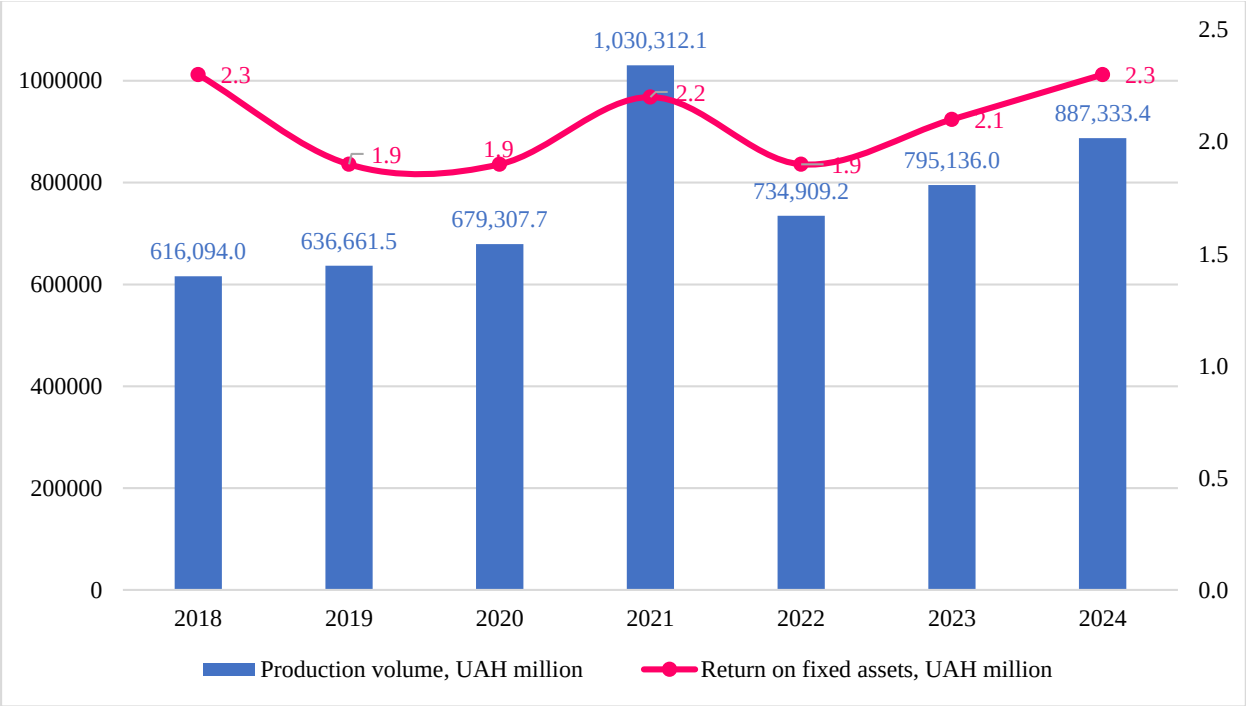


Fig. 3. Dynamics of production volume and return on assets of agricultural enterprises in Ukraine for 2018-2024.
Source: compiled by the authors based on [35].

The analysis shows that during the analyzed period, there was an uneven change in the indicators of production volume and return on assets of enterprises in the agricultural sector of Ukraine. In particular, production volume grew moderately during 2018–2020, after which in 2021 there was a sharp increase to UAH 1,030,312.1 million. At the same time, during the specified time interval, the return on capital decreased from UAH 2.3 to 1.9 million, which indicates a faster increase in the cost of fixed capital compared to the efficiency of its involvement in the production process. The subsequent decline in production volume in 2022 was accompanied by the persistence of a low level of asset turnover (1.9), which in turn, led to an increase in the share of depreciation and maintenance costs for fixed assets in the cost structure of agricultural enterprises. At the same time, the revival of production activities and improvement in capital return indicators in 2023–2024 reflect an increase in the intensity of capital utilization and a reduction in inefficiency in the area of costs.

In general, one can state a structural transformation of the cost formation model of Ukraine's agricultural sector, which manifests itself in the simultaneous reduction of labour potential, rising labour costs, and unstable efficiency of fixed asset utilization. The

divergence between employment dynamics and wage growth creates increasing pressure on production costs through higher specific labour costs, while fluctuations in production volume and return on fixed assets lead to variable capital intensity of production processes. Taken together, this indicates the strengthening role of factor-based cost management as a key condition for ensuring the economic balance of agricultural enterprises. In order to comprehensively determine the impact of individual factors on the value of production costs in the agricultural sector of Ukraine, using the tools of the MS Excel analytical package, we will conduct a correlation-regression study aimed at identifying and quantitatively interpreting the relevant relationships. The variables include the cost formation factors discussed above, which characterise the labour and production-resource parameters of agricultural enterprises' activity (Table 1).

Table 1. Dynamics of analytical indicators for constructing a correlation and regression model of the impact of factors on production costs in the agricultural sector of Ukraine for 2010–2024

Year	Production costs of agricultural enterprises, million UAH (y)	Number of employed persons in agriculture, thousand persons (x_1)	Average monthly wage in the agricultural sector, thousand UAH (x_2)	Volume of agricultural output, million UAH (x_3)	Return on fixed assets of agricultural enterprises, million UAH (x_4)
2010	121,219.2	3,094.5	1.47	189,405.0	2.2
2011	172,426.9	3,393.8	1.85	253,569.0	2.3
2012	134,317.9	3,496.0	2.09	258,270.1	2.3
2013	157,670.9	3,577.5	2.34	196,385.2	1.9
2014	189,915.6	3,091.4	2.56	286,905.6	2.5
2015	274,981.5	2,870.6	3.31	416,620.0	3.5
2016	326,544.6	2,866.5	4.20	474,884.1	2.8
2017	388,918.6	2,860.7	6.06	524,120.7	2.5
2018	481,539.6	2,937.6	7.56	616,094.0	2.3
2019	508,633.7	3,010.4	8.86	636,661.5	1.9
2020	512,270.3	2,721.2	9.76	679,307.7	1.9
2021	606,168.2	2,692.7	12.29	1,030,312.1	2.2
2022	599,650.5	2,631.0	13.06	734,909.2	1.9
2023	694,529.2	2,581.8	14.63	795,136.0	2.1
2024	723,109.0	2,710.9	18.01	887,333.4	2.3

Source: [36].

The correlation and regression model equation obtained as a result of the conducted analysis reflects the dependence of production costs of agricultural enterprises in Ukraine on a set of labour and production-resource determinants and has the following form:

$$y = –18,2547.3 + 48.2x_1 + 21,365.7x_2 + 0.54x_3 – 32,418.5x_4$$

From the presented equation it can be seen that the coefficient for the variable "number of employed persons" (48.2) indicates that an increase in the number of employees by 1 thousand persons is, on average, accompanied by an increase in production costs by UAH 48.2 million, which reflects a direct scale effect of labour resource expansion on the overall level of costs. The parameter estimate for the "average wage" factor (21,365.7) indicates that an increase in the average monthly wage by UAH 1,000 is associated with an increase in total production costs by approximately UAH 21.4 billion, which confirms the leading role of labor payments as a cost driver in the formation of the cost of agricultural products. The most significant impact on costs is exerted by the variable "production volume", the coefficient of which equals 0.54, meaning that production costs increase on average by UAH 0.54 million when production volume increases by UAH 1 million, which reflects the technological dependence of costs on output dynamics. At the same time, the coefficient for the indicator of return on fixed assets has a negative value (–32,418.5), which indicates a decrease in production costs on average by UAH 32.4 billion when the return on fixed assets increases by one unit. This confirms the compensatory effect of improving the efficiency of fixed asset utilization and its role in restraining the accumulation of costs of agricultural enterprises.

Summarizing the results of the correlation and regression analysis, it can be concluded that the constructed model adequately reflects the

economic nature of production cost formation in the agricultural sector of Ukraine and is characterized by high explanatory power. The dominant influence on the level of costs is exerted by production volume and average wages, which confirms the decisive role of the scale of activity and the cost of labour resources in the cost model of agricultural enterprises. At the same time, the negative effect of return on fixed assets indicates the restraining effect of increasing capital efficiency, which creates potential for optimizing production costs without reducing production performance.

Table 2 presents the main parameters of the developed regression model that describes the impact of explanatory variables on production costs of agricultural enterprises in Ukraine.

Table 2. Coefficient characteristics of the regression-correlation model of the influence of explanatory variables on the level of production costs of entities in the agricultural sector of Ukraine

Indicator	Coefficient (B)	Standard error	t-statistic	p-value
Production costs of agricultural enterprises (y)	-182,547.3	74,120.5	-2.46	0.029
Number of employed persons in agriculture (x_1)	48.2	20.0	2.41	0.033
Average monthly wage in the agricultural sector (x_2)	21,365.7	3,457.8	6.18	<0.001
Volume of agricultural output (x_3)	0.54	0.056	9.72	<0.001
Return on fixed assets of agricultural enterprises (x_4)	-32,418.5	15,650.2	-2.07	0.048

Source: own research.

The main parameters of the developed correlation and regression model indicate the following.

- the coefficient of determination $R^2 = 0.96$ points to a very high level of explanatory power of the model, since about 96% of the variation in production costs is explained by the combined influence of the included determinants. This confirms the adequacy of the formed system of factors for analyzing the cost behaviour of agricultural enterprises;
- the adjusted coefficient of determination Adj. $R^2 = 0.94$ practically does not differ from the basic R^2, which indicates the absence of redundant variables and high stability of the estimates taking into account the sample size and the number of factors;
- the value of the Fisher F-statistic F = 56.8 at the significance level $p < 0.001$ confirms the overall statistical significance of the model and allows rejection of the null hypothesis about the absence of a relationship between costs and explanatory variables, which testifies to the econometric reliability of the constructed model;
- the analysis of Student's t-statistics shows that statistically significant factors are production volume and average wages, for which the p-values are less than 0.05. The number of employed persons and return on fixed assets also have a significant effect, but of lower magnitude, which reflects the dominance of scale and value-based determinants in the formation of costs of agricultural enterprises.

In addition, let us evaluate the correlation matrix (Table 3).

Table 3. Pearson pairwise correlation matrix

Indicators	Production costs of agricultural enterprises (y)	Number of employed persons in agriculture (x_1)	Amount of wages in the agricultural sector (x_2)	Volume of production of agricultural enterprises (x_3)	The return on assets of agricultural enterprises (x_4)
Agricultural production costs (y)	1.00	0.62	0.94	0.97	-0.41
Agricultural employment (x_1)	X	1.00	0.58	0.55	-0.12
Amount of wages in the agricultural sector (x_2)	X	X	1.00	0.91	-0.36
Volume of agricultural output (x_3)	X	X	X	1.00	-0.29
Return on fixed assets of agricultural enterprises (x_4)	X	X	X	X	1.00

Source: own research.

The analysis of the correlation matrix indicates the presence of strong positive relationships between production costs of agricultural enterprises and most explanatory variables. In particular, the highest correlation coefficient is observed between costs and production volume (r = 0.97), which confirms the decisive role of

the scale of economic activity in the formation of production costs. A high level of correlation is also found between costs and average wages (r = 0.94), which indicates a significant influence of the cost of labour resources on cost dynamics. A moderate positive relationship between costs and the number of employed persons (r = 0.62) reflects the scale effect of labour involvement. At the same time, a negative correlation is recorded between costs and return on fixed assets (r = –0.41), which points to the compensatory nature of improving the efficiency of fixed asset utilisation. In addition, it should be noted that strong interrelationships are observed among some explanatory variables, in particular between production volume and wages (r = 0.91), which indicates the presence of multicollinearity and explains the reduced statistical autonomy of certain coefficients in the regression model.

Additionally, using the constructed correlation-regression relationship, we will forecast trends in changes in production costs in the agricultural sector of Ukraine for the following time horizons. (Figure 4).

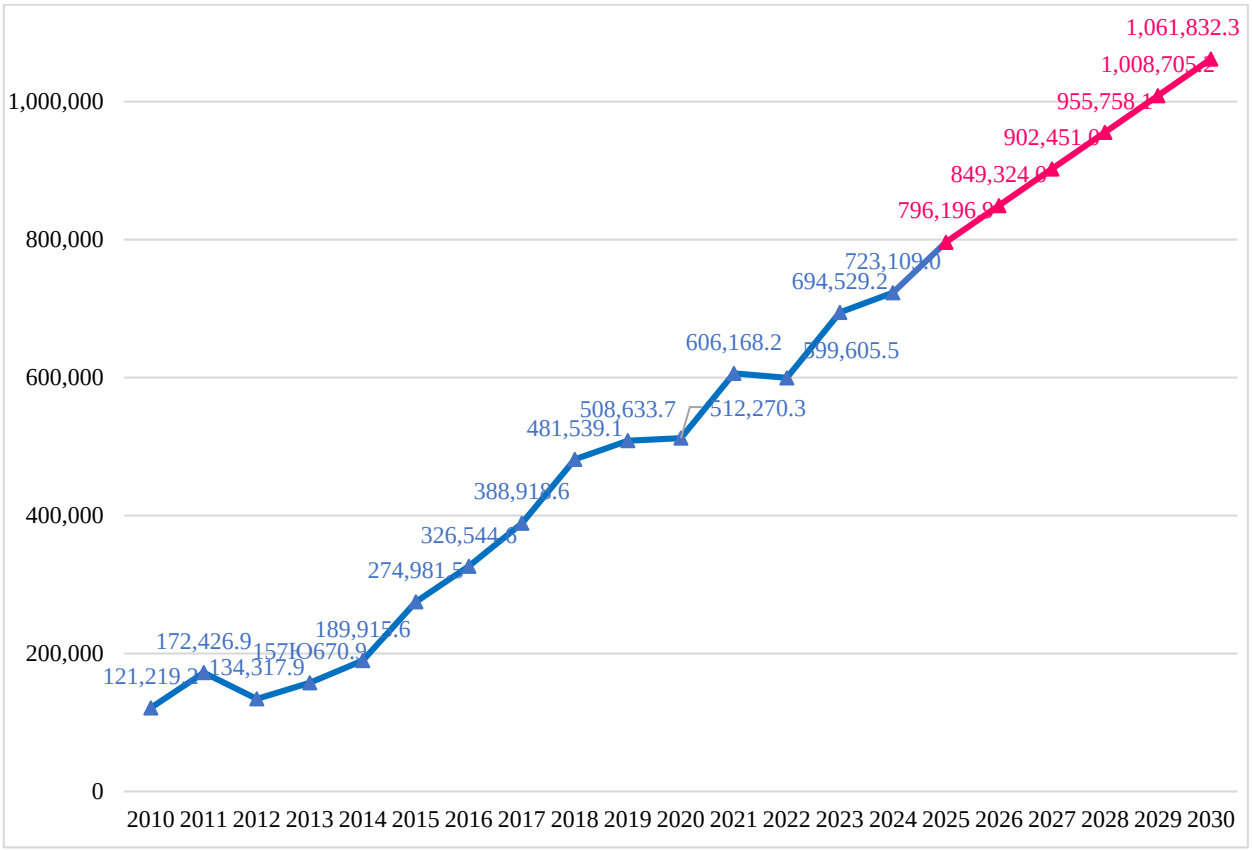


Fig. 4. Forecast of changes in production costs in the agricultural sector of Ukraine until 2030, million UAH.
Source: own calculations.

The results of the obtained estimates give grounds to state the preservation of a stable vector of growth of production costs in the agricultural sector of Ukraine in the medium-term time interval. The forecast construction is built on the basis of correlation-regression dependence, demonstrates a gradual increase in total costs without sharp structural breaks, which indicates the inertial nature of cost dynamics provided that the current parameters of the factor environment are maintained. In particular, the forecast values increase from approximately UAH 796 billion in 2025 to more than UAH 1.06 trillion in 2030, which implies an increase of almost one third over the forecast period. It is expected that the main contribution to this growth will be ensured by the expansion of production volumes and the further increase in the cost of labour resources, which reflects the dominance of scale and value-based determinants in the cost model. At the same time, it is advisable to take into

account the restrictive effect of the return on capital indicator, which manifests itself in preventing a rapid increase in costs, indicating partial compensation through improved efficiency of fixed asset utilization. Overall, the forecast illustrates that by 2030 cost growth will have an evolutionary character, and their further optimization will require structural changes in resource provision and management of production processes in the agricultural sector.

CONCLUSIONS

The obtained results of the study made it possible to form a generalized analytical idea of the mechanisms for regulating production cost factors in the agricultural sector of Ukraine through integrated consideration of labor and resource-production parameters. The analysis shows that the dynamics of costs is not a consequence of the action of individual isolated influences, but arises as a result of their interconnected functioning within a single economic mechanism. At the same time, it was established that the scale of agricultural output and the level of average wages play a decisive role in the formation of the level of costs, which indicates the predominance of scale-price factors in the cost structure and emphasizes the key importance of both production volumes and labor costs. At the same time, the number of employed persons acts as a factor of a scale nature, the influence of which is manifested through the expansion of organizational and production costs. The negative impact of return on fixed assets indicates the compensatory effect of increasing the efficiency of fixed asset utilization, which creates potential for restraining costs without reducing production performance.

Thus, it is appropriate to state that the rationalization of production cost policy in the agricultural sector involves the use of a comprehensive approach aimed not so much at their formal reduction, but at increasing the effectiveness of transforming the resources involved into the final economic results of the activities of business entities. This determines the need for a coordinated combination of personnel, production, and financial policies of agricultural enterprises within a unified cost management strategy. The implementation of such an approach will make it possible to ensure long-term economic balance and functional sustainability of the development of Ukraine's agricultural sector.

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AGRITOURISM FARMSTEADS AS A DRIVER OF AGRITOURISM ACTIVATION AT THE REGIONAL LEVEL IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT: A CASE STUDY OF THE VOLYN REGION, UKRAINE

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Abstract

The purpose of the article is to examine the development of agritourism farmsteads as a key factor in activating agritourism at the regional level, using the Volyn region as a case study, and to substantiate their role in ensuring balanced socio-economic development of rural areas. The role of agritourism farmsteads as economically active business entities that contribute to the diversification of rural household incomes and to strengthening the economic resilience of the region is substantiated. The empirical basis of the study was statistical data from the State Statistics Service of Ukraine for 2014–2024. The study identifies a stable upward trend in the growth of the number of agritourism farmsteads in the region, despite the presence of certain short-term fluctuations. A comparative analysis of different trend models made it possible to justify the feasibility of their application within a scenario-based approach, where the linear model is interpreted as an optimistic scenario, the polynomial model as a pessimistic scenario, and the power model as a baseline inertial scenario. It is demonstrated that agritourism farmsteads are characterized by higher adaptability and financial performance compared to traditional forms of agricultural activity, which enhances their significance in ensuring the sustainable development of rural territories.

Key words**:** *agritourism, agritourism farmsteads, regional sustainable development, rural areas, analysis*

INTRODUCTION

The current specifics of shaping an effective model for agritourism development at the regional level under the conditions of transformation of Ukraine's rural areas determine the need to stimulate the development of agritourism farmsteads as economically active business entities capable of ensuring the diversification of rural incomes and enhancing regional tourism attractiveness. Despite the growing interest in agritourism activities observed in recent years, the development of agritourism farmsteads in Ukraine remains fragmented, uneven, and often lacks systemic support, which reduces their potential as economically active actors of regional development. The absence of a comprehensive management approach to this segment results in inefficient use of local resources and weak integration of agritourism farmsteads into regional tourism products.

Moreover, this issue is of particular relevance for border and predominantly rural regions, including the Volyn region, where agritourism farmsteads can serve as a tool for activating entrepreneurial initiative among the population, diversifying household income sources, and reducing socio-economic disparities between urban and rural areas. At

the same time, the lack of functional alignment between the interests of agritourism farmstead owners and the requirements of the tourism market complicates the process of developing effective models for their growth.

Contemporary scholarly contributions on this topic are characterized by a limited number of empirical studies aimed at assessing the long-term dynamics of agritourism farmstead development. Significant research on this issue is presented in the works of scholars and practitioners such as N. Antoniuk [1], I. Arakelova [2], I. Dydiv [3], M. Dziamulych [4–13], N. Khomiuk [14], V. Kostiuk [15], I. Mazniev [17], L. Mialkovska [18], L. Marcuta [19], M. Pavliuk [20], A. Popescu [21–29], M. Rudenko [30], V. Sarioglo [31], R. Sodoma [32–33], M. Stanciu [34], N. Vavdiiuk [36–37] and A. Verzun [38]. However, there is currently an objective need to deepen research in the field of agritourism to ensure effective socio-economic development of rural areas on the basis of sustainable development.

MATERIALS AND METHODS

In the process of studying the features of the development of agritourism farmsteads, the article applies trend analysis methods using various functional forms. In particular, a linear trend model of the form:

$$y = a \cdot x + b \quad (1)$$

where:

y – denotes the number of agritourism farmsteads;

x – represents the time factor;

a and b – model parameters.

In addition to the linear model, an exponential model was applied:

$$y = a \cdot e^{(b \cdot x)} \quad (2)$$

a logarithmic model:

$$y = a \cdot \ln(x) + b \quad (3)$$

a second-order polynomial model:

$$y = a \cdot x^2 + b \cdot x + c,$$

as well as a power model:

$$y = a \cdot x^b \quad (4)$$

This approach made it possible to comprehensively assess the nature of changes in the indicator and the sensitivity of forecasts to the choice of functional form.

The quality of approximation of the trend models was evaluated using the coefficient of determination (R^2), which reflects the share of variation in the dependent variable explained by the constructed model. In addition, the statistical significance of all models was tested using the Fisher F-test, calculated according to the formula:

$$F = \left(\frac{R^2}{1-R^2}\right) \times \left(\frac{n-k-1}{k}\right) \quad (5)$$

where:

n – the number of observations;

k – the number of factors included in the model.

Based on the obtained results, a scenario-based forecast of agritourism farmstead development in the region was developed, in which the linear model is interpreted as an optimistic scenario, the polynomial model as a pessimistic scenario, and the power model as a baseline inertial scenario. This methodological approach ensured a combination of statistical robustness and economic feasibility of the forecast estimates for agritourism development in the Volyn region.

RESULTS AND DISCUSSIONS

The current specificity of the development of agritourism lies in its direct impact on the sustainable development of rural areas, which is associated with its impact on entrepreneurial activity and employment of the population of the relevant territorial communities. It is also worth noting that agritourism has a positive impact on the development of small businesses in the countryside in the form of agritourism farmsteads, which results in an increase in the income of the local population and a decrease in dependence on monofunctional agricultural activities. In turn, the expansion of agritourism services stimulates domestic demand for locally produced goods and related services, leading to stronger systemic interaction

between agriculture, the service sector, and related types of economic activity. Ultimately, this contributes to the formation of more resilient economic linkages at the local level and enhances the financial capacity of territorial communities. It should also be noted that a secondary effect of agritourism development is its social function, as the provision of self-employment opportunities creates conditions for the long-term development of rural areas without the loss of their economic viability.

In this context, it is important to emphasize that agritourism farmsteads play a leading role in agritourism development, as they serve as the basic organizational form for providing agritourism services and directly combine agricultural activity with tourism services. It is at the level of agritourism farmsteads that the primary tourism product is formed, oriented toward the use of local resources and the labor potential of households. Their operation ensures a low entry threshold to the tourism business, which in turn stimulates entrepreneurial activity among the rural population. At the same time, agritourism farmsteads are able to quickly adapt to changes in demand and offer differentiated services, which strengthens the competitiveness of agritourism at the regional level and creates a foundation for its sustainable development.

At the same time, the activation of the activities of agritourism farmsteads creates both direct and indirect effects for achieving strategic guidelines for sustainable development of territories, because this form of management integrates entrepreneurial initiative, job creation and effective involvement of local resource potential. In this aspect, it is advisable to outline the key areas and tools for implementing such an impact (Fig. 1).



Fig. 1. The role of agritourism farmsteads in implementing the goals of sustainable development of rural areas
Source: developed by the authors.

Overall, it can be argued that agritourism farmsteads function as a multifunctional instrument of regional resilience, combining economic performance with long-term territorial development. Their activities contribute not only to the activation of entrepreneurial initiatives but also to the creation of additional income sources for the rural population and the overall strengthening of the financial capacity of territories. At the same time, agritourism farmsteads forms the prerequisites for the rational involvement of

local resource potential and the activation of intra-regional economic interactions. In the context of Ukrainian realities, the spatial distribution of agro-estate is characterized by significant unevenness between individual regions of the country, which reflects differences in the level of their development and specialization (Fig. 2).

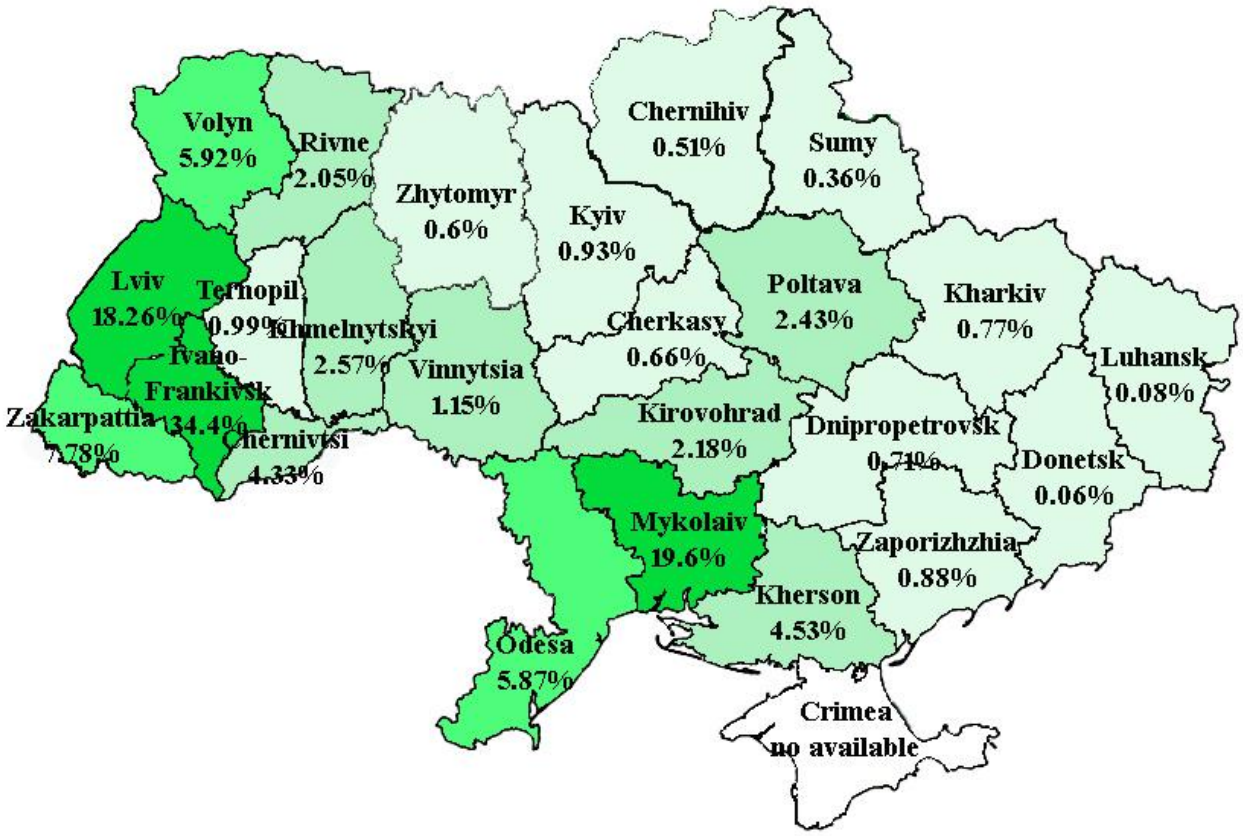


Fig. 2. Territorial structure of agritourism farmsteads in Ukraine by region in 2021
Source: developed by the authors based on [3].

As can be seen, the analysis indicates a significant territorial unevenness in the distribution of agritourism farmsteads in Ukraine. The cartogram clearly illustrates the concentration of the highest shares of agritourism farmsteads in the western regions, in particular Lviv (18.26%), Ivano-Frankivsk (9.40%), Zakarpattia (7.78%), and Volyn (5.92%) regions, which points to the established specialization of these territories in agritourism. It should also be noted that such specialization is largely determined by the high recreational potential of the Carpathian region and the lake systems of Volyn Polissia. A high share of agritourism farmsteads is also observed in the Mykolaiv region (19.6%), indicating the presence of region-specific patterns of agritourism farmstead development beyond the traditionally western zone. In contrast, most central, northern, and eastern regions are characterized by a low share of agritourism farmsteads (less than 1%), reflecting the insufficient involvement of rural areas in agritourism activities. This differentiation points to the existence of substantial unrealized potential of agritourism farmsteads as a tool for activating agritourism and fostering regional development.

In order to assess the impact of agritourism farmsteads on agritourism development in the Volyn region, the dynamics of their number are considered in comparison with agricultural enterprises and farms operating in the region (Fig. 3).

According to the data presented in Fig. 3, within the studied period in Volyn region there was a general decrease in the number of agricultural enterprises and farms, which indicates deep transformations in the structure of the agricultural sector. On the other hand,

the number of agritourism farmsteads demonstrates a stable upward trend, increasing from 154 units in 2014 to 426 in 2023. Such growth confirms the rising interest of the population in this type of activity and its gradual institutionalization within the regional economic system.

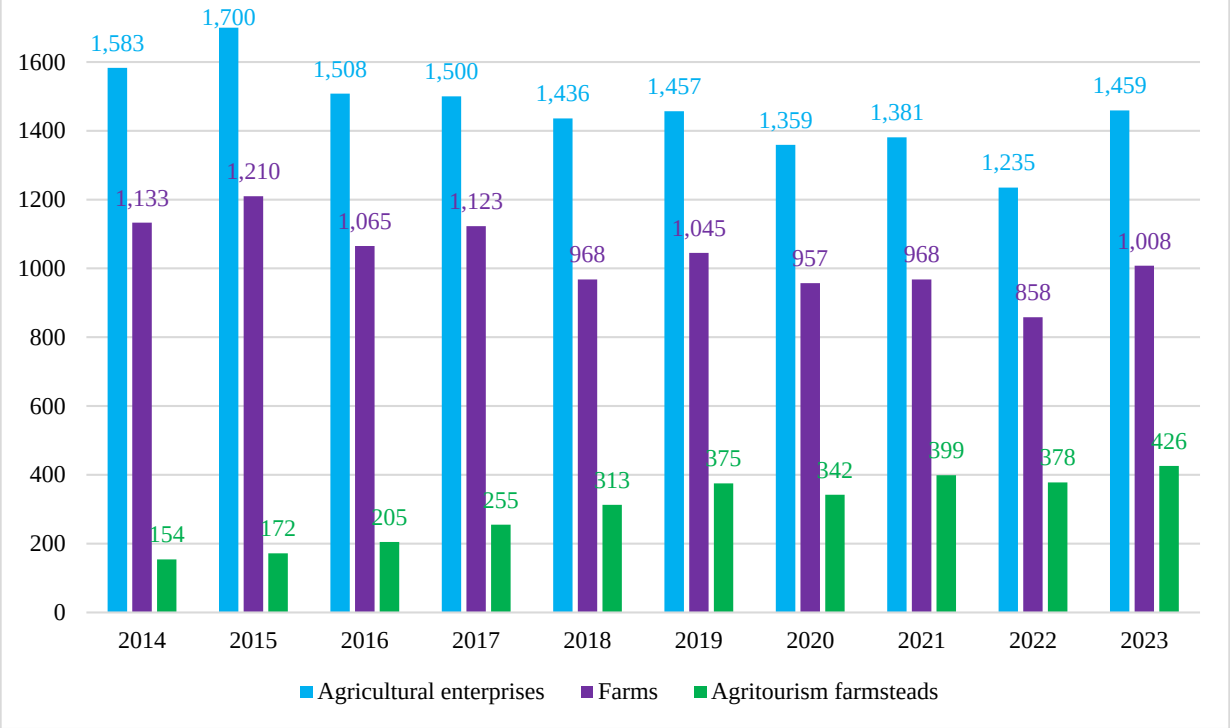


Fig. 3. Dynamic changes in the structure of agricultural business entities of the Volyn region in 2014–2023.
Source: developed by the authors based on [16; 35].

It is also worth noting that an increase in the number of agritourism farmsteads ensures the intensification and expansion of agrotourism activities in the region, as they constitute the core components of the supply of relevant tourism products. At the same time, the development of an agritourism farmsteads network leads to an increase in the hosting capacity of the territory, the diversification of tourist routes, and the attraction of a broader range of visitors. Moreover, the growth in the number of agritourism farmsteads partially offsets the decline in traditional forms of agricultural business, thereby contributing to the creation of alternative income-generating opportunities for rural residents. Overall, agritourism farmsteads act as a significant catalyst for the development of agrotourism in the Volyn region and directly enhance the economic resilience of rural communities.

However, at present, a unified approach to assessing the performance of agritourism farmsteads in the Volyn region is methodologically inappropriate, as they are characterized by a high degree of internal differentiation in terms of types of economic activity and income structure. In particular, some agritourism farmsteads specialize mainly in providing temporary accommodation and catering services, focusing on short-term tourist stays. Other agritourism farmsteads combine tourism activities with the production and sale of agricultural products, forming a mixed business model. A separate group of agritourism farmsteads focuses on the organization of leisure, recreational, and educational services, including excursion programs, workshops, and seasonal events. In addition, some agritourism farmsteads operate as specialized family households with a minimal level of commercialization, while others exhibit a clearly pronounced entrepreneurial orientation. Therefore, such diversity of activities necessitates the application of differentiated approaches to assessing their economic performance and

contribution to the development of agritourism in the region. In particular, to determine the effectiveness of agritourism farmstead activities, a comparison of their average profitability level with the profitability of the agricultural sector and the hospitality industry is conducted (Fig. 4).

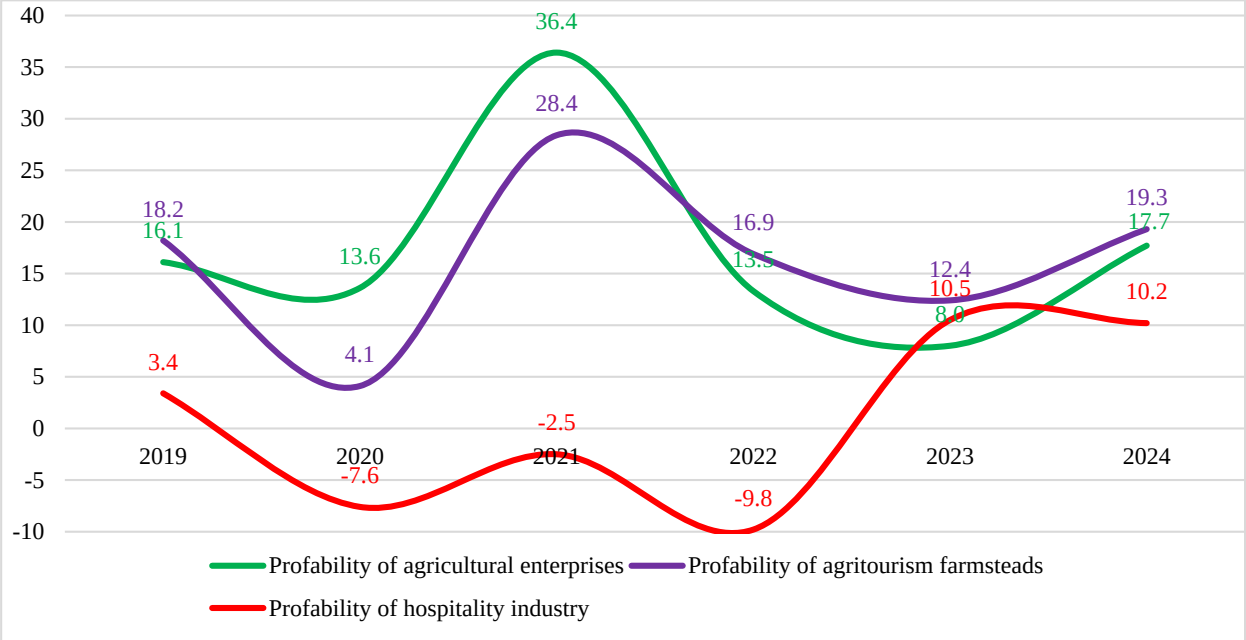


Fig. 4. Dynamics of the average profitability level of agricultural enterprises, the hospitality entities and agritourism farmsteads in the Volyn region in 2019–2024
Source: developed by the authors based on [16; 35]

The graph shows a significant difference in the financial results of business entities in the analyzed types of activity. In particular, agricultural enterprises during the analyzed period demonstrated moderate and relatively stable profitability, fluctuating within the range of 10–18%, which reflects their dependence on production cycles and external conditions. In contrast, the hospitality industry was characterized by high volatility of performance indicators. Specifically, negative profitability was recorded in 2020–2022, indicating the vulnerability of this segment to crisis phenomena and declining effective demand. At the same time, agritourism farmsteads consistently exhibited the highest average profitability throughout the period, with peak values in 2021 and 2023 exceeding 28–36%. This indicates their strong capacity to generate value added at a relatively low cost level. However, a sharp decline in profitability was observed in 2022, highlighting the sensitivity of agritourism farmsteads to external shocks. Nevertheless, the subsequent recovery of profitability confirmed their adaptive capacity. Thus, it can be concluded that agritourism farmsteads represent the most financially efficient segment within the regional agritourism economy, ensuring higher margins compared to traditional types of economic activity.

As we can see, unlike traditional agricultural enterprises, agro-estate farms are characterized by a specific cost structure, dominated by variable costs of the service sector and the use of households' own resources. This leads to a higher share of added value in the income structure and forms a higher relative profitability with a lower capital intensity of the business model. Accordingly, this feature can be highlighted as one that distinguishes agro-estate farms from traditional forms of agricultural activity.

Accordingly, to assess the impact of agritourism farmsteads on the development of agritourism in the region, it is necessary to analyze their dynamics. However, such an assessment is more appropriately conducted

using trend lines, since changes in their number generally exhibit a gradual, inertial character and reflect long-term development tendencies rather than short-term fluctuations. Trend analysis makes it possible to smooth the influence of one-off external factors and seasonal deviations, which is particularly important for agritourism farmsteads, whose activities depend on long-term processes of investment attraction, changes in employment structure, and the formation of entrepreneurial motivation among the rural population. In addition, the use of trend lines ensures simplicity of interpretation and enables a consistent assessment of changes in the number of agritourism farmstead (Fig. 5).

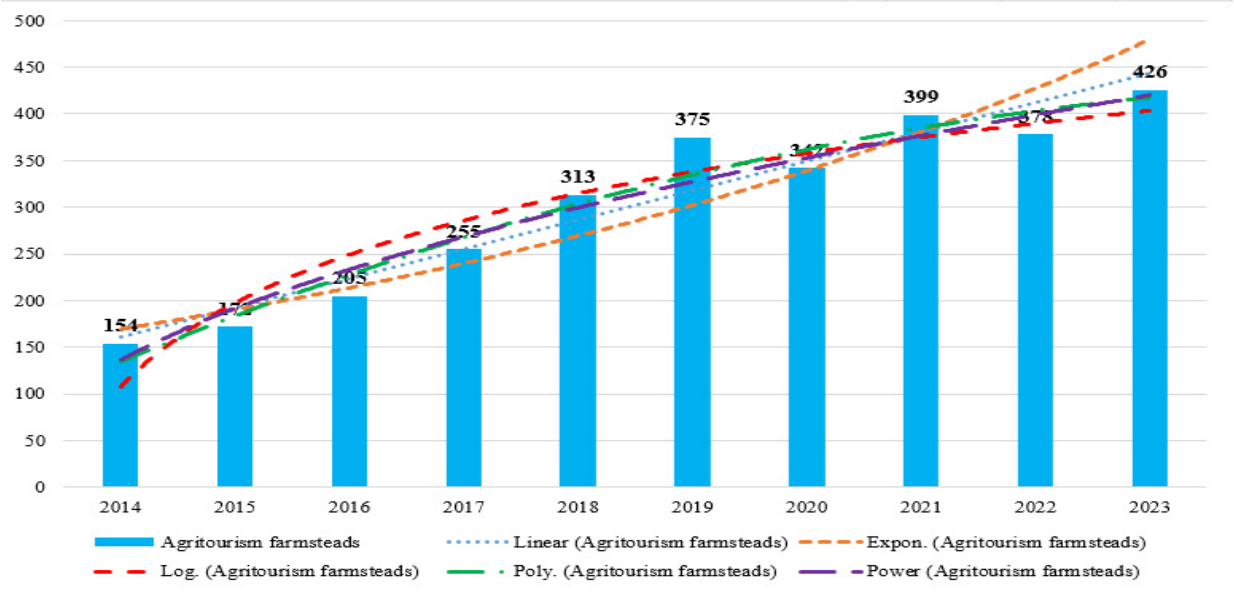


Fig. 5. Trend assessment of changes in the number of agritourism farmsteads in the Volyn region in 2014–2023
Source: calculated by the authors based on [16].

Trend analysis shows that during the analyzed period, there was a constant increase in the number of agritourism farmstead in the Volyn region. Over ten years, their number increased from 154 to 426 units, despite some fluctuations in 2020 and 2022. A comparison of different types of trend models shows that the linear model most adequately reflects the gradual nature of changes, capturing a stable average annual increase without excessive distortion of the dynamics. The exponential and power curves tend to overestimate the intensity of growth, whereas the polynomial model overreacts to short-term deviations. Overall, the graph confirms the inertial and systemic character of agritourism farmstead development in the region. However, for an analytical assessment of the trend and a generalized interpretation of this dynamic, a forecast of the number of agritourism farmsteads is constructed using all trend analysis equations (Table 1).

Table 1. Forecast values of the number of agritourism farmsteads in the Volyn region based on trend analysis

Model type	Trend equation	Coefficient of determination (R^2)	F	2024	2025	2026	2027	2028	2029
Linear	$y = 31.412x + 129.13$	0.9247	98.3	475	506	538	569	600	632
Exponential	$y = 151.13e^{0.1155x}$	0.8974	70.0	538	604	678	761	855	959
Logarithmic	$y = 128.26\ln(x) + 108.18$	0.9036	75.0	416	427	437	447	456	464
Polynomial	$y = -2.1477x^2 + 55.037x + 81.883$	0.9524	160.1	427	433	434	432	424	413
Power	$y = 136.44x^{0.4884}$	0.9402	125.8	440	459	478	495	512	529

Source: own research.

A comparison of the calculated and tabulated values of the Fisher criterion indicates that for all constructed trend models the condition Fcal > Fcrit is satisfied, confirming their statistical significance at the 95% confidence level. This means that the identified trend relationships are non-random and adequately describe the dynamics of the number of agritourism

farmsteads. The analysis of Table 1 demonstrates the feasibility of applying a scenario-based approach to the interpretation of forecasting results. The coefficients of determination and F-test values presented in the table confirm the statistical significance of all models, while simultaneously revealing substantial differences both in the form of the trends and in the projected development trajectories.

In particular, the linear model is characterized by a high level of determination and a statistically significant Fisher criterion value. It generates a forecast with uniform and stable growth in the number of agritourism farmsteads throughout the entire forecast period. Such dynamics correspond to the actual pattern of changes observed in previous years and reflect the inertial development of this segment under the condition that existing trends are maintained. In this context, the linear trend can be interpreted as a positive or baseline forecast scenario. In contrast, the polynomial model demonstrates the highest values of the coefficient of determination and the Fisher criterion, indicating its maximum explanatory power with respect to the statistical data. However, it is worth noting that the forecast based on this model shows a trend towards a slowdown and further reduction in the number of agritourism farmsteads in the region. This allows us to define the polynomial forecast as a negative scenario, reflecting the possible realization of unfavorable operating conditions that may constrain the development of agritourism.

The power model occupies an intermediate position between these alternatives. With sufficiently high statistical indicators, it generates a forecast that preserves positive dynamics but with a gradual decrease in growth rates. This form of trend is appropriate for interpretation as an averaged or inertia-constrained development scenario.

Thus, the obtained results substantiate the possibility of using different trend models as tools for scenario-based forecasting, where the linear model serves as the baseline scenario, the polynomial model as the pessimistic one, and the power model as a compromise assessment of the future dynamics of agritourism farmsteads in the region. We will also form a forecast of changes in the number of agritourism farmsteads (Fig. 6).

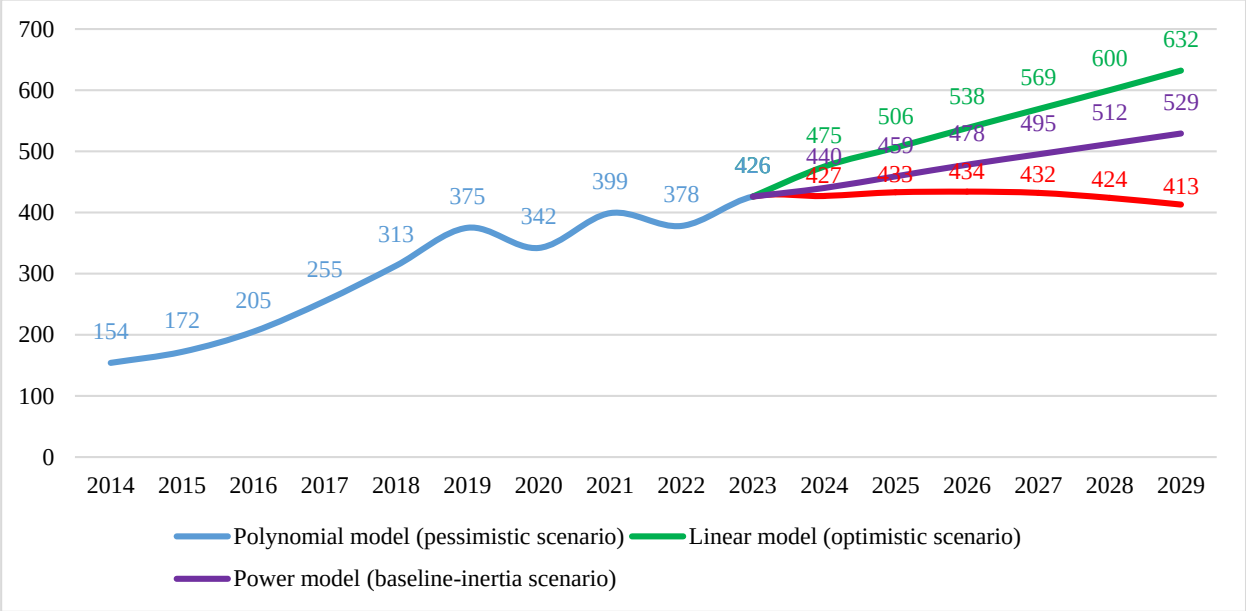


Fig. 6. Scenario forecast of changes of the number of agritourism farmsteads in the Volyn region for 2024–2029
Source: own research.

Thus, the analyzed indicators for 2014–2023 demonstrate a generally stable trend in the growth of the number of agritourism farmstead, despite some deviations due to the influence of external shocks. This confirms the possibility of using scenario modeling to assess

further changes. At the same time, the integrated processing of various scenarios allows us to outline a range of potential development directions and increases the reliability of forecast conclusions within the framework of the strategic analysis of agrotourism development in the Volyn region.

Thus, the scenario forecast of changes in the dynamics of the number of agritourism farmstead numbers indicates the need for a flexible management approach to agritourism development in the Volyn region, taking into account possible trajectories of its evolution. Specifically, the optimistic scenario, which assumes stable growth in the number of agritourism farmsteads, requires a focus on supporting inertial development by creating favorable conditions for entrepreneurial activity, expanding the range of agritourism services, and strengthening the integration of agritourism farmsteads into regional tourist routes. Under this scenario, it is advisable to stimulate cooperation between agritourism farmsteads and entities in the hospitality sector in order to enhance the overall competitiveness of the region.

The baseline inertial scenario, which assumes moderate growth with a gradual slowdown in future rates, highlights the need to increase the economic efficiency of agritourism farmstead operations. In this case, priority should be given to the development of additional intangible services within agritourism farmsteads and the optimization of their cost structures. At the same time, the formation of local interaction networks among agritourism farmsteads becomes particularly important, as it can reduce individual risks and improve the overall financial resilience of the agritourism sector.

Since the pessimistic scenario signals a possible decline in the number of agritourism farmsteads in the future, it necessitates the implementation of preventive measures aimed at preserving the economic viability of agritourism entities. In this context, it is advisable to recommend the adaptation of existing agritourism farmstead business models to conditions of market instability based on the rationalization of available resource use.

Overall, the scenario-based forecast confirms that agritourism development in the Volyn region cannot occur spontaneously and requires a systematic management approach. Accordingly, the implementation of such an approach should be aimed at timely responses to potential risks associated with changes in the dynamics of agritourism farmstead development and at maintaining their economic viability. In the long term, this may create preconditions for ensuring the sustainable functioning of agritourism farmsteads as a key element of rural development and regional agritourism.

It is worth noting that in addition to the direct economic impact, the development of agro-manors contributes to the long-term consolidation of territorial communities by strengthening social interaction and network cooperation between households. At the same time, agro-manors form horizontal connections in the community and stimulate the participation of residents in collective socio-economic projects. In the long term, this contributes to increasing the level of trust and institutional capacity of communities, which goes beyond the purely economic effects of agro-tourism.

CONCLUSIONS

Thus, it can be concluded that agritourism farmsteads play a system-forming role in the development of agritourism at the regional level and create a sustainable economic foundation for the activation of entrepreneurial activity in rural areas. It has been established that the growth dynamics of the number of agritourism farmsteads in the Volyn region are inertial in nature and are accompanied by an increase in their financial performance, which distinguishes this segment from traditional forms of agricultural activity and the hospitality sector. The obtained results indicate the ability of agritourism farmsteads to generate higher value added with a relatively flexible cost structure, thereby strengthening their role as a factor of regional economic

resilience. Also, in our opinion, it is advisable to integrate proactive management decisions into the regional strategy for the development of agritourism through the formation of target benchmarks, coordination of institutional interaction, and the implementation of tools for cooperation between agro-estate farms within a single tourist space of the region.

The application of trend-based and scenario-based approaches made it possible to outline the range of possible development trajectories of agritourism farmsteads in the medium term and to substantiate the feasibility of using the linear model as a baseline for forecasting assessments. At the same time, the results of scenario modeling showed the possibility of slowing down the growth rate in the event of negative external and internal factors, which highlights the need to strengthen targeted management influence on the development processes of this activity. In view of this, the further evolution of the agritourism sector in the Volyn region should be based on a systematic approach to the management of agritourism farmsteads as key actors of economic activity capable of ensuring the long-term development of rural areas.

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COST AND PROFITABILITY OF RAISING DOMESTIC CATTLE IN TÜRKİYE

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Abstract

This study aimed to conduct an economic analysis of domestic cattle farms in Türkiye. The aim was to analyse the production costs and profitability of domestic cattle farming operations. The primary material for the study consisted of data obtained from 215 domestic cattle farms in the provinces of Diyarbakır, Ağrı, Şanlıurfa, Muş, and Samsun, which constitute 34.22% of Türkiye's domestic cattle population. The data obtained covered the production period from May 2021 to April 2022. In the study region, domestic cattle farming prevails because it is an activity suited to the land structure and climate conditions. The average domestic cattle population of the interviewed farms in the region was 15.11 AU. According to the cattle unit, the production cost of local breed cattle was calculated as $533.13; GPV was $853.28; and the relative profit was 1.60. The cost management and market prices, production efficiency, reproductive performance, herd health, economies of scale, and management practices are key factors that contribute to the overall profitability of domestic breed cattle farms. These factors are also crucial for the productivity and profitability of farms. Indeed, the large-scale farms in the study benefit from economies of scale. Domestic breed cattle farms must continuously monitor their costs and demonstrate sound management to ensure or increase the economic sustainability of their operations. Furthermore, they should implement cost-cutting strategies, optimise feed efficiency, and increase labour productivity.

Key words**:** *domestic cattle, cost, profitability, Türkiye*

INTRODUCTION

The economic sustainability of domestic cattle farming is a critical area of study, given its significant contribution to global food systems and rural economies. The complex relationship between production costs and profitability in this sector is crucial for ensuring sustainable agricultural practices and supporting farmers' livelihoods. Cattle farming, whether for meat or milk, involves a complex interplay of various cost components and income streams. Feed costs typically constitute a significant portion of total production costs and consistently emerge as the largest expense item. Other significant expenses include fixed costs such as labour, veterinary care, rearing costs, animal depreciation, and housing. The efficiency with which these inputs are managed directly impacts the farm's overall profitability. For example, efficient grazing practices can significantly reduce reliance on purchased feed, thereby lowering costs. Cost management does not solely determine profitability in domestic cattle farming. It is also heavily influenced by market dynamics, including beef and meat prices, as well as consumer demand.

This study aimed to conduct an economic analysis of farms breeding domestic cattle, both for the protection of biodiversity and animal genetic resources. The share of domestic cattle breeds in Türkiye's total cattle population has declined to 8.9%. This has decreased by 55.8% compared to 2004, although the context of what 'this' refers to is not specified. This situation poses a threat to the protection of animal genetic resources. Therefore, the study aims to reveal the economic structure of farms engaged in this breeding activity and to demonstrate the importance of domestic cattle breeding in this context. Therefore, the question of whether

domestic cattle breeding is profitable for the farm will also be answered.

When evaluating national and international studies directly or indirectly related to the research theme, it was found that, for example, [4] determined that feed cost was the most significant factor affecting operating costs in dairy cattle farms in Ankara, accounting for approximately 60% of the total cost. [27] found that the family workforce potential of dairy cattle farms in Izmir province was not fully utilised, and that 28.57% of the total workforce employed on the farm was provided by family labour. [5] stated that feed costs accounted for the highest share of production costs in dairy farms in Konya province. [10] examined the economic structures of farms raising dairy cattle for the market in the central district of Kütahya and determined optimal farm organisation using linear programming. [26] found that in 66 livestock farms in the central districts of Seyhan and Yüreğir, Adana, the largest share of the gross production value per farm was milk sales revenue (63.7%). They found that as farms grow, total profit and gross profit per animal increase. [11] compared gross and net profit in three types of dairy cattle farms based on the genetic material in Eastern Anatolia. They found that the highest gross profit and profitability rate are obtained by farms raising culture-bred cows, followed by farms with cross-breed cows and in last position are situated the farms growing native-breed cows. [18] analysed the profitability and productivity of dairy cattle farms in Bursa province. He stated that current market milk prices create significant differences in farm income over the years. [22] determined that the most influential factors on milk production in dairy farms in the Lavras region of Brazil are feed (55.90%) and labour (19.10%). In Romania, [25] found that the main criteria for classifying dairy farms are farm size, milk yield and milk production, which are closely connected and have a deep impact on gross margin, profit and net profit rate. [17] calculated the milk cost of dairy cattle farms in the Bafra district of Samsun province as 0.61 TL/kg. They found that feed costs account for the highest share of production costs. In the production function, they found that the number of milking cows and the use of concentrate feed had a statistically significant effect on milk production, and that increasing returns to scale were present on the farms. Determined that feed costs constituted the most important cost element in dairy cattle farms in the Thrace region, accounting for 86%, determined that feed costs were the most important item in milk production costs in cattle farms in India [19, 30]. [12] examined the economic structure of dairy cattle farming in Uşak Province and identified its associated problems. The cost of milk production per cattle unit was 5,337.61 TL, and feed costs accounted for the highest share of cost elements in dairy cattle farming, at 45.49%. Agricultural income constituted 99.34% of the total family income. In their study, [24] found that in farms that did not receive government support, 68.01% of animal production costs were variable costs, and 31.99% were fixed costs. They reported that these values were 67.64% and 32.36%, respectively, in farms receiving support. [29] calculated the average gross product of dairy cattle farms in Hatay province to be US$76,187 and gross production value to be US$66,467. They calculated the total production cost to be US$50,968. They determined that the share of variable costs in total production costs was 77.52% and the share of fixed costs was 22.48%. Searches of academic databases revealed over 314,000 publications worldwide on the economics of cattle breeding. Türkiye has approximately 1,400 publications. The number of studies analysing the economics of local cattle breeds worldwide is minimal (approximately 4% of these publications). In Türkiye, however, very few studies specifically addressing the economic analysis of the subject of this study—namely, local cattle breeding—were found. Therefore, this study aimed to provide a socio-economic assessment of local cattle breeding at the farm level.

MATERIALS AND METHODS

The provinces of Diyarbakır, Ağrı, Şanlıurfa, Muş, and Samsun, which constitute 34.22% of

Türkiye's domestic breed cattle population according to the 2020 livestock statistical data from the Turkish Statistical Institute, are also among the top five in terms of Türkiye's domestic breed cattle population. These provinces were selected as the research area. The data obtained pertained to the production period of May 2021 — April 2022. The Stratified Sampling Method was applied to the sampling frame. Since the farms included in the population were not homogeneously distributed in terms of animal numbers, similar farms were grouped homogeneously. The "Neyman Method" was used to separate the sample farms into strata [7]. Since distribution is based on stratum variance in the Neyman method, to prevent imbalances in sample sizes among strata, the stratum boundaries were determined. Enterprises with one head of domestic cattle and farms with more than 200 head of domestic cattle were not included in the framework list. The sample size of farms with between 2 and 200 head of domestic cattle was calculated based on the average number of domestic cattle per farm, with a 5% margin of error and a 95% confidence level. Accordingly, the number of farms was determined as 215. Proportional distribution was considered in allocating the sample farms to the provinces. In determining the sample farm size, farms were divided into strata according to their breeding stock (bulls and cows). Accordingly, farms with 2-5 head of domestic cattle (62 farms) were included in Group I; farms with 6-15 head of domestic cattle (58 farms) in Group II, and farms with 16-30 head of domestic cattle (21 farms) in Group III. Enterprises with between 31 and 200 head of domestic cattle (74 farms) were grouped as Group IV farms. In calculating family labour wages, the daily wages paid to wage labour in the region were used as a proxy for the actual wages paid to family labour. The number of animals held by farms was converted to an animal unit (AU) [8]. Expense elements for domestic cattle breeding were calculated at the farm level and converted to a cattle unit. Cost elements in raising domestic cattle were examined in two groups: variable and fixed costs, depending on whether they changed with production volume [21].

In calculating family labour wages, the daily wages paid to the wage earners in the region were used as a proxy. General administrative expenses constituted 3% of the total variable expenses incurred by the farms for raising domestic cattle [21]. Fixed capital interest expenses consisted of building capital interest, equipment and machinery capital interest, domestic livestock capital interest, and debt interest.

The depreciation costs calculated for cattle farming activities consisted of building depreciation, depreciation on domestic animals, and depreciation on equipment and machinery. In calculating building capital interest, tool-machinery capital interest, tool-machinery depreciation, and building depreciation, the joint costs were distributed according to the share of the gross production value to eliminate any confusion that might arise if the farm shared the same tool-machinery or building with another activity [21]. [1] suggested that a 5% interest rate could be applied to calculating the interest on capital used in the production of the products whose costs are to be calculated. In the interest calculations used in this study, the interest rate was assumed to be 5%.

In calculating the gross production value of domestic cattle in farms, income from milk and dairy products, fertiliser income, and productive value increase (PVA) were taken into account. To calculate productive fixed asset value increases, a herd movement schedule was prepared by gathering information on births, deaths, age changes, purchases, sales, and consumption of livestock during the year. The formula for calculating the productive fixed asset value increase was as follows:

PVA = (End-of-period cattle herd value + value of cattle sold + value of cattle slaughtered) – (Beginning-of-year cattle herd value + value of cattle purchased) [21].

Positive values from the calculation were reflected in the gross production value. In farms with negative PVA, these values were included in production costs when inventory

values decreased. The formula Gross profit = GPV – Variable Costs was used to calculate the gross profit (GP) obtained by farms from breeding domestic cattle [2, 21].
The formula Absolute profit = GPV – Production Cost was used to calculate absolute profit (AP) [21].
The relative profit obtained by the interviewed farms from breeding domestic cattle was determined by dividing the gross production value by the production cost [21]. The farms' milk unit costs were calculated using the relative sales value method. The relative sales value method is used to calculate unit costs when multiple products are produced in a production activity and the resulting revenues are close to each other [20, 21].
Information was provided above regarding the use of the Neyman method, a stratified sampling method, in determining the sample from the farm population. In this method, since more samples are taken from the stratum with high variance, the farm average does not reflect the regional average. Therefore, the regional average was calculated by dividing the number of observations falling within the class boundaries (strata) by the total number of farms in the sample [13, 14].

RESULTS AND DISCUSSIONS

In the interviewed farms in the region, it was determined that the average number of domestic cattle breeds, in terms of cattle unit (AU), was 15.11 AU, while the regional average of domestic cattle in the same terms was 5.61 AU. The number of domestic cattle breeds within the farm size groups varied between 3.23 and 32.07 AU. The highest age group raised in the region is cows. Domestic breed cows were found to have an average milk yield of 10.15 AU across the farms. The presence of domestic breed cows within the farm size groups varied between 1.69 and 21.81 AU. Following the cows, heifers were reported with 1.51 AU, male calves with 1.11 AU, and bullocks with 1.06 AU (Table 1).
Production costs are a key factor determining the economic sustainability of domestic cattle farms.

Table 1. Presence of local breed cattle in farms by animal unit

Age group	Group				FA*	RA**
	I	II	III	IV		
	AU/farm					
Ox	0.00	0.00	0.00	0.06	0.02	0.00
Bull	0.03	0.17	0.40	0.62	0.31	0.11
Cow	1.69	4.56	9.43	21.81	10.15	3.48
Heifer	0.30	0.82	0.83	3.26	1.51	0.56
Bull	0.79	0.47	1.26	1.70	1.06	0.77
Female calf	0.18	0.42	0.63	2.09	0.94	0.32
Male calf	0.23	0.37	0.80	2.52	1.11	0.37
Total	3.23	6.81	13.36	32.07	15.11	5.61

Source: Own calculation *FA: Farms average **RA: Regional average

These costs are generally categorised as variable and fixed costs. Variable costs are directly incurred during the cattle-raising process. Fixed costs, on the other hand, relate to the capital invested in the farm. Effectively understanding and managing these costs is vital to maximising profitability.
According to the AU, the total production costs for raising domestic cattle in the interviewed farms were calculated as $533.13 based on the farm average, and $802.33 based on the regional average. According to the AU, the average production costs were calculated as $869.62 for Group I farms, $717.94 for Group II farms, $565.99 for Group III farms, and $470.07 for Group IV farms (Table 2). According to the AU, the total variable costs associated with raising domestic breed cattle were calculated as $326.70 based on the farm average and $501.98 based on the regional average. The total variable costs associated with AU within farm size groups ranged from $286.67 to $548.94 (Table 2).
According to the AU, the highest cost element was feed at $262.05, based on the farm average. According to the farm average, concentrate feed comprised $123.95 of these feed costs, and roughage feed accounted for $138.10. The total feed costs associated with AU ranged from $244.55 to $346.28 across farm size groups. The total feed costs were calculated to be $331.29, based on the regional average. Feed costs in domestic cattle farming operations were followed by family labour costs at $73.74, fixed capital interest at $56.20, depreciation at $34.81, temporary labour at $26.21, and veterinary, medication, and

vaccine costs at $22.75, according to the farm average (Table 2).

In domestic cattle farming, production costs per animal unit decreased as the farm size increased (Table 2). The statistical significance of this difference between farm size groups was examined. According to the findings, a statistically significant difference was observed between production costs per animal unit and farm size groups ($p < 0.05$). This difference was determined to be statistically significant among all four farm groups after multiple comparisons.

Table 2. Production costs and elements according to animal unit in domestic breed cattle breeding

Cost elements	Group				FA	RA
	I	II	III	IV		
	$/AU					
Roughage	185.90	193.56	135.74	125.11	138.10	182.90
Concentrate feed	160.38	121.31	139.78	119.45	123.95	148.38
Total feed costs	***346.28***	***314.88***	***275.52***	***244.55***	***262.05***	***331.29***
Temporary labor	89.50	53.03	20.96	17.02	26.21	74.33
Veterinary-vaccine-medicine	59.29	38.49	28.84	16.33	22.75	51.09
Inventory depreciation	17.37	9.82	16.65	1.42	4.74	14.99
Pasture rent	13.58	3.44	0.00	1.72	2.51	9.94
Salt	4.62	3.30	2.06	2.09	2.39	4.07
Lighting-electricity	8.49	5.71	2.20	1.01	2.15	7.21
Vitamin-mineral-licking stone	4.00	2.82	1.48	1.05	1.48	3.47
Chain-bell	1.88	2.85	0.31	0.33	0.73	1.98
Water-cleaning material	1.05	0.99	0.66	0.52	0.62	1.00
Litter	0.83	1.01	0.66	0.47	0.57	0.85
Natural insemination	0.91	0.75	0.55	0.08	0.25	0.82
Artificial insemination	1.13	0.71	0.21	0.08	0.23	0.94
Total insemination fee	2.04	1.46	0.76	0.16	0.48	1.76
Other costs	4.18	6.62	7.91	6.23	6.30	5.06
Total variable costs	**548.94**	**437.82**	**350.10**	**286.67**	**326.70**	**501.98**
Family labour wage provision	90.39	95.34	77.82	68.25	73.74	90.16
Fixed capital interest	86.37	71.74	60.13	50.59	56.20	80.14
Depreciation	90.54	57.27	35.94	26.23	34.81	77.22
Permanent foreign labour wage	16.29	22.05	15.52	15.71	16.50	17.63
Building repair and maintenance	20.62	20.59	15.97	14.01	15.39	20.13
General administrative expenses	16.47	13.13	10.50	8.60	9.80	15.06
Total fixed costs	**320.69**	**280.13**	**215.89**	**183.40**	**206.43**	**300.35**
Production costs	**869.62**	**717.94**	**565.99**	**470.07**	**533.13**	**802.33**

Source: Own calculation.

When the proportional distribution of costs and elements incurred in indigenous cattle breeding activities in the research region was examined, the share of variable costs in production costs was 61.28% according to the farm average. This share was calculated to be 62.09%, in line with the regional average. The share of variable costs in production costs varied between 60.98% and 63.12% across farm size groups. The share of total fixed costs in production costs was 38.72%, according to the farm average. The share of fixed costs in production costs varied between 36.88% and 39.02% across farm size groups. The share of fixed costs in total production costs was calculated to be 37.91%, based on the regional average (Table 3).

In the interviewed farms, feed costs accounted for the highest share of production costs, constituting 49.15%. Feed costs were followed by family wages, at an average of 13.83%. The share of family labour wages in production costs varied between 10.39% and 14.52% across farm size groups (Table 3).

Feed constitutes the most significant component of production costs in both beef and dairy farms. Previous studies indicate that it accounts for 40% to 80% of total costs. These costs also include supplementary feed expenses, such as pasture, hay, silage, grain, protein supplements, and minerals. Feed costs are influenced by various factors, including commodity prices, weather conditions affecting forage availability, and the nutritional requirements of different cattle breeds and production stages. For example, dairy cows and rapidly growing beef calves have higher nutrient requirements. This necessitates more intensive feeding regimes and, consequently, higher feed costs. Improving pasture availability and effective grazing management, such as rotational grazing, can reduce farms' reliance on purchased feed and lower overall feed costs. [9], in his study on dairy cattle

farming in the central district of Çorum Province, he found that feed costs account for the highest share of production costs, at 39.51%, while other important cost elements include labour and depreciation costs. [33], in their study on the economic analysis of dairy cattle farming in the central district of Van Province, they found that the share of variable costs in production costs for domestic breed cattle breeding was 53.48%, while the share of fixed costs was 46.52%. The cost element with the highest share in production costs is feed costs at 44.60%. Feed costs, at 28.72%, are followed by depreciation costs, at 9.03%, in importance after permanent labour costs. In their study, [6] examined dairy cattle farms in the Erbaa Plain of Tokat Province and found that feed costs have the highest proportional share in domestic breed cattle breeding, accounting for 42.30%. [31] found, in their study on milk costs and marketing margins of dairy cattle farms in Tokat Province, that feed costs accounted for 47.99% of the total costs for farms raising domestic cattle. These were followed by temporary labour costs at 19.75%, capital interest at 14.78%, and depreciation at 8.49%. [32] found that the highest variable costs in farms raising domestic dairy cattle were feed costs at 84.17% and temporary labour wages at 6.59%. [15] found, in their study examining dairy cattle farms in Burdur province, that feed costs accounted for the highest proportion at 64.41%.

Labour costs include wages paid to hired workers as well as the estimated value of unpaid family labour. In small-scale farms, labour accounts for 22.55% of total costs. On these farms, labour is dependent mainly on family members. Labour accounts for 21.48% of total costs on large-scale farms. Large-scale farms typically require a significant amount of labour for daily tasks, such as feeding, milking, managing herd health, and maintaining facilities. Labour utilisation efficiency, influenced by factors such as farm layout, technology use, and herd size, directly impacts per-unit labour costs. High labour costs can significantly reduce profit margins, particularly in regions with high minimum wages or labour shortages.

Table 3. Proportional distribution of production costs and elements in domestic breed cattle breeding

Cost elements	Group				FA	RA
	I	II	III	IV		
	Rate (%)					
Roughage	21.38	26.96	23.98	26.61	25.90	23.96
Concentrate feed	18.44	16.90	24.70	25.41	23.25	19.51
Total feed costs	***39.82***	***43.86***	***48.68***	***52.03***	***49.15***	***43.47***
Temporary labour	10.29	7.39	3.70	3.62	4.92	7.89
Veterinary-vaccine-medicine	6.82	5.36	5.10	3.47	4.27	5.79
Inventory depreciation	2.00	1.37	2.94	0.30	0.89	1.71
Pasture rent	1.56	0.48	0.00	0.37	0.47	0.92
Salt	0.53	0.46	0.36	0.44	0.45	0.48
Lighting-electricity	0.98	0.80	0.39	0.21	0.40	0.77
Vitamin-mineral-licking stone	0.46	0.39	0.26	0.22	0.28	0.39
Chain-bell	0.22	0.40	0.05	0.07	0.14	0.23
Water-cleaning material	0.12	0.14	0.12	0.11	0.12	0.12
Litter	0.09	0.14	0.12	0.10	0.11	0.11
Natural insemination	0.10	0.10	0.10	0.02	0.05	0.09
Artificial insemination	0.13	0.10	0.04	0.02	0.04	0.10
Total insemination fee	0.23	0.20	0.13	0.03	0.09	0.19
Other costs	0.48	0.92	1.40	1.33	1.18	0.82
Total variable costs	**63.12**	**60.98**	**61.86**	**60.98**	**61.28**	**62.09**
Family labour wage provision	10.39	13.28	13.75	14.52	13.83	12.12
Fixed capital interest	9.93	9.99	10.62	10.76	10.54	10.13
Depreciation	10.41	7.98	6.35	5.58	6.53	8.65
Permanent foreign labour wage	1.87	3.07	2.74	3.34	3.09	2.50
Building repair and maintenance	2.37	2.87	2.82	2.98	2.89	2.64
General administrative expenses	1.89	1.83	1.86	1.83	1.84	1.86
Total fixed costs	**36.88**	**39.02**	**38.14**	**39.02**	**38.72**	**37.91**
Production costs	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Source: Own calculation.

In the research region, the farm average gross production value from domestic cattle breeding activities was $853.34 per animal unit. The gross production value obtained per animal unit was calculated as $932.76 in Group I farms, $911.18 in Group II farms, $772.85 in Group III farms, and $846.41 in Group IV farms. There was no statistically significant

difference in the gross production value obtained per animal unit in domestic cattle breeding across the farm size groups ($p > 0.05$). The gross production value obtained from domestic cattle breeding activities, based on the regional average, was determined as $888.06 AU (Table 4). The calculated productive value increase (PVA) in the domestic cattle breeding activities of the interviewed farms was determined to be $323.02 per animal unit according to the farm average and $356.55 according to the regional average (Table 4).Among the income elements that constitute the gross production value of the farms, the income from milk and dairy products consists of sales revenue from the marketing of milk and dairy products, the monetary equivalent of milk and dairy products consumed at home, and the monetary equivalent of milk consumed by calves. The weaning age of calves is considerably higher in domestic cattle compared to purebred and crossbred breeds. Therefore, the inclusion of milk consumed by calves in the gross production value is a topic that is not often discussed in the literature. [16], in their study on dairy cattle farming planning in Izmir and Manisa provinces, they subtracted the monetary equivalent of milk consumed by calves from the milk income obtained from cows. In a study conducted in Aydın Province to determine the productivity of dairy farms engaged in market-oriented production, [23] evaluated the monetary value of milk consumed by calves as part of the gross production value. Indeed, the total milk production at the farm includes the milk consumed by calves. Therefore, there is no difference in the milk produced by cattle between home consumption and marketing. Therefore, in this study, milk consumed by calves was included under the "Income from milk and dairy products" heading in the gross production value calculations. Among the income items constituting the gross production value of the farms, milk and dairy products generated an average of $ 469.68 per animal unit and a regional average of $474.41. Income from milk and dairy products ranged from $436.60 to $528.50 across farm size groups (Table 4). The manure income generated by the farms from their local breed cattle operations averaged $30.30 per animal unit. This value varied from $29.29 to $33.66 across farm size groups, with a regional average of $32.25 (Table 4). The support and incentive income received by the interviewed farms, provided by the Ministry of Agriculture and Forestry, was determined to average $30.34 per animal unit (Table 4). Of the farms' gross production value, the income from milk and dairy products accounted for the largest share, at 55.04%. This rate varied between 46.59% and 63.30% across farm size groups, while the regional average accounted for 53.42%. Among the farms interviewed, PVA received a 37.85% share of the income generated from raising indigenous cattle, according to the farm average, and 40.15%, according to the regional average (Table 4).

Table 4. Gross production value obtained from domestic breed cattle breeding

Income elements	Group				FA	RA
	I	II	III	IV		
	$/AU					
PVA	**452.56**	**314.07**	**223.67**	**325.28**	**323.02**	**356.55**
Milk and dairy products	**434.60**	**528.50**	**489.24**	**460.47**	**469.68**	**474.41**
Milk and dairy products are sold	138.13	435.46	438.01	433.81	416.19	321.18
Milk and dairy products consumed at home	263.57	63.92	25.12	2.99	28.38	124.08
Milk consumed by calves	32.90	29.12	26.11	23.67	25.12	29.15
Manure income	**32.89**	**32.63**	**33.66**	**29.29**	**30.30**	**32.25**
Support and incentives	**12.71**	**35.98**	**26.28**	**31.36**	**30.34**	**24.84**
Total GPV	**932.76**	**911.18**	**772.85**	**846.41**	**853.34**	**888.06**
Rate (%)						
PVA	**48.52**	**34.47**	**28.94**	**38.43**	**37.85**	**40.15**
Milk and dairy products	**46.59**	**58.00**	**63.30**	**54.40**	**55.04**	**53.42**
Milk and dairy products are sold	*14.81*	*47.79*	*56.67*	*51.25*	*48.77*	*36.17*
Milk and dairy products consumed at home	*28.26*	*7.01*	*3.25*	*0.35*	*3.33*	*13.97*
Milk consumed by calves	*3.53*	*3.20*	*3.38*	*2.80*	*2.94*	*3.28*
Manure income	**3.53**	**3.58**	**4.36**	**3.46**	**3.55**	**3.63**
Support and incentives	**1.36**	**3.95**	**3.40**	**3.71**	**3.56**	**2.80**
Total GPV	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Source: Own calculation.

The share of productive value within gross production value varied between 28.94% and 48.52% across farm size groups. In the interviewed farms, manure revenue accounted for an average of 3.55% of the gross production value generated from domestic cattle breeding, while revenue from support and incentives accounted for 3.56% (Table 4).

[28] conducted an economic analysis of cattle breeding in the Suluova district of Amasya, finding that milk revenue accounted for 68.66% of the gross production value, while 26.52% came from domestic dairy cattle and 4.82% from fertiliser revenue. [33], who conducted economic analyses of dairy cattle farms in the central district of Van province, found that the share of milk and dairy product income within the gross production value in domestic cattle breeding was 36.49%, PVA was 56.42%, and fertiliser income was 7.10%. [6] found that the share of milk income within the gross production value in domestic cattle breeding was 62.63%, and the share of fertiliser income was 3.41%. In his study conducted in the Niksar district of Tokat province, [32] found that the share of milk and dairy product income within the gross production value in domestic dairy cattle farms was 72.60%, the share of animal manure income was 3.8%, and the share of inventory value increase was 23.59%.

In domestic cattle farming, profitability is a complex outcome influenced by the interaction of production costs, market prices, and management efficiency. While cost control is important, income generation and strategic market positioning are equally crucial for achieving sustainable economic returns. Profitability is assessed through various metrics, including gross profit, absolute profit, and relative profit.

In addition to cost management and market prices, other factors contributing to the overall profitability of cattle farms include production efficiency, utilisation rate, reproductive performance, herd health, genetic and breed selection, farm size, economies of scale, management practices, and risk management.

The gross profit per unit of cattle produced by the farms was calculated as $526.58 according to the farm average and $412.98 according to the regional average. Within farm size groups, gross profit from raising domestic breed cattle ranged from $383.08 to $559.81 per animal unit.

The absolute profit per unit of cattle was determined to be $320.15 according to the farm average. The absolute profit was calculated as $62.39 in Group I farms,$193.32 in Group II farms, $206.97 in Group III farms, and $376.41 in Group IV farms. The absolute profit, based on the regional average, was calculated to be $112.63 (Table 5). In domestic breed cattle production, the absolute profit per unit of cattle increased with farm size (Table 5). The statistical significance of this difference between the groups was examined. Accordingly, a statistically significant difference was found between groups based on absolute profit and farm size ($p < 0.05$). This difference was determined to be statistically significant among all four farm groups after multiple comparisons.

However, there was no statistically significant difference between the gross profit indicators obtained for the cattle unit across different farm size groups.

Relative profit for farms was calculated by dividing the gross production value of domestic cattle breeding by the total production costs. Accordingly, the calculated relative profit was 1.07 for Group I farms, 1.27 for Group II farms, 1.37 for Group III farms, and 1.80 for Group IV farms. This value, which was 1.16 according to the regional average, was calculated as 1.60 based on the farm average (Table 5).

Accordingly, farms earned a profit of $60 for every $100 in expenses. The relative profit from domestic breed cattle breeding increased as the farm size increased. The statistical significance of this difference between the groups was examined. According to the test, a statistically significant difference was found between the relative profit and farm size groups ($p < 0.05$). Multiple comparisons determined that this difference exists between farms in Groups I and II and Group IV.

[31] calculated the relative profit as 1.34 in previous studies on domestic cattle breeding,

specifically in farms raising domestic dairy cattle in Tokat Province. [6] found the relative profit to be 1.18 in domestic cattle breeding. [3] found the relative profit to be 1.84 in some studies on cultivated breeds. The relative profitability of domestic cattle breeding is significantly lower than the regional average.

Table 5. Profitability indicators in domestic breed cattle breeding according to the AU

Profitability indicators	Unit	Group				FA	RA
		I	II	III	IV		
Gross profit	$/AU	383.08	473.45	422.86	559.81	526.58	412.98
Absolute profit	$/AU	62.39	193.32	206.97	376.41	320.15	112.63
Relative profit	Rate	1.07	1.27	1.37	1.80	1.60	1.16

Source: Own calculation.

CONCLUSIONS

The production costs and profitability of indigenous cattle farms are subject to a complex interplay of internal and external factors. This study examined the components of production costs on indigenous cattle farms and revealed that feed costs consistently stand out as the most significant component. Effective management of these costs, along with strategic investments in labour, veterinary care, and breeding, is fundamental to economic sustainability. Furthermore, the selection of cattle breeds, whether for beef or dairy purposes, has a profound impact on productivity, efficiency, and market suitability. This highlights the importance of genetic selection tailored to specific production objectives and environmental conditions. Farm profitability is not solely a function of cost control. It also depends on revenue generation, which is heavily influenced by dynamic market forces. Fluctuations in the industry's product prices, driven by supply and demand, commodity prices, and consumer preferences, necessitate marketing strategies and robust risk management. Furthermore, adopting sound management practices encompassing herd health, nutrition, breeding, and data-driven decision-making processes to optimise performance is essential for the economic viability of indigenous cattle farms. Furthermore, increasing farm resilience against market volatility and unforeseen challenges is also vital for the sector. Consequently, achieving sustainable profitability in domestic cattle breeding requires a holistic and adaptable approach.
Farmers must continuously evaluate their cost structures, leverage genetic potential through informed breed selection and breeding programs, and strategically navigate market dynamics. By integrating efficient resource utilisation with proactive management and a deep understanding of economic principles, cattle farms can increase their long-term sustainability and continue to play a vital role in global food production.

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STUDY ON THE GLOBAL RICE MARKET, 2020-2024

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Abstract

Rice is an important source of food for a significant part of the world's population. This is due to its rich content in protein and other nutrients and also easy to be processed in various dishes. This study aimed to study the evolution of the global rice market during the period 2020-2024. The paper analyzed the most important indicators related to the rice market, as follows: global rice area, production, average rice production per hectare, average annual consumption of rice and rice products, global rice imports and exports. The statistical data that formed the basis of the study were taken from the FAOSTAT website. The results showed that the most significant rice production is obtained in Asian countries, due to the climate that favors this crop. Currently, India and China are the leaders of the top of the largest rice producers recorded worldwide. In the future, it is estimated that Asia will remain the main rice producer worldwide.

Key words*: rice, cultivated area, production, yield, imports and exports, worldwide*

INTRODUCTION

Rice (*Oryza sativa* L.) is the third most important cereal crop worldwide. For example, in 2024, the following cereal areas were cultivated worldwide: wheat 219,518,805 ha, maize 209,954,361 ha, rice 172,414,425 ha [7]. According to studies, rice is cultivated in most tropical and subtropical regions of the globe. The most significant areas cultivated with rice are found in the following countries: China, India and Bangladesh [11, 12].

Currently, rice is widely consumed globally, representing an important source of food for a significant portion of the world's population, as it is a calorie-rich food and is cheaper compared to other staple foods[1, 3, 5].

In the aforementioned countries, there are climatic conditions favorable to rice cultivation, which directly contributes to obtaining significant quantities of rice, part of which is intended for domestic supply, and another part is intended for export [10, 11, 20].

According to statistical data published by the FAO, as well as other authorized institutions, in 2024, a global rice consumption of over 510 million tons was recorded. The level of consumption was influenced by the following factors: demographic growth in Asia and Africa; the lower price of rice compared to other cereals used in food, as well as large-scale urbanization in certain regions [19].

In the field, an increase in the demand for rice is anticipated in the future due to several factors, including: global population growth; food diversification; economic growth; climate change, etc. [4].

It is important to remember that there are also a number of vulnerabilities specific to the rice market, such as: climatic distortions; the concentration of rice production in certain regions of the world and agricultural policies [2, 9].



Photo 1. Rice fields
Source: [16].

In this context, the purpose of this research is to study the global rice market during the

period 2020-2024, using the main based indicators: cultivated area, production, yield, annual consumption of rice and rice products, and trade in terms of imports and exports.

MATERIALS AND METHODS

To carry out the research, the data regarding the indicators taken into account have been collected from FAOSTAT website, the main provider of statistical data.
Also, numerous specialized works were consulted to create an image about the results obtained in scientific research up to present. The research results were presented in a graphical form.



Photo 2. Rice terraces.
Source: [17].

RESULTS AND DISCUSSIONS

During the period 2020-2024, the global rice market recorded numerous fluctuations determined by a series of factors, such as: cultivated area, production obtained, consumption achieved, quantity of rice traded worldwide, etc.
The surface cultivated with rice has had variations during the period under analysis at the global level. According to published data, the largest area under rice cultivation was in 2024 (172.4 million ha), and the smallest area of 164.4 million ha was recorded in 2020 (Figure 1).
Asia, according to official statistical data, is the world's largest rice grower. Here, the area cultivated with rice varied from one year to another, in the analyzed interval (Figure 2).

In 2024, the largest area with rice was cultivated in Asia, 147 million hectares.

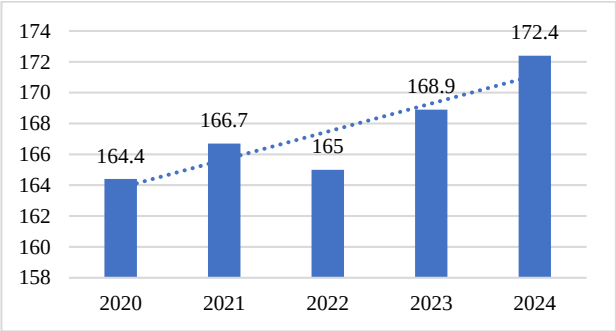


Fig. 1. Global rice area, 2020-2024 (million ha)
Source: Own calculations based on FAOSTAT data [7].

In 2024, the area cultivated with rice worldwide increased by 4.8%, compared to 2020.



Photo 3. Rice terraces -Japan
Source: [18].

At the opposite pole, the smallest cultivated area was 141.1 million hectares. Here, in 2024, the area cultivated with rice increased by 4.1%, compared to 2020.

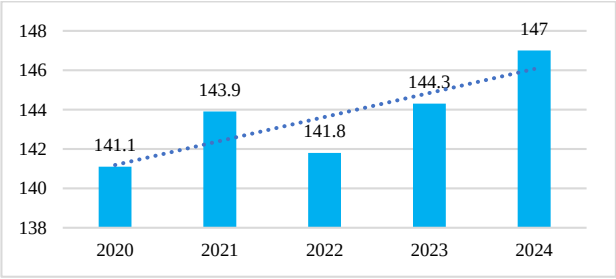


Fig. 2. Area under rice cultivation in Asia, 2020-2024 (million ha)
Source: Own calculations based on FAOSTAT data [7].

In 2024, Asia cultivated over 85% of the world's rice area.

This justify why rice is a staple food for a significant part of the planet's population. It is necessary to specify that rice is a staple food, especially in Asia. Due to this fact, we can say that Asia will remain the main rice grower worldwide [11, 12].



Photo 4. Rice culture (organic)
Source: [14].

Regarding the area cultivated with rice at continental level in 2024, it is observed that Asia is followed at a great distance by: Africa (10.9% of the total area cultivated with rice); Americas (3.3%); Europe (0.3%) and Oceania with an insignificant area (Figure 3).

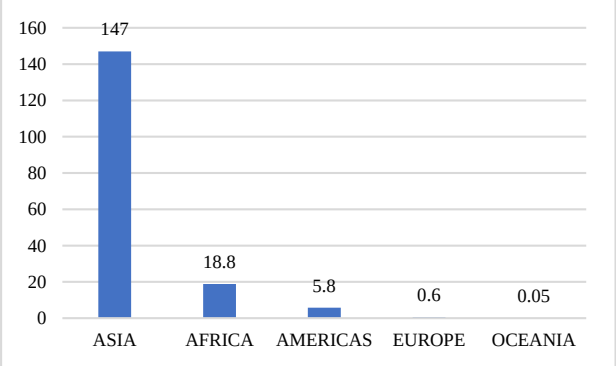


Fig. 3. Area under rice cultivation at continental level, in 2024 (million ha)
Source: Own calculations based on FAOSTAT data [7].

The top 5 rice growers registered worldwide by cultivated area for the analyzed period are the following countries: India, China, Bangladesh, Indonesia and Thailand [11, 7].
From the statistical data presented in Figure 4, it can be seen that, in 2024, India together with China cultivated 54.2% of the area cultivated with rice in Asia, respectively 46.2% of the total area cultivated with rice worldwide.

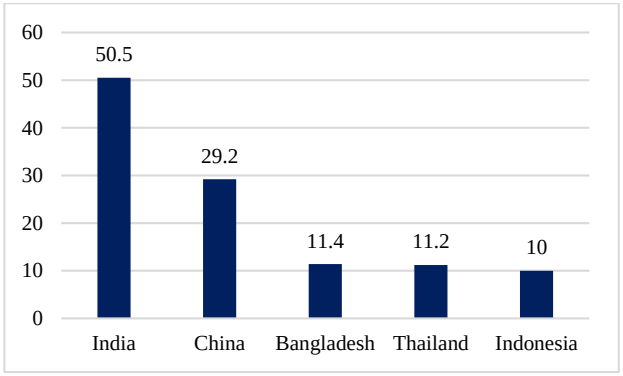


Fig. 4. The surface cultivated with rice in the top 5 rice-growing countries in 2024 (million ha)
Source: Own design based on the data from FAOSTAT [7].

The global top producer of rice is India, where the cultivated area followed an upward trend during the period of the analysis as shown in Figure 5. Compared to 2020 level, in 2024, the area under rice cultivation increased by 12.2%. In 2024, the share of the cultivated area with rice in India accounted for 29.3% of the total rice surface under cultivation worldwide and 34.3% of the rice cultivated land in Asia.
Among the most important factors underlying the cultivation of rice on large areas in this country we find: favorable pedoclimatic conditions; very important food for the population's diet; large number of inhabitants, assured market for sales, etc.

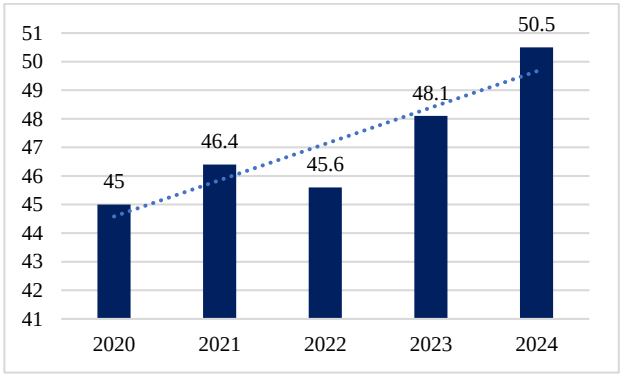


Fig. 5. Rice area in India, 2020-2024 (million ha)
Source: Own calculations based on FAOSTAT data [7].

During the analyzed period, world rice production varied from year to year due to several factors, such as: climatic conditions; economic interest of rice growers; market price level; areas cultivated with rice, etc [6, 8].



Photo 5. Rice field
Source: [15].

In 2024, the highest rice production of 820.2 million tons was recorded, while in 2021, the lowest production of only 771.6 million tons was achieved (Figure 6).

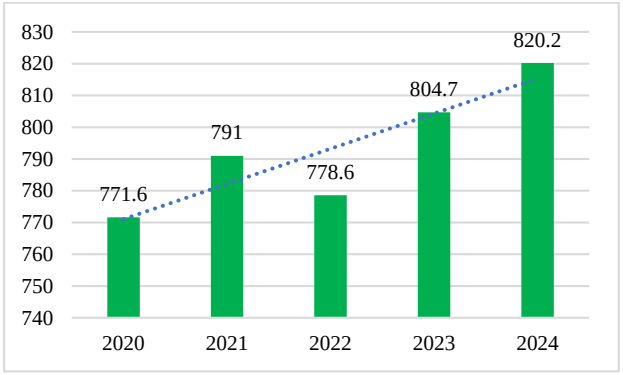


Fig. 6. Global rice production 2020-2024 (million tons)
Source: Own calculations based on FAOSTAT data [7].

Global rice production increased by 6.28% in 2024, compared to 2020.

This increase is due to several factors, including: increased investment in technology; favorable weather conditions for rice cultivation; increased yield per hectare; improved agricultural subsidy policies, etc.

The average yield per hectare for the global rice crop during 2020-2024 has recorded a series of variations (Figure 7).

The highest yield per hectare was achieved in 2023 (4,764 kg/ha). On the other hand, the lowest yield was recorded in 2020 (4,691.6 kg/ha).

The yield per hectare for rice cultivation worldwide in 2024 increased by 1.40% compared to 2020.

The increase in yield was based on a number of factors, such as: the efficient use of irrigation systems during dry periods; the cultivation of rice varieties that have a higher yield; the application of fertilizers in optimal doses; the use of modern technologies, etc.



Photo 6. Basmati rice
Source: [13].

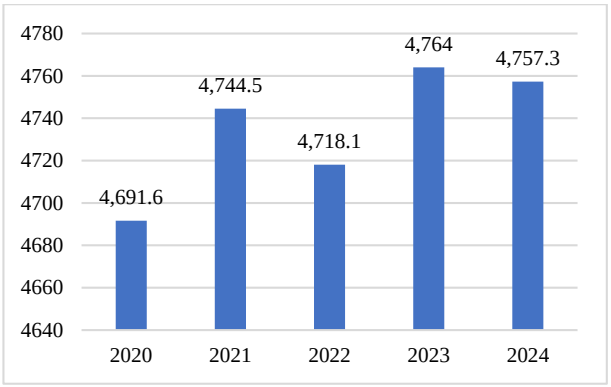


Fig. 7. Average production per hectare of rice worldwide (kg/ha)
Source: [7].

In the interval 2020-2023, the average annual consumption of rice and rice products changed as reflected by Figure 8. The highest consumption level was 81.35 kg/capita registered in the year 2020 and the lowest level was 79.76 kg/capita accounted in 2021.

In comparison with the 2020 level, in 2023, the average annual per capita consumption of rice and rice products declined by 1.91%, the main causes can be attributed to changing eating habits in those regions where rice is a staple food.

This change in diet is mainly due to the increase in incomes of the population.

The quantitative imports of rice at the global level varied from one year to another in the analyzed interval (Figure 9).

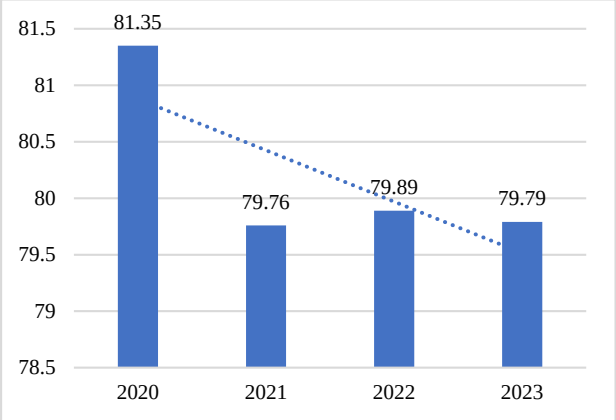


Fig. 8. Average annual per capita consumption of rice and rice products worldwide, 2020-2023 (kg/capita)
Source: [7].

From the statistical data presented, it is easily observed that the highest imports of rice were recorded in 2024 (4,388,504.09 tons), and the lowest were 3,102,251.4 tons. In 2024, global quantitative imports of rice increased by 40.61%, compared to 2020.

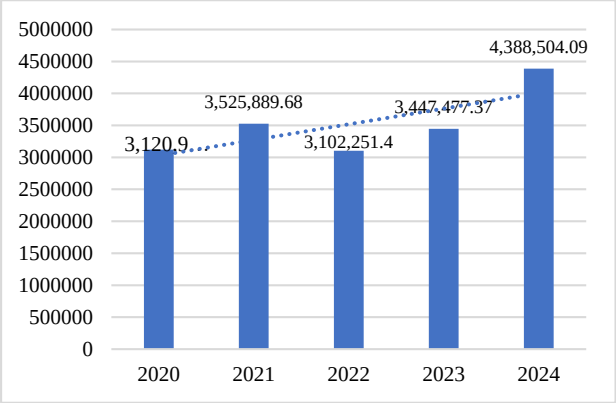


Fig. 9. Quantitative imports of rice worldwide, 2020-2024 (tons)
Source: [7].

The increase in quantitative imports of rice worldwide in 2024 was due to several factors, including: population growth in certain regions of the world, which led to increased demand for rice; lower rice production in certain importing countries; lower import tariffs; price reductions encouraged increased imports by certain countries in order to achieve safety stocks, etc.

Regarding the global value of imported rice worldwide, the statistical data presented shows that it varied over the analyzed period (Figure 10). The highest value of imported rice was recorded in the period 2023-2024 (1,952,336 thousand dollars), and the lowest value was 1,357,157 thousand dollars (2020). In 2024, the total value of imported rice worldwide increased by 43.85% compared to 2020.

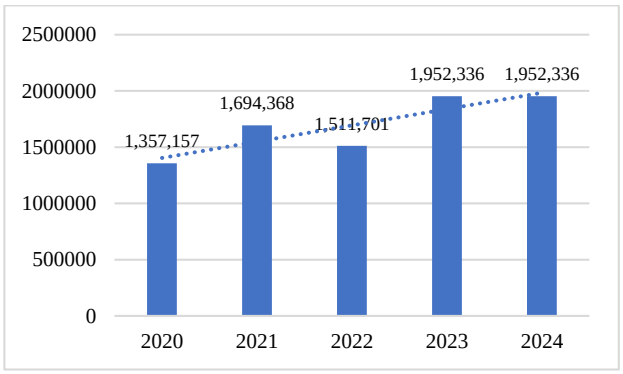


Fig. 10. Total value of rice imports worldwide, 2020-2024(thousand dollars)
Source: [7].

According to published statistical data referring to the most representative rice importers registered worldwide in 2024, it was observed that the largest imported quantity was 1,453,314 tons, which was carried out by Vietnam (Figure 11). Vietnam's quantitative rice imports in 2024 represented 33.11% of the total transactions carried out on the international market.

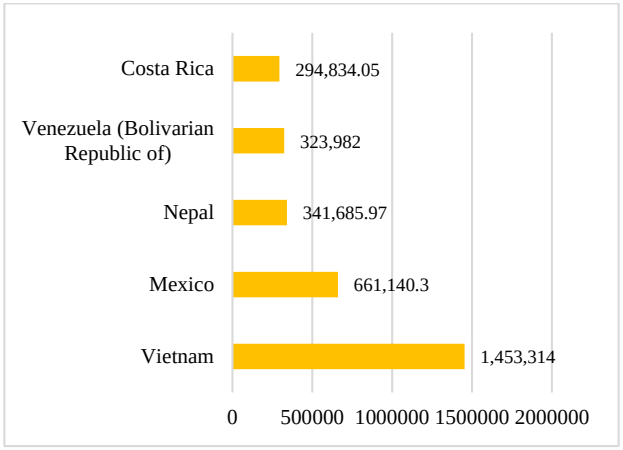


Fig. 11. Top 5 rice importers registered worldwide in 2024 (tons)
Source: [7].

It is necessary to mention that this country, which is located in Southeast Asia, also

produces a significant amount of rice that is intended for export. However, Vietnam imports rice from the international market at lower prices for: animal feed; industrial processing; the creation of safety stocks; price stability, etc.

In the top 5 rice importers registered worldwide in 2024, alongside Vietnam, we find, but with a large difference: Mexico; Nepal; Venezuela and Costa Rica (Figure 11).

Quantitative rice exports worldwide have evolved differently during the analyzed period, as follows: in the period 2020-2022, exports were relatively stable, with a slight decrease in 2021 and a recovery in 2022; in 2023, an increase is observed compared to both 2020 and 2022; and in 2024, the largest increase in the analyzed period is observed (Figure 12). According to the statistical data presented, the smallest quantity of rice exported worldwide was 3,033,079.68 tons (2021), and the most significant was recorded in 2024 (8,128,726.90 tons).

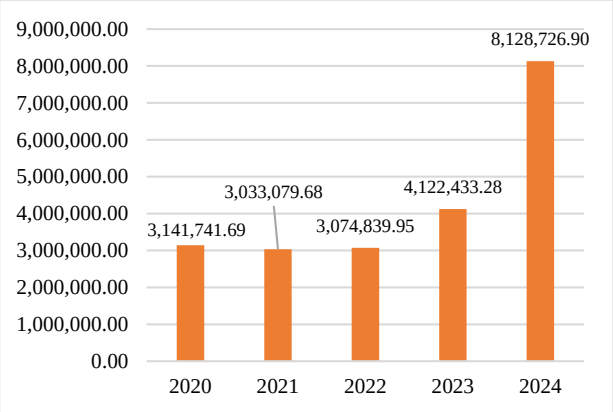


Fig. 12. Quantitative exports of rice worldwide, 2020-2024 (tons)
Source: [7].

Quantitative rice exports in 2024 increased significantly, namely by 168%, compared to 2020. This increase was mainly due to the following factors, such as: the increase in rice production recorded worldwide; the increase in global demand for rice; the practice of competitive prices on the international market, etc.

Regarding the total value of rice exported worldwide, it can be easily seen from the presented statistical data that this has changed during the analyzed period (Fig. 13). The lowest value for rice exported worldwide was 1,090,428 thousand dollars (2021), and the most significant value was recorded in 2024 (2,900,197 thousand dollars).

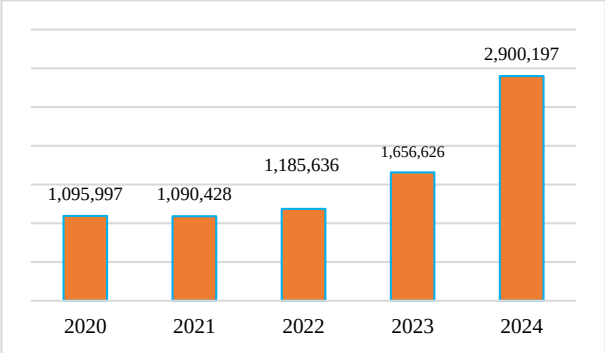


Fig. 13. Total value of global rice exports, 2020-2024 (thousands of dollars)
Source: [7].

The total export value in 2024 increased by 165.96%, compared to 2020. This significant value for rice exports was due to higher production and higher quantity of rice commercialized in the international market, and also to the attractive export price linked to the higher demand.

According to data published by FAOSTAT for 2024, it was observed that the top 5 rice exporters (in terms of quantity) recorded worldwide were: Cambodia; USA; Brazil; India and Uruguay (Fig. 14).

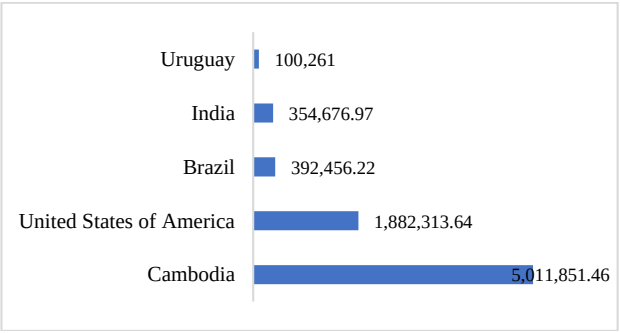


Fig. 14. Top 5 rice exporters registered worldwide in 2024 (tons)
Source: [7].

Cambodia exported 61.65% of the total amount of rice exported worldwide in 2024.

In the coming future, for a medium and long term, it is expected as global rice production to raise and also the rice transactions with rice to be intensified, because rice is and will be a

staple food for a significant part of the world's population.

CONCLUSIONS

This analysis of the main aspects regarding the global rice market has led to the following conclusions:

-The year 2024 was notable for the largest area cultivated with rice, of 172.4 million ha;

-Asia cultivated the most significant area of rice in 2024, 147 million hectares;

-In 2024, India and China together cultivated 54.2% of the world's rice-growing area;

-The highest rice production achieved globally was 820.2 million tons (2024);

-The most significant yield per hectare for rice crop was 4,764 kg/ha (2023);

-In 2020, the highest consumption of rice and rice products was recorded worldwide, at 81.35 kg/capita;

-The most significant rice imports globally were 4,388,504.09 tons (2024);

-In the period 2023-2024, the highest value of imported rice was recorded globally, at 1,952,336 thousand dollars;

-In 2024, the largest amount of rice was imported by Vietnam, at 1,453,314 tons.

-In 2024, the largest quantitative exports of rice worldwide were recorded, at 8,128,726.90 tons;

-The highest export value for the "Rice" category worldwide was 2,900,197 thousand dollars (2024);

-Cambodia, in 2024, stood out as the largest recorded rice exporter worldwide, trading 8,128,726.90 tons.

Specialists in the field estimate an increase in transactions on the international rice market because it represents a staple food for a considerable part of the planet's population.

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A CONCEPT FOR CIRCULAR, ECOLOGICAL AND HEALTHY VEGAN FOOD

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Abstract

This study presents the development, biochemical evaluation, and economic analysis of a novel food product derived from a blend of apples, carrots, and okra—using both fresh and residual plant material from juice production. The aim is to utilize fruit and vegetable processing waste to create a nutritionally valuable, organoleptically appealing, and economically viable product, while supporting principles of circular economy and sustainable food systems.
Organoleptic assessment shows that the final product has a fresh, crisp texture, mosaic-like visual appearance, and a delicate flavor profile combining fruity sweetness with vegetal freshness. Biochemical analysis (sugars, pH, glucose, fructose, vitamin C, and redox potential) demonstrates a well-balanced composition with reduced sugar content, enhanced antioxidant properties due to okra's high ascorbic acid content (700 mg/L), and moderated acidity and conductivity levels. The production method involves fine shredding, cold pressing (for okra), and drying at pasteurization temperature (80°C) to preserve nutrients and ensure microbiological safety. The drying process is optimized until residual moisture matches the natural sugar content of the raw materials (18.5% °Brix). Economic analysis reveals that 5 kg of raw material (1/3 apple and 1/3 carrot juice processing residue and 1/3 fresh okra) yield 1 kg of dried product at a production cost of approximately €3/kg. The estimated market value of the dried blend reaches up to €47/kg, highlighting high added value and strong commercialization potential. This zero-waste approach transforms by-products into functional foods with health-promoting attributes, low environmental impact, and aligns with EU and global strategies for sustainable agriculture, food security, and resource efficiency.

Key words*: circular economy, food waste valorization, functional food, Apple · Carrot · Okra blend, drying technology, sustainable food production*

INTRODUCTION

Circular economy is a new concept called to contribute to the reduction of wastes, carbon footprint, recycling materials, creating value added and new products, and increasing economic efficiency based on creativeness and innovation [3].
Vegan food could be an alternative to traditional food products [2] and requires an appropriate study on consumers' perception, consumption and purchase behavior [12].
In this context, the main objective of the research is to develop a concept for the production of "circular", cheap and quality food, more exactly an innovative product, namely: ecological and healthy food from fruits and vegetables with minimal processing of raw materials, waste-free and low production value.
The idea is to select and combine different fruits and vegetables in certain quantities through a preliminary analysis of the biochemical and technological characteristics, using waste from them from other industries in a circular manner, so as to obtain quality food with good nutritional, biochemical and microbiological indicators, small volume and weight and desired durability.
To protect the presented concept, three types of popular fruits and vegetables were used, possibly organic and eco-production, these are: apples (*Malus domestica*) variety Pinova, carrots (*Carota*) variety Coral and green okra (*Hibiscus esculentus/Abelmoschus*) variety Clemson). The reason for their choice is as follows: apples and carrots are the so-called. basis (standard) for creating fruit and vegetable products, and okra is the missing link, the solder between the particles of apples and

carrots. Another reason is that the three types complement each other to obtain a final product with high nutritional value and quality. Apples provide sugars and acids, carrots provide mineral salts and electrolytes and vitamin A, and okra provides vitamin C and vitamin K, as well as some vegetable protein. This is evident from the already published literature. For example, [14] did a study on the probiotic fermentation of a mixture of carrot, beet and apple juice with *Lactobacillus casei*. Optimization of a formula for a functional drink with okra to achieve good texture, stability and taste published [9]. A study on the fiber and antioxidant activity of waste (pomace) from apple and carrot make [11]. They determine the usefulness of how carrot + apple can combine beneficial properties, especially for fiber and antioxidants. Article about fruit drinks that contain carrot + various fruit juices (including apple) and their effects on enzymes, antioxidant activity, etc. have been published are represented by [13]. Another team of scientists evaluated the functional properties of the plant mucilagin, obtained from eight varieties of okra grown in Ethiopia. They measured: mucilagin content (1.25-3.45 g/100 g), density, water and oil absorption capacity, emulsifying and foaming ability, stability and antioxidant properties [5], and [7] developed edible films made from okra mucilagin extract (from scrapped fruits). They are examined using various methods: FTIR, XRD, thermogravimetric analysis, swelling index, degree of solubility in water, etc. In another study, okra mucilagin was compared to other parts of the plant (e.g., peels/seeds) to assess hypoglycemic effect (lowering blood sugar) and effect on blood lipids [6]. Extraction techniques, composition (monosaccharides such as galactose, rhamnose, galacturonic acid), properties and potential for applications in food, pharmacy and health are reviewed [4]. He examines the extraction of mucilagin with ultrasound and evaluates the rheological properties of aqueous solutions [1]. A very thorough review study that looks at extraction methods, composition, applications and potential health benefits is being done by a team of scientists [4]. A team [8] evaluates extraction and physicochemical properties, with a focus on potential in pharmacy. A review of extraction methods and the use of mucilagin as an excipient for pharmaceutical drug supply describe [10].

As can be seen, there is ample data on the health benefits of okra, which, together with the excellent adhesion ability of its plant mucilage, made it an important component in the current study. On nutritional value, health benefits, and on the fact that apples and carrots are a basic raw material for the processing and food industries, many works have been written, some more important for the current work have been mentioned above.

MATERIALS AND METHODS

For the implementation of the study, digital instrumental methods were used: to determine the total amount of dissolved sugars (Brix, %) - digital refractometer "Milwaukee MA871", to determine the fructose content (Fru, %) - digital refractometer "Milwaukee MA872", to determine the glucose content (Glu, %) - digital refractometer "Milwaukee MA873".

A combined digital instrument was used as a conductivity-potentiometer meter, "Waterproof-IP57" tester to perform measurements to determine total acidity (pH), redox potential (Eh, mV), electrical conductivity EC (mS/cm), total amount of dissolved solids TDS (%), total salt content (%), specific gravity S.G., temperature (t°C) of plant fluids. The devices are automatically adjusted, depending on the temperature of the solution, and have Bluetooth data transfer to a computer.

The moisture content of the product measured with a KWB moisture meter.

Sensory analyses, organoleptic tests, such as taste, aroma, color and appearance of fruits and vegetables were also performed. Apples and carrots are crushed with a crusher, and okra is pressed using a press.

Ascorbic acid was measured by semi-quantitative colorimetry with MQuantTM test strips with a range of 0-25-50-100-200-300-500-700-1,000-2,000 mg/l. Ascorbic acid reduces yellow molybdophosphoric acid to phosphomolybdenum blue. The concentration

of ascorbic acid is measured semi-quantitatively by visually comparing the reaction zone of the test strip with the fields of the color scale.

RESULTS AND DISCUSSIONS

Organoleptic indicators of the raw materials used and the finished product

Apples are yellow-green with reddish shades and are characterized by the following organoleptic qualities: the flesh is yellowish, sweet and sour, crunchy, with a fresh aroma typical of an apple. After cutting or chopping, it quickly acquires a light brown color, that is, it oxidizes. The measured biochemical characteristics are presented in Table 1.

Carrots are bright orange, crunchy, sweetish, with a fresh aroma typical of a carrot. After breaking their integrity, they retain their color, i.e. they do not oxidize easily upon contact with air. The measured biochemical characteristics are presented in Table 1.

Okra is green in color; When crushed, only the white seeds are browned, while the rest is divided into a semi-dry paste and vegetable mucus (mucilagin) — both with a fresh light green color and a typical "green" aroma reminiscent of chlorophyll. The measured biochemical characteristics are shown in Table 1.

The resulting final product has a mosaic texture with colors from the three ingredients. To preserve the colors, if necessary, ascorbic acid can be added in the amount of 25 mg/kg, in powder form, immediately after crushing the apples. The taste is subtle and delicate, with a slight herbaceous hue coming from okra, a fruity admixture from apples, slightly sweet and pleasant. The product successfully replaces light desserts, causes a feeling of satiety and at the same time stimulates salivation, quenching thirst. It is also suitable for culinary use.

Table 1 Biochemical indicators of the fruits and vegetables used and average values for the resulting product

Examined indicator	Apples	Carrots	Okra	Average for the finished product
Sugars (Brix, %)	18.50	10.00	9.20	12.53
Fructose, Fru (%)	17.80	8.90	7.50	10.50
Glucose, Glu (%)	4.70	5.00	2.50	4.06
Acidity, pH	3.91	6.44	5.49	5.28
Brix/pH ratio	4.71	1.21	1.67	2.53
Brix/Glu ratio	3.91	2.00	3.68	3.19
Electrical conductivity, EC (mS/cm)	2.35	6.61	4.22	4.39
Dissolved solids, TDS (ppm)	0.118	0.375	0.211	0.230
Salt, Salt (%)	0.11	0.30	0.21	0.20
TDS/Salt ratio	0.99	1.21	1.00	1.066
Specific weight, S.G.	1.001	1.001	1.000	1.000
Redox potential, Eh (mV)	315	-1	100	138
Vitamin C, (mg/l)	75	50	700	273

Source: Own results.

Method of preparation of the proposed food product

Apples, carrots and okra (or leftovers thereof obtained in other productions) are finely chopped in different proportions, depending on the quantity available. In this case, the ratio is apples: carrots: okra = 1:1:1.

It is important to note that okra can be pressed by cold pressing if not enough mucilagin is released from the residue. A large amount is not needed – it is enough to get a dough that can be kneaded after adding finely chopped apples and carrots (Photo 1, Photo 2 and Photo 3).

The mixture is thoroughly mixed so that the plant mucus impregnates the fruit and vegetable pieces and prevents decay. It is then spread in a layer 3–5 mm thick and dried at a pasteurization temperature (80°C) for 4–6 hours, depending on the dryer and the characteristics of the products.

Drying is carried out until the moisture content of the finished product reaches the sugar content of the used apples – 18.5%, according to Table 1.



Photo 1. Products used from left to right: apples, carrots and okra.
Source: Original.



Photo 2. Preparation of products from left to right: chopped carrots, added chopped apples, added pressed okra in a ratio of 1:1:1.
Source: Original.



Photo 3. Kneading and spreading the resulting fruit mass and preparation for drying – from left to right: raw product before drying, dried finished product, dried product under a microscope, magnification x30, ordinary light, air environment.
Source: Original.

Biochemical indicators of the raw materials used

Table 1 shows the following:

-Apples have the highest content of total soluble sugars and fructose.

-Glucose in apples and carrots is almost the same, while in okra it is about 2 times lower.

-Carrots contain approximately half as much fructose and sugars as apples.

-Okra has the lowest sugar content, but the values are close to those of carrots.

Additional biochemical considerations:

-In terms of most biochemical indicators, okra occupies intermediate values between apples and carrots. It acts as a natural biochemical balancer in the mixture.

-In the finished product, it: Reduces the total content of sugars (fructose and glucose);

-Reduces the values of electrical conductivity, salt content and dissolved solids, mainly coming from carrots;
-Brings the relative density of juice closer to that of water;
-Corrects the redox potential (Eh), balancing the high values in apples;
-Helps maintain sweetness through the Brix/pH ratio and promotes low glucose concentration through the Brix/Glu ratio.

Vitamin C:

-Okra contains about 9 times more vitamin C than apples and 14 times more than carrots. It:
-Increases the antioxidant value of the final product;
-Improves the stability of the apple mass, protecting it from oxidation;
-It preserves the organoleptic and nutritional qualities of the product without the need for additional additives.

Cost-effectiveness

The proposed concept can be successfully applied in the practice of micro-enterprises for processing fruits and vegetables, especially in the region of Kyustendil, Bulgaria, where enterprises have a maximum capacity of 1 ton/hour or 8 tons/day, which is rarely reached. In order to preserve the nutritional value of the products (through lower heating, reduced oxidation, etc.), it is recommended to use:
-Lower crushing and cutting speeds,
-Cold pressing or vacuum deaeration,
-Temperatures up to 80°C (pasteurization) when drying.

Real ratio between raw material and waste.

Under these conditions, **the yield of juices** is about up to **60%,** and **40% of the mass remains as a residue**. In the period **2020–2024**, this waste was sold to **livestock breeders** for **50 euros/ton**, which with 3.2 tons of waste per day gives an income of about **160 euros/day** (Table 2 and Table 3)**.**

Table 2. Prices of raw materials and their production residues

Raw material	Purchase price raw (€/t)	Residual (%)	Balance residue (t/day)	Value residue (€/t)	Total residue (€/day)
Apples	100	40%	3.2	50	160
Carrots	350	40%	Included	50	Included
Okra	500 (unprocessed)	-	small quantities	50	Minor

Source: Fruit Processing Plant "Velanto Group" Ltd.

Daily from 3.2 tons of waste mass, approximately 0.6 tons (18.5%) of dried product can be obtained.
Commercial value of dried products individually:

Product	-	Sale price (€/kg)
Dried apples	-	12
Dried carrots	-	30
Dried okra	-	100

Table 3. Production costs and revenues (EUR): from 5 kg of raw material = 1 kg of dried product. The okra in the mixture is fresh, while the apples and carrots are in the form of a residue of juice production

Price per 1 kg of raw okra	Cost of 1 kg of leftover apple	Price of 1 kg of leftover carrot	Consumption for 5 kg of raw material (1:1:1)	Consumption per 1 kg of dried product	Income from 1 kg of dried product
0.50 €	0.05 €	0.05 €	3.00 €	3.00 €	47.00 €

Source: Fruit Processing Plant "Velanto Group" Ltd.

The figures in Table 3 reflect that the use of waste fruit and vegetable mass and a minimum amount of fresh okra creates a highly profitable product. With a consumption of 3 euros/kg of dried product, the final income can reach 47 euros/kg.

This represents a more than 15-fold increase in the value of the materials used.
In addition to economic benefits, the model also offers environmental and social benefits: reduced waste, better sustainability and added value in agriculture.

CONCLUSIONS

Based on the studies and analyses performed, the following main conclusions can be drawn:
(a)Waste-free production cycle;
(b)Excellent organoleptic characteristics;
(c)The combination of apples, carrots and okra leads to the creation of a product with:
-Pleasant appearance (mosaic texture and natural colours);
-New, subtle and delicate taste – herbaceous with a fruity admixture;
-Aroma combining the freshness of foliage and fruit;
-Biochemically balanced composition;
-Reduced content of total sugars, fructose and glucose (thanks to okra);
-Improved electrolyte properties by including carrots;
-Enhanced antioxidant properties through the high content of vitamin C in okra.
(d)Healthy, minimally processed product.
The product is prepared by minimal human intervention, without added ingredients, only through: Crushing, Cold pressing (for okra), Drying at pasteurisation temperature (80°C).
This process ensures natural preservation and longevity, without the use of chemicals or artificial additives.
(e)Low carbon footprint
-Low energy consumption in production;
-Possibility to use solar drying or reflector-thermal technologies;
-Suitable for businesses with limited resources.
(f)Contribution to societal priorities
The product and technology contribute to:
-Circular economy (waste reuse); Food security (high nutritional value);
-Healthy eating (lower levels of salt, sugar and fat);
-Sustainable development of agriculture and local economies.
The product, derived from apples, carrots and okra, is innovative, cost-effective, healthy and sustainable. It is suitable for both direct consumption and culinary processing. It represents high added value from otherwise low-value waste raw materials and meets modern requirements for functional foods and sustainable production.

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ECONOMIC-MATHEMATICAL APPROACH TO DETERMINING THE LIMIT VALUES OF PROFITABILITY OF COW'S MILK PRODUCTION

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Abstract

The subject of this research is the profitability of cow's milk production on family holdings in Serbia. The aim of the research is to determine the limit values of selected indicators of profitability of milk production, as well as the possibility of its improvement. The focus is on market-oriented holdings in the region of Shumadiya and Western Serbia, from which an average of 30,000 and more liters of cow's milk are delivered to dairies annually. Data were collected through a survey with a total of 219 family holdings. Based on production capacities, zootechnical standards and the balance of required food for different farm sizes of 8, 14, 20 and 30 dairy cows and accompanying categories, different models of family holdings were created. The economic-mathematical procedure determined the minimum volume of milk production, the minimum sales revenue and the minimum selling price of milk, as critical points at which milk production is at the profitability limit. The research results show that the holding - Model 3, where there is a farm of 20 dairy cows, achieves the highest financial result per dairy cow, in the amount of 20,966.80 RSD. The cost price of one liter of milk is lower than its market price, i.e. 39.86 RSD/L < 42.00 RSD/L. For the same volume of milk production, the profitability threshold is achieved at a market price of milk of 39.32 RSD/L. Although this model is the most favorable, it cannot be said that this type of business should be pursued. Without incentives, about 90% of the produced milk would be needed to cover the total costs of keeping dairy cows. By analyzing critical points and potential risks, possibilities for moving the profitability limit of milk production were identified, which would contribute to more efficient operations, better competitiveness of production, and the sustainability of family holding in certain regions of Serbia.

Key words: *economic-mathematical approach, cow's milk, profitability, limit values*

INTRODUCTION

Livestock farming is an important branch of agriculture and the food industry and a major driver of food production worldwide [1]. Feedback loops between several different sectors, e.g. agriculture, food technology and banking, drive initiatives and innovations for sustainable solutions, addressing challenges related to food quality and safety and environmental sustainability [8]. Modern dairy production is typically intensive and requires significant investments in feed production, cattle and feed facilities, equipment and the primary herd [13]. The Simmental breed of cattle is the most important breed in Serbia and has been for the last hundred years [7].

Milk is an important food in the human diet, and more than 6 billion people worldwide consume milk and dairy products [12]. Total milk production on family holdings in the Republic of Serbia in 2024 amounted to about 1,379 thousand tons, of which cow's milk accounted for 1,350 thousand tons, i.e. about 98% [25].

Therefore, cow's milk is the dominant part of total milk production. Dairy cows are kept on about 177,500 family holdings in Serbia [6]. The highest productivity in milk production was recorded in the Belgrade region, where the largest average amount of milk per milked

head is produced in a year, namely 5,335 liters of cow's milk, 200 liters of sheep's milk, and 345 liters of goat's milk [23]. Agricultural producers have an important role in the economy and rural development, and increasing their activities can stimulate regional and rural development and the local economy [11, 19]. Romania is a modest producer of milk and dairy products and has a foreign trade balance in these products, i.e., it imports larger quantities than it exports [14].

EU farmers need to continue to reduce the number of farms and dairy cows and increase yields in order to produce and deliver more raw milk to dairies [15]. Romania has the lowest milk yield in the EU and is twice the EU average of 7,653 kg per cow. This is due to the inadequate farm structure, where over 80% of farms have 1-2 cows [16].

Research distinguishes two approaches to holding development. The first approach involves an orientation towards economies of scale in terms of diversification of agricultural activities, while the second approach aims at economies of scale in terms of diversification of income from holding-related activities [5]. For small and medium-sized holdings, subsidies are the primary source of financing fixed assets, while large holdings use subsidies more flexibly, both for capital investments and for maintaining short-term liquidity [7].

The profitability threshold in milk production is 5,760 liters of milk per cow per year, delivered to the dairy [10]. In the cost structure of dairy cows, the share of feed costs is 50 to 60% [21, 22]. A dairy farmer should keep detailed financial records and economic administration of the herd [2, 17]. The efficiency of dairy cow farming cannot be analyzed only by milk production, but it is necessary to include complementary production lines, which, as a rule and in practice, often existing together [20].

The profitability threshold is at the level of capacity utilization where total revenue is equal to total costs. Any change in the physical volume of achieved results directly determines changes in the value of these results, expressed in total revenue and profit [20]. One of the main ways to improve profitability is to reduce operating costs, which is manifested through a decrease in the cost price per unit of product [20, 24].

The subject of this research is the profitability of cow's milk production on family holdings operating in the region of Shumadiya and Western Serbia. The focus is on market-oriented holdings from which an average of 30,000 and more liters of cow’s milk is delivered to dairies annually. The goal is to determine the profitability limits of milk production and the possibilities of moving them, which would contribute to more efficient operations, better competitiveness and sustainability of production on family holdings.

MATERIALS AND METHODS

The data were collected through a survey of family holdings located in the Shumadiya and Western Serbia regions. As an additional source of data, statistical yearbooks and bulletins of Statistical Office of the Republic of Serbia (SORS), relevant FAO yearbooks, as well as other available sources and electronic databases were used. Databases are widely used to store different information in the field of economics and agriculture [4]. Artificial intelligence is becoming an integrated part of our lives. New alternative methods for collecting data and solving problems are emerging [3].

Based on the data collected from 219 surveys conducted, as well as zootechnical standards and balances of necessary food for different sizes of dairy farms, family holding models were created.

The models represent a realistic picture of holdings focused on cow milk production, which are most common in the practice of the studied region [19, 22].

According to the values of fixed assets, fixed costs at the holding level were determined. Based on the feed plan and other parameters, the amounts of variable costs for one production cycle were calculated. Certain economic indicators in milk production were determined using a calculation procedure.

First, the profit margin (MP) was calculated as the difference between the production value

(VP) and variable costs (VT), and then the financial result (FR) was calculated as the difference between the production value and total costs (UT).

Total costs are the sum of variable (VT) and fixed costs (FT). Quantitative methods for data modeling play an important role in agricultural economics [9].

By applying economic-mathematical methods and procedures, the limit values of individual indicators in milk production have been determined, namely [21]:

- The minimum market value of production;
- The volume of production at which the break-even point is achieved; and
- The minimum acceptable price of milk.

The minimum market value of production (VP) at which total cost coverage is achieved, i.e., the production profitability limit, is calculated according to the formula:

$$VP = \frac{FT}{1 - \frac{vt}{t_c}} \quad (1)$$

FT - total amount of fixed costs (amortization costs, interest, etc.);

vt - variable costs per unit of product;

t_c - market price per unit of product

The production volume (x) at which the break-even point is reached, i.e., the production profitability limit, is determined according to the formula:

$$x = \frac{FT}{t_c - vt} \quad (2)$$

From the ratio of sales revenue (P_{min}) and cow's milk production volume (Q) for the representative year, the minimum acceptable price of milk (pc_{min}) was calculated, i.e.:

$$pc_{min} = \frac{P_{min}}{Q} \quad (3)$$

The economic analysis of milk production was carried out using several calculation procedures - at the level of variable costs (Direct Costing method), differential calculation, full cost calculation, etc [21, 22]. Critical points, potential risks were examined and recommendations were given for the compiled farms and holdings models.

RESULTS AND DISCUSSIONS

Models of holdings according to different size of cow's farms

The basis of the size of the farm, although an insufficient criterion, is the used arable area [20, 26]. The amount of investment, volume, value of production and economic results on the holding depend on numerous factors, the most important of which are: available production capacities - arable area, buildings, technical means, technology and intensity of production and engaged workforce [19, 18].

Based on the data from the survey and the application of zootechnical norms, four models of holdings of different sizes were compiled, with farms of 8, 14, 20 and 30 heads of dairy cows and accompanying categories. Crop production represents the fodder base for feeding livestock on the farm and is completely subordinate to cattle production.

Considering the balance of food requirements for individual categories of livestock, based on the yield of the most important crops, it was determined that one hectare of arable land is required for one dairy cow and supporting categories. The period of use of dairy cows is five years. The annual fertility rate is 88%. Supporting categories (female animals for herd repair) consist of: calves from 0 to 4 months; female breeding offspring from 4 to 6 months; heifers from 6 to 12 months; and heifers from 12 to 24 months. Milk production per dairy cow is 5,400 liters in 305 days. The value of a calved cow is 118,000 RSD. The market value of a naturally pregnant heifer is 200,600 RSD. The average milk production is with 3.8 - 4.2% fat.

Construction facilities are used for 40 to 50 years. Drive machinery also has a different period of use from 10 to 12 years. Attachment machinery is used for 10 to 12 years. The tillage and sowing line and the haymaking line are used for 12 to 15 years. Other machinery, depending on the type of assets, has a period of use from 12 to 15 years. Amortization costs are determined according to rates by asset groups. For construction facilities, rates of 2 to 2.5% were used, for drive machinery from 10 to 12%, for the tillage and sowing line and the haymaking line, rates of 12 to 15% and for

other machinery, rates of 10 to 12% were applied. Given that assets within the same group have different periods of use, different amortization rates were applied within the same group. Investment maintenance costs were determined in accordance with the value of the individual asset and the corresponding maintenance coefficient, and the final amount is given according to the models in Table 1. In addition to amortization and investment maintenance, the fixed costs charged to milk and calf production include insurance of fixed assets (dairy cows, etc.), interest on long-term loans, and the work of permanent workers. Interest costs on long-term loans were determined according to the planned amount of borrowed funds and the corresponding interest rate, and the annual amounts for each farm model are given in Table 1.

Permanent workers consist of two family members, and the costs of their engagement were calculated based on the number of hours of work and the hourly rate (Table 1).

The work of casual workers (who are hired during "peak hours") is calculated later in the calculations in variable costs, within the item "other services".

Table 1. Fixed costs at the holding level by models

Elements of cost	Amount of fixed costs at the holding level (RSD)			
	Model 1	Model 2	Model 3	Model 4
1. Amortization and investment maintenance				
Buildings	39,120.00	79,520.00	95,200.00	107,300.00
Propulsion machines	93,100.00	149,300.00	192,700.00	202,700.00
Soil cultivation and sowing line	34,000.00	48,000.00	67,500.00	71,500.00
Hay preparation line	37,000.00	57,000.00	64,000.00	69,000.00
Other machinery	24,840.00	51,000.00	66,000.00	76,000.00
Total:	228,060.00	384,820.00	485,400.00	526,500.00
2. Insurance of basic funds	26,400.00	46,200.00	66,300.00	99,400.00
3. Interest on long-term loan	8,200.00	12,100.00	17,300.00	23,200.00
4. Labor of permanent employees	180,200.00	260,300.00	310,400.00	370,200.00
Sum (1+2+3+4):	**442,860.00**	**703,420.00**	**879,400.00**	**1,019,300.00**

Source: Authors' calculation.

In the structure of total fixed costs (Table 1), amortization and investment maintenance costs account for 51.50% (model 1), 54.71% (model 2), 55.20% (model 3) and 51.65% (model 4). The labor of permanent employees in fixed costs accounts for 40.69% (model 1), 37.00% (model 2), 35.30% (model 3) and 36.32% (model 4).

The remaining share in fixed costs is made up of the costs of insurance of fixed assets and the costs of interest on long-term loans. Crop production is aligned with the needs of cattle production. For example, 10 tons of alfalfa hay is produced from an area of 1 ha, and then 8.5 tons of corn grain is produced from an area of 1 ha, and so on for other field crops grown on holdings.

Limit values of profitability of cow's milk production for different farm sizes

Given that the annual amounts of fixed costs have been determined by the models, feed rations and other inputs for keeping dairy cows on a family farm have been planned, as parameters in the calculation for determining economic indicators.

By applying the formulas listed above, the limit values of the selected indicators for the profitability of milk production have been determined using a mathematical procedure (Tables from 2 to 5).

Table 2. Calculation of keeping 8 dairy cows – **Model 1**

Economic parameters		Unit of measure	Quantity		Price (RSD/unit)	Amount (RSD)	Share (%)
			By the cow	Total			
I	**Production value**						
	Milk	L	5,400.00	43,200.00	42.00	1,814,400.00	80.07
	Calves (up to 15 days)	head	0.88	7.00	35,400.00	247,800.00	10.94
	Base herd growth	kg	30.00	240.00	182.00	43,680.00	1.93
	Manure	t	10.00	80.00	2,000.00	160,000.00	7.06
Total (I):						**2,265,880.00**	**100.00**
II	**Variable costs**						
	Animal feed					1,541,232.00	67.05
	Energy, Water, bedding and other inputs					118,600.00	5.16
	Mechanization work					102,800.00	4.48
	Veterinary services (insemination, etc.)					58,000.00	2.52
	Other services					35,000.00	1.52
	Total (II):					**1,855,632.00**	***80.73***
	By the milk cow (II):					**231,954.00**	
III	**Margin coverage**					**410,248.00**	
IV	**Fixed costs**						
	Amortization and investment maintenance					228,060.00	9.92
	Fixed assets insurance					26,400.00	1.15
	Interest on long-term loans					8,200.00	0.36
	Labor of permanent employees (family members)					180,200.00	7.84
	Total (IV):					**442,860.00**	***19.27***
V	**Total costs (II+IV)**					**2,298,492.00**	**100.00**
VI	**Financial result (I-V):**					**-32,612.00**	
	By the milk cow (VI):					**-4,076.50**	
VII	**The cost of one liter of milk**					**42.42**	
VIII	**Selected profitability threshold indicators for keeping 8 dairy cows**						
	Minimum milk production volume (liters)					43,976.48	
	Minimum milk production volume per dairy cow (liters)					5,497.06	
	Minimum market value of milk (RSD)					1,847,012.16	
	Minimum market price per liter of milk (RSD)					42.75	

Source: Authors' calculation.

Keeping dairy cows on the farm produces several related products: milk, calves, growth of dairy cows and manure. For all farm models, 5,400 liters of milk per dairy cow were planned, the number of calves in accordance with the calving index of 88%, growth per dairy cow of 30 kg and the amount of manure in the amount of 10 t per cow. When calculating the value amounts of inputs and outputs, average market prices were used at the current exchange rate in the Republic of Serbia, 1 euro equals 117 RSD.

For model 1, where the farm has 8 dairy cows, in the determined total production value of all products in the milk and calf production line, the market value of milk is 80.07% of the total value in the line (2,365,880.00 RSD). The share of other products is 19.93% (Table 2). In the structure of total costs in the milk and calf production line, the share of variable costs is 80.73%, and the share of fixed costs is 19.27%. Of the variable costs, the largest share in the total is the cost of feed for dairy cows in the amount of 67.05%. The coverage margin for model 1 is 410,248.00 RSD, and the financial result is negative, i.e. the farm is operating with a loss of -32,612.00 RSD, or -4,076.50 RSD per dairy cow. The cost price of one liter of milk is above the market price and amounts to 42.42 RSD. This means that, according to the given inputs and outputs, it is economically unjustified to keep 8 dairy cows

on the farm. In order for model 1 to achieve the profitability threshold at which the financial result is equal to zero, the minimum volume of milk production on the farm should be 43,976.48 liters, or 5,497.06 liters per dairy cow. Therefore, to cover the total costs of keeping 8 dairy cows, it is necessary that the minimum market value of the total milk produced is 1,847,012.16 RSD.

If the volume of milk production remained at the same level as in the compiled calculation (Table 2), to cover the total costs in the line, the minimum market price of milk should be 42.75 RSD per liter. On farm model 2, where the farm size is 14 dairy cows, the total value of production in the line amounts to 3,905,464.00 RSD (Table 3).

Table 3. Calculation of keeping 14 dairy cows - **Model 2**

Economic parameters		Unit of measure	Quantity		Price (RSD/unit)	Amount (RSD)	Share (%)
			By the cow	Total			
I	**Production value**						
	Milk	L	5,400.00	75,600.00	42.00	3,175,200.00	81.30
	Calves (up to 15 days)	head	0.88	12.00	35,400.00	373,824.00	9.57
	Base herd growth	kg	30.00	420.00	182.00	76,440.00	1.96
	Manure	t	10.00	140.00	2,000.00	280,000.00	7.17
	*Total **(I):***					**3,905,464.00**	**100.00**
II	**Variable costs**						
	Animal feed					2,697,156.00	69.77
	Energy, Water, bedding and other inputs					136,600.00	3.53
	Mechanization work					132,800.00	3.44
	Veterinary services (insemination, etc.)					120,000.00	3.10
	Other services					76,000.00	1.96
	*Total **(II):***					**3,162,556.00**	***81.80***
	By the milk cow (II):					**225,896.86**	
III	**Margin coverage**					**742,908.00**	
IV	**Fixed costs**						
	Amortization and investment maintenance					384,820.00	9.95
	Fixed assets insurance					46,200.00	1.20
	Interest on long-term loans					12,100.00	0.32
	Labor of permanent employees (family members)					260,300.00	6.73
	Total (IV):					**703,420.00**	***18.20***
V	**Total costs (II+IV)**					**3,865,976.00**	**100.00**
VI	**Financial result (I-V):**					**39,488.00**	
	By the milk cow (VI):					**2,820.57**	
VII	**The cost of one liter of milk**					**41.58**	
VIII	**Selected profitability threshold indicators for keeping 14 dairy cows**						
	Minimum milk production volume (liters)					74,659.80	
	Minimum milk production volume per dairy cow (liters)					5,332.84	
	Minimum market value of milk (RSD)					3,135,711.60	
	Minimum market price per liter of milk (RSD)					41.48	

Source: Authors' calculation.

The market value of the milk produced is 81.30% of the total value of all products in the production line, and the share of other products is 18.70%. In the structure of the total costs of milk and calf production, the share of variable costs is 81.80%, while the share of fixed costs is 18.20%. The costs of animal feed in the total costs are 69.77%. The profit margin is 742,908.00 RSD, and the financial result is positive, i.e. a profit of 39,488.00 RSD is achieved or 2,820.57 RSD per head of dairy cow. The cost price of one liter of milk is 0.42

RSD per liter lower than its market price. In this case, the business is profitable, but the business is close to the break-even point.

The lower point of covering total costs for model 2 is achieved at a production volume of 74,659.80 liters on the farm, or 5,332.84 liters per dairy cow and at a market value of the total amount of milk produced of 3,135,711.60 RSD. At the same volume of milk production as in the compiled calculation (Table 3), in order to meet the condition for covering total costs in the line, it is necessary that the minimum market (selling) price of milk is 41.48 RSD per liter. On the farm model 3, where there is a dairy farm of 20 dairy cows, the total value of production in the line is 5,682,400.00 RSD (Table 4).

Table 4. Calculation of keeping 20 dairy cows - **Model 3**

Economic parameters		Unit of measure	Quantity		Price (RSD/unit)	Amount (RSD)	Share (%)
			By the cow	Total			
I	**Production value**						
	Milk	L	5,400.00	108,000.00	42.00	4,536,000.00	79.83
	Calves (up to 15 days)	head	0.88	18.00	35,400.00	637,200.00	11.21
	Base herd growth	kg	30.00	600.00	182.00	109,200.00	1.92
	Manure	t	10.00	200.00	2,000.00	400,000.00	7.04
Total (I):						**5,682,400.00**	**100.00**
II	**Variable costs**						
	Animal feed					3,853,080.00	71.45
	Energy, Water, bedding and other inputs					198,600.00	3.68
	Mechanization work					192,800.00	3.58
	Veterinary services (insemination, etc.)					174,000.00	3.22
	Other services					95,000.00	1.76
	Total (II):					**4,513,480.00**	***83.69***
	By the milk cow (II):					**225,674.00**	
III	**Margin coverage**					**1,348,920.00**	
IV	**Fixed costs**						
	Amortization and investment maintenance					485,400.00	9.00
	Fixed assets insurance					66,300.00	1.23
	Interest on long-term loans					17,300.00	0.32
	Labor of permanent employees (family members)					310,400.00	5.76
	*Total **(IV):***					**879,400.00**	***16.31***
V	**Total costs (II+IV)**					**5,392,880.00**	**100.00**
VI	**Financial result (I-V):**					**289,520.00**	
	By the milk cow (VI):					**14,476.00**	
VII	**The cost of one liter of milk**					**39.86**	
VIII	**Selected profitability threshold indicators for keeping 20 dairy cows**						
	Minimum milk production volume (liters)					101,106.66	
	Minimum milk production volume per dairy cow (liters)					5,055.33	
	Minimum market value of milk (RSD)					4,246,479.72	
	Minimum market price per liter of milk (RSD)					39.32	

Source: Authors' calculation.

The market value of the milk produced is 79.83% of the total value of all products in the production line, and other products account for 20.17%. In the structure of total costs in the milk and calf production line, variable costs account for 63.69%, and the share of fixed costs is 16.31%. The costs of animal feed for feeding cows account for 71.45% of total costs. The profit margin is 1,348,920.00 RSD, and a positive financial result is also achieved, i.e. a profit of 289,520.00 RSD in the line, i.e. 14,476.00 RSD per dairy cow. The cost price

of one liter of milk is 2.14 RSD per liter lower than its market price, i.e. 39.86 RSD per liter < 42.00 RSD per liter.

At the same volume of milk production as in the compiled calculation (Table 4), the profitability threshold is met at a market price of milk of 39.32 RSD per liter. This is the minimum market price of milk to cover the total costs of keeping 20 dairy cows on the farm. On the farm model 4, where there is a dairy farm of 30 dairy cows, the total value of production in the line is 8,488,200.00 RSD (Table 5).

Table 5. Calculation of keeping 30 dairy cows - **Model 4**

Economic parameters		Unit of measure	Quantity		Price (RSD/unit)	Amount (RSD)	Share (%)
			By the cow	Total			
I	**Production value**						
	Milk	L	5,400.00	162,000.00	42.00	6,804,000.00	80.16
	Calves (up to 15 days)	head	0.88	26.00	35,400.00	920,400.00	10.84
	Base herd growth	kg	30.00	900.00	182.00	163,800.00	1.93
	Manure	t	10.00	300.00	2,000.00	600,000.00	7.07
	*Total **(I):***					**8,488,200.00**	**100.00**
II	**Variable costs**						
	Animal feed					5,779,620.00	71.01
	Energy, Water, bedding and other inputs					348,600.00	4.28
	Mechanization work					382,800.00	4.71
	Veterinary services (insemination, etc.)					354,000.00	4.35
	Other services					255,000.00	3.13
	*Total **(II):***					**7,120,020.00**	***87.48***
	By the milk cow (II):					**237,334.00**	
III	**Margin coverage**					**1,368,180.00**	
IV	**Fixed costs**						
	Amortization and investment maintenance					526,500.00	6.47
	Fixed assets insurance					99,400.00	1.22
	Interest on long-term loans					23,200.00	0.28
	Labor of permanent employees (family members)					370,200.00	4.55
	*Total **(IV):***					**1,019,300.00**	***12.52***
V	**Total costs (II+IV)**					**8,139,320.00**	**100.00**
VI	**Financial result (I-V):**					**348,880.00**	
	By the milk cow (VI):					**11,629.33**	
VII	**The cost of one liter of milk**					**40.27**	
VIII	**Selected profitability threshold indicators for keeping 30 dairy cows**						
	Minimum milk production volume (liters)					153,693.33	
	Minimum milk production volume per dairy cow (liters)					5,123.11	
	Minimum market value of milk (RSD)					6,455,119.86	
	Minimum market price per liter of milk (RSD)					39.85	

Source: Authors' calculation.

The market value of the milk produced is 80.16% of the total value in the production line, while other products account for 19.84%. In the structure of the total costs of keeping dairy cows, the share of variable costs is 87.48%, and the share of fixed costs is 12.52%. The share of feed costs in the total costs is 71.01%. The coverage margin is 1,368,180.00 RSD and a positive financial result is achieved, i.e. a profit of 348,880.00 RSD, i.e. 11,629.33 RSD per dairy cow. The production of one liter of milk is only 1.73 RSD lower than the market price, i.e. 40.27 RSD per liter < 42 RSD per liter.

The lower point of covering total costs for model 4 is achieved at a production volume of

153,593.33 liters of milk on the farm, or 5,123.11 liters per dairy cow and at a market value of the total amount of milk produced in the amount of 6,455,119.86 RSD. At the same volume of milk production as in the compiled calculation (Table 5), the conditions for covering total costs in the line, or the costs of keeping 30 dairy cows on the farm, are met at a minimum market (selling) price of milk in the amount of 39.85 RSD per liter.

Analysis of critical points at the holding level

The profitability threshold is located at the level of capacity utilization where total revenue equals total costs. Any change in the physical amounts of achieved results directly causes changes in the value of those results, expressed in total revenue and profit [24. 26]. According to the established indicators and their comparison, while meeting certain criteria, when state incentives and the costs of raising young stock for herd renewal have been calculated, the most favorable holding model with the appropriate size of the dairy cow farm can be selected (Table 6).

Table 6. Indicators for choosing the most favorable family holding model on an appropriately sized dairy farm

Indicator	Amounts by holding model			
	Model 1	Model 2	Model 3	Model 4
At the farm level of different sizes (without incentives)				
Financial result per dairy cow (RSD)	-4,076.50	2,820.57	**14,476.00**	11,629.33
The cost of one liter of milk (RSD)	42.42	41.58	**39.86**	40.27
Minimum milk production volume per head of cow (liters)	5,497.06	5,332.84	**5,055.33**	5,123.11
Minimum market price per liter of milk (RSD)	42.75	41.48	**39.32**	39.85
At the holding level (with incentives)				
Financial result per dairy cow (RSD)	-7,746.75	10,919.36	**20,966.80**	18,734.47

Source: Authors' calculation.

According to the results in Table 6, at the farm level, model 1 operates with a loss of -7,746.75 RSD. However, milk producers cannot influence the market (selling or purchasing) price. Is the solution to increase premiums for delivered milk, the amount of incentives per dairy cow, etc.? The solution should be sought in the possibility of reducing operating costs on the farm. At the holding level, model 2, the financial result is 10,919.36 RSD per dairy cow. The solution to achieving a more favorable result and a lower cost of milk, and therefore to moving the profitability limit of keeping dairy cows, should be sought in the rationalization of animal feed costs.

Looking at model 3, at the holding level, a financial result of 20,966.80 RSD per dairy cow is achieved, which means 419,336.00 RSD per year from keeping 20 dairy cows. Although this model is the most favorable, it cannot be said that this type of business should be pursued. The amount of income of 1,304,640.00 RSD based on incentives from keeping 20 dairy cows is significant but not reliable for producers.

On the holding model 4, the profitability limit is at a very high level, at almost 95% of the total amount of milk, which means that production also entails a high business risk. In total income, the share of income from incentives is 19.77%, or 1,959,200.00 RSD. Better and fairer prices and long-term strategies can help milk producers be more secure in their income.

Encouraging the consumption of domestic milk can reduce the need for imports and help domestic producers. If the main goal of keeping dairy cows is to receive income from incentives, then the question arises of the motivation of producers to strive to rationalize production costs on holdings, improve hygiene conditions and strive to achieve better milk quality. However, it is safer for agricultural producers to "rely" on the results of their work, to ensure the security and sustainability of further operations on the farm based on the cash inflow from the sale of products from their own production. It is recommended that assistance to producers be directed towards rationalizing costs, addressing problems on

farms and holdings, to determine "bottlenecks" and appropriate measures and methods, encouraging household management, independence and survival from one's own work, the economic justification of milk production, as well as the sustainability of family holdings.

CONCLUSIONS

The influence of producers on the increase in the selling (purchase) price of milk is quite limited. Producers should strive to rationalize production costs, that is, to achieve the lowest possible cost price per unit of milk produced through their operations. Rationalization of milk production costs is based on proper planning of the quantity, quality, structure and price of livestock rations.

For holding model 1, where the farm size is 8 dairy cows, according to the listed inputs and outputs on the farm, it is economically unjustified for producers. In order for model 1 to achieve the profitability threshold at which the financial result is equal to zero, the minimum volume of milk production on the farm should be 43,976.48 liters, or 5,497.06 liters per dairy cow. Therefore, to cover the total costs of keeping 8 dairy cows, it is necessary that the minimum market value of the total milk produced be 1,847,012.16 RSD. If the volume of milk production remained at the same level and in order to meet the condition for covering the total costs in the line, the minimum market price of milk should be 42.75 RSD per liter. Although it has been determined that keeping 8 dairy cows on a farm is economically unjustified, producers would be reluctant to decide to sell dairy cows. If they have enough arable land to produce feed for livestock and able-bodied family members to work, the market price of milk will not be a decisive factor for producers to give up keeping dairy cows.

For holding model 2, where the farm has 14 dairy cows, the cost of one liter of milk is 0.42 RSD per liter lower than its market price. This business is profitable, but the business is close to the break-even point. The lower point of covering total costs is achieved at a production volume of 74,659.80 liters on the farm, or 5,332.84 liters per dairy cow and at a market value of the total amount of milk produced of 3,135,711.60 RSD. At the same volume of milk production, and in order to meet the condition for covering total costs in the line, the minimum market price of milk is 41.48 RSD per liter. The solution to achieving a more favorable result and a lower cost of milk, and thus to pushing the profitability limit of keeping dairy cows, should be sought in the rationalization of feed costs.

For holding model 3, where there is a dairy farm with 20 dairy cows, the cost price of one liter of milk per liter (39.86 RSD) lower than its market price per liter (42.00 RSD). With the same volume of milk production as in the prepared calculation, the profitability threshold is met at a market price of milk of 39.32 RSD per liter. This is the minimum market price of milk to cover the total costs of keeping 20 dairy cows on the farm. Although this model is the most favorable, it cannot be said that this type of business should be pursued. Therefore, without incentives, about 90% of the produced milk would be needed to cover the total costs of keeping dairy cows. In the structure of total farm income, the amounts of incentives account for about 20%. The amount of income of 1,304,640.00 RSD based on incentives for keeping 20 dairy cows is significant but not reliable for producers.

For holding model 4, where there is a dairy farm with 30 dairy cows, the production of one liter of milk is only 1.73 RSD lower than the market price, i.e. 40.27 RSD per liter < 42 RSD per liter. The lower point of covering total costs is achieved at a production volume of 153,593.33 liters of milk on the farm, i.e. 5,123.11 liters per dairy cow, and at a market value of the total amount of milk produced in the amount of 6,455,119.86 RSD. At the same volume of milk production, the conditions for covering total costs in the line, i.e. the costs of keeping 30 dairy cows on the farm, are met at a minimum market price of milk in the amount of 39.85 RSD per liter.

Given that the profitability limit is at a very high level of production, at almost 95% of the total amount of milk, production also entails a high business risk. In total revenues, the share

of income from incentives is 19.77% (≈20%), or 1,959,200.00 RSD. The question arises: Is this income structure a favorable solution for producers? Do incentives in this way really encourage the business and sustainability of cow's milk production and family holdings themselves? Larger investments have been made on such farms, so to speak, capital is "tied up", slow and unfavorable turnover, invested funds cannot be recovered, and the business result is made dependent on state grants. It is more profitable and safer for producers to "rely" on the results of their work, to ensure the security of further business and the sustainability of family holdings based on the cash inflow from the sale of products from their own production.

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COARSE WOOL IN TRANSITION: MATERIAL PROPERTIES, NON-TEXTILE VALORISATION PATHWAYS AND SYSTEMIC CONSTRAINTS IN A CIRCULAR BIOECONOMY CONTEXT

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Abstract

In many extensive sheep-farming regions, coarse wool has lost its role as an economic co-product and has become an unmanaged material flow, generating environmental pressure and farm-level losses. This review synthesises current research on coarse wool valorisation within a circular bioeconomy framework, with the objective of linking intrinsic fibre properties to non-textile applications and identifying the systemic constraints that limit large-scale implementation. An integrative systematic literature review was conducted using the Web of Science Core Collection (2000–January 2026), combining structured screening, bibliometric mapping and qualitative thematic synthesis. Peer-reviewed studies were analysed across five interconnected domains: fibre physico-chemistry, construction and insulation materials, agricultural soil applications, bio-refining pathways, and regulatory and logistical system constraints. The results reveal a clear shift in scientific focus from textile performance towards non-textile valorisation of coarse wool fibres with diameters exceeding 35 μm. Research increasingly highlights the functional relevance of wool's α-keratin structure, hygroscopic behaviour and thermal performance for insulation systems, slow-release fertilisers and bio-based materials. Romania, accounting for approximately 18.5% of the European Union's sheep population, exemplifies how the absence of collection and primary processing interfaces transforms an estimated75% of estimated 25,000 tonnes of annual wool produced into a residual management burden rather than a bio-resource. The review concludes that the under-utilisation of coarse wool is driven primarily by structural and regulatory fragmentation rather than material limitations. A Regional Circularity Hub model is proposed as a territorial solution capable of integrating collection, sanitation, regulatory end-points and diversified valorisation pathways, thereby supporting the transition of coarse wool from agricultural residue to multifunctional bio-resource within circular bioeconomy strategies.

Key words**:** *coarse wool, physico-chemical properties, non-textile applications, circular bioeconomy, regional resource management*

INTRODUCTION

Sheep are highly important for food security providing milk and meat, but also wool, for livelihood growth, environment sustainability and biodiversity preservation globally [42].
Sheep wool has historically represented an ancient strategic natural fibre within agricultural systems all over the globe, and particularly in Europe, where ovine husbandry has been closely associated with rural livelihoods, land stewardship, and agri-environmental policy instruments [38].
Throughout the 20th century, wool functioned as a valuable co-product of sheep farming, supported by local grading practices, organised collection systems, and regional processing infrastructures that linked primary production to textile manufacturing [9, 44].
Over recent decades, however, profound structural transformations in the global fibre economy have progressively eroded the market relevance of wool, particularly for coarse and

heterogeneous fibre categories. The expansion of synthetic fibres, the growing demand for fine and standardised natural fibres, and the geographical relocation of textile processing capacities have collectively undermined traditional wool value chains across Europe [4, 30]. Fine wool continues to sustain niche textile applications, coarse wool has become increasingly disconnected from established industrial pathways, leading to its reclassification from a marketable co-product to a low-value residual material associated primarily with compulsory shearing practices. The continuously higher demand of our civilization on new biological resources shifted this paradigm and today wool becomes relevant again not only for textile industry but also for new bio-based solutions in the current trends of bioeconomy in the European Union [18] and not only [39]. The major wool fibers' pool of animal origin for the European countries are provided for the sheeps breeding [34]. Sheep populations in several European regions have remained stable or have increased under agricultural support schemes and agri-environmental measures that promote extensive grazing systems [14,17]. As a result, wool production has not declined in parallel with market demand, generating a growing structural mismatch between resource availability and valorisation capacity.

This is particularly evident in regions dominated by extensive sheep-farming systems and traditional breeds that produce coarse and structurally heterogeneous wool. Romania provides a representative example in this respect. Ranking 2nd within the EU in terms of sheep number and accounting for approximately 18.5% of the total EU flock, Romanian sheep farming generates substantial quantities of milk and meat [32, 33], but also of coarse wool, primarily from traditional breeds such as Țurcană [13, 31, 43]. The lack of functional collection networks and primary processing infrastructure, determined the accumulation of big amounts of renewable biomass or informally disposed in the farm, becoming a management and environmental burden [7, 15]. The marginalisation of coarse wool is commonly attributed to unfavourable textile properties, including large fibre diameter, medullation, and structural heterogeneity, which constrain spinnability and processing efficiency in conventional textile industries [21, 28]. However, this interpretation overlooks the broader material potential of coarse wool beyond textile-oriented value chains.

From a material science perspective, coarse wool remains a complex and functionally versatile biopolymer.

Composed predominantly of α-keratin, a sulphur-rich structural protein stabilised by extensive disulfide cross-linking, wool exhibits favourable properties such as thermal resistance, hygroscopic behaviour, chemical reactivity, and slow biodegradation [1, 2].

While these characteristics limit conventional textile processing, they confer clear long term functional advantages in a range of non-textile applications.

Over the past two decades, research has increasingly explored alternative valorisation pathways for coarse wool [34], including thermal and acoustic insulation materials for sustainable construction, slow-release organic fertilisers and soil amendments in agriculture, absorbent and filtration materials for environmental remediation, and bio-refining routes targeting keratin and lanolin recovery [5, 6, 8, 24].

Despite this growing body of research, the literature remains fragmented across disciplinary and sectoral boundaries. Many studies address application-specific performance without systematically linking intrinsic fibre properties to implementation conditions, while logistical, economic, and regulatory dimensions are frequently treated as secondary considerations [26]. In particular, the classification of raw wool as a Category 3 animal by-product under European legislation introduces specific handling and processing requirements that significantly shape feasible valorisation pathways, yet these constraints are rarely integrated into technical assessments [36]. Against this background, the present study adopts an integrative systematic literature review approach to synthesise research published between January 2000 and

January 2026 on coarse wool valorisation within a circular bioeconomy context by applying bio-based solutions. By explicitly linking physico-chemical fibre properties to non-textile valorisation pathways and to the systemic conditions governing their implementation, the review seeks to move beyond application-specific analyses. Accordingly, the central research questions guiding this review are: how do the intrinsic physico-chemical properties of coarse wool enable non-textile valorisation pathways, and which technological, economical, and regulatory constraints or barriers currently limit their large-scale implementation within circular bioeconomy strategies?

MATERIALS AND METHODS

This study was conducted as an integrative systematic literature review aimed at analysing how coarse wool has been investigated as a resource for non-textile valorisation and which constraints currently limit its practical implementation. The methodological approach combined structured literature screening, bibliometric analysis, and qualitative thematic synthesis, enabling the identification of research trends alongside the interpretation of material, technological, and systemic dimensions relevant to circular bioeconomy frameworks. The review design explicitly separates methodological procedures from analytical interpretation, in line with the requirements of systematic review reporting standards.

Data sources and literature retrieval

The bibliographic dataset was retrieved exclusively from the Web of Science Core Collection (WoSCC). The search covered the period January 2000 to January 2026. Only peer-reviewed journal articles were included. National livestock and wool production statistics were used solely for contextual interpretation and were not included in the bibliometric dataset. The search was performed within the Web of Science "Topic" field (title, abstract, author keywords, and Keywords Plus), ensuring consistent retrieval across application domains.

Search strategy and thematic structure

A structured search strategy was developed using combinations of wool-related descriptors and application-oriented terms. Boolean operators ("AND", "OR") were applied within the Topic field of Web of Science.

Table 1. Search strategy, thematic pillars, and research objectives used for the systematic review of coarse wool valorisation (Web of Science Core Collection, 2000–2026).

Valorisation Pillar	Web of Science Search Query (Topic)	Records Retrieved (WoS)	Research Objective
General overview	("wool waste" OR "coarse wool") AND (valoriz* OR recycl* OR "circular economy")	147	Global trends and circular bioeconomy context
P1: Fibre physics & chemistry	("sheep wool" OR "coarse wool") AND (fiber* OR keratin OR structure OR medullation)	447	Physico-chemical properties enabling non-textile use
P2: Construction	("wool waste" OR "sheep wool") AND (building* OR construction OR insulation OR composite*)	338	Insulation and technical building applications
P3: Agriculture	("wool waste" OR "wool pellets") AND (fertiliz* OR soil OR nutrient* OR agriculture)	70	Fertiliser and soil amendment pathways
P4: Bio-refining	("wool waste" OR "waste wool") AND (keratin OR lanolin OR extraction OR hydrolysis)	127	Keratin and lanolin recovery
P5: Circular economy & systems	("wool waste") AND ("circular economy" OR regulation OR logistics OR waste management)	89	Regulatory, logistical, and systemic constraints

Source: authors' own elaboration .

To reflect the interdisciplinary nature of coarse wool research, search queries were grouped into five thematic pillars corresponding to major valorisation pathways and system-level perspectives. Table 1 reports the full set of search strings, the number of records retrieved per pillar, and the corresponding research objectives.

Scope of retrieved records and screening procedure

The initial search returned 2,102 records. After deduplication, 1,682 unique publications remained. Titles and abstracts were screened to exclude unrelated domains. Screening was conducted in two stages: (i) title and abstract screening to remove non-relevant domains (e.g., unrelated animal fibres, purely fashion-oriented textile studies, or non-wool keratin sources); and (ii) eligibility assessment based on relevance to coarse wool properties, non-textile applications, or implementation constraints. A subset of representative and high-impact studies was selected for in-depth qualitative discussion, while the remaining publications were used as aggregated evidence to support general trends. For transparency, the inclusion logic prioritised studies that (a) explicitly addressed coarse wool or wool waste, (b) reported material properties or performance indicators relevant to non-textile uses, or (c) analysed logistics, regulation, or system-level implementation conditions.

Literature selection flow and transparency

The complete process of literature identification, screening, eligibility assessment, and final inclusion was documented to ensure transparency and reproducibility (Figure 1).

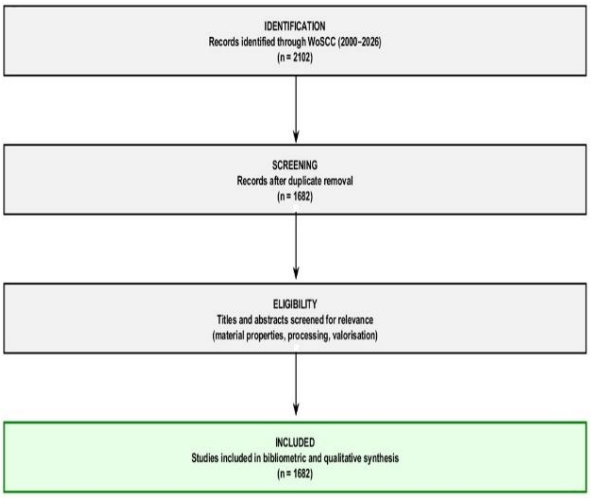


Fig. 1. Flow diagram of literature identification and selection process (generated in MATLAB).

Note: The total screened dataset (n = 1,682) was used for bibliometric mapping, while the qualitative synthesis focused on a targeted selection of 145 high-impact studies to define the technical parameters and valorisation pathways.

Bibliometric analysis

Keyword co-occurrence analysis was performed using VOSviewer. The bibliometric analysis was used exclusively as a structural support tool and not for inferential statistical interpretation. VOSviewer was used to map keyword co-occurrence and identify dominant thematic clusters and temporal shifts in research focus across the 2000–2026 period.

Thematic classification and qualitative synthesis

Publications were assigned to one primary thematic pillar: (i) fibre physics and keratin chemistry; (ii) construction and industrial applications; (iii) agriculture and soil science; (iv) bio-refining and co-product valorisation; and (v) circular economy, waste management, and systemic constraints. Qualitative synthesis focused on linking intrinsic physico-chemical wool properties (e.g., fibre diameter, medullation, keratin chemistry, hygroscopicity) to functional performance in non-textile applications, while explicitly considering logistical, economic, and regulatory conditions affecting implementation.

RESULTS AND DISCUSSIONS

Bibliometric evolution of coarse wool research: from textile fibre to multifunctional bio-resource

The keyword co-occurrence network derived from the Web of Science Core Collection (Figure 2) reveals a clear temporal and conceptual transition in coarse wool research over the last two decades.

Early research clusters, dominant prior to the early 2000s, were primarily anchored in textile-oriented themes such as fibre fineness, spinning performance, dyeing behaviour, and apparel-related quality attributes [9, 21].

From approximately 2000 onwards, and with a marked acceleration after 2015, the network shows a progressive shift toward application-oriented and system-level research domains.

Keywords such as wool waste, keratin, thermal insulation, bio-composites, fertiliser, soil amendment, and circular economy emerge as increasingly central nodes [6, 8].

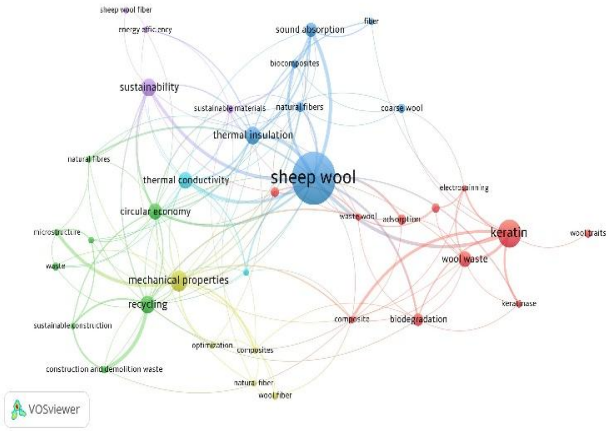


Fig. 2. Keyword co-occurrence network of coarse wool research based on Web of Science data (2000–2026), generated using VOSviewer.

This shift reflects a paradigmatic re-framing of wool—particularly coarse and heterogeneous fibres—from a downgraded textile material to a multifunctional bio-based resource.

The bibliometric evidence therefore supports the central premise of this review: the scientific relevance of coarse wool has increased precisely because of its structural heterogeneity, which enables functional performance in non-textile and circular bioeconomy applications rather than limiting its value [25, 26, 27].

Fibre physics and keratin chemistry as the material foundation for non-textile valorisation (P1)

Research grouped within the Fibre Physics and Keratin Chemistry pillar (P1) provides the material-science foundation for all subsequent non-textile valorisation pathways. This body of literature addresses fibre morphology, keratin molecular structure, disulfide cross-linking, medullation, hygroscopic behaviour, and thermo-mechanical performance, all of which directly influence functional performance beyond conventional textile uses [1, 21].

Coarse wool fibres are typically characterised by diameters exceeding 35 μm, pronounced structural variability, and a high degree of medullation [20, 28]. While these characteristics severely limit spinnability and conventional textile processing, they simultaneously enhance bulkiness, resilience, thermal resistance, and acoustic scattering. The presence of a hollow medullary canal increases air entrapment within the fibre structure, contributing to low thermal conductivity and improved sound absorption [6].

It is well established that the molecular architecture of wool confers mechanical stability, chemical resistance, and slow biodegradation kinetics, explaining both the persistence of wool as an unmanaged waste and its suitability for controlled agricultural and bio-refining applications [5].

A defining functional attribute of coarse wool is its hygroscopic behaviour. Moisture regain values of up to approximately 33% by weight can be achieved without loss of insulation performance, enabling passive moisture buffering and indoor climate regulation [22]. This property clearly differentiates wool from mineral and synthetic insulation materials [25].

The principal physico-chemical characteristics enabling non-textile valorisation are synthesised in Table 2, explicitly linking intrinsic material properties to functional performance in construction, agricultural, and composite applications.

Construction and insulation applications (P2)

Research addressing the use of coarse wool in construction and building insulation (P2) has expanded significantly over the past decade, driven by the search for bio-based alternatives to mineral and synthetic insulation materials. This body of literature focuses primarily on thermal and acoustic insulation performance, hygrothermal behaviour, fire response, and material durability under building-relevant conditions.

Experimental studies consistently report thermal conductivity values for wool-based insulation materials in the range of conventional natural insulators, typically between 0.038 and 0.045 $W \cdot m^{-1} \cdot K^{-1}$, depending on fibre density, orientation, and processing method [5, 25].The intrinsic fibre crimp, bulkiness, and internal porosity associated with coarse and medullated fibres enhance air entrapment, supporting stable thermal performance even under fluctuating moisture conditions. In parallel, the viscoelastic structure of wool fibres contributes to effective acoustic damping, making wool-

based panels particularly suitable for combined thermal–acoustic insulation applications in lightweight building systems [26].

A distinctive advantage of coarse wool insulation materials is their hygroscopic behaviour. Unlike mineral or polymer-based insulators, wool fibres can absorb and desorb substantial amounts of moisture without compromising insulation efficiency, enabling passive regulation of indoor humidity and reducing condensation risks within building envelopes [25].This hygrothermal buffering capacity is increasingly recognised as a functional asset in bio-based construction materials, particularly in retrofitting and low-energy building contexts.

Fire behaviour represents a further critical performance dimension. Due to its high nitrogen and sulphur content, wool exhibits inherent flame resistance, characterised by high ignition temperatures and self-extinguishing behaviour. Several studies report favourable reaction-to-fire classifications for wool-based insulation systems when compared with untreated lignocellulosic materials, although compliance with specific building fire standards typically requires controlled processing conditions and, in some cases, additional treatment or hybridisation with mineral binders [6, 27].

Despite this favourable technical profile, the deployment of coarse wool insulation materials remains limited to pilot projects, niche markets, and small-scale commercial applications. The literature identifies this gap not as a consequence of insufficient material performance, but rather as the result of systemic constraints, including inconsistent feedstock supply, lack of standardised primary processing, certification barriers, and regulatory requirements associated with the classification of raw wool as a Category 3 animal by-product under European legislation [36]. As a result, the transition from laboratory-scale validation to large-scale construction deployment remains strongly dependent on the existence of integrated collection, sanitation, and processing infrastructures.

Agricultural and soil applications (P3)

In agricultural systems, the slow biodegradation and nitrogen-rich composition of keratin emerge as key functional advantages. Pelletisation improves handling and application efficiency while preserving controlled nutrient release dynamic [23, 40].

Multiple studies demonstrate gradual nitrogen mineralisation, enhanced soil water-holding capacity, increased microbial activity, and reduced nitrate leaching compared to mineral fertilisers [8].These properties contribute to improved drought resilience and soil structure, particularly in degraded soils.

Bio-refining and co-product recovery (P4)

Bio-refining pathways focus on the recovery of keratin and lanolin as higher-value bio-based products. Chemical and enzymatic hydrolysis routes have demonstrated high extraction yields with reduced environmental impact [5,12]. Keratin hydrolysates are increasingly explored for applications in agriculture, cosmetics, and bio-based materials. Tabel 2 presents the linkage between coarse wool properties and its functional relevance for non-textile use.

Table 2. Key physico-chemical properties of coarse wool relevant for non-textile applications

Property	Typical characteristics / Quantitative values	Functional relevance for non-textile use	Key references
Fibre diameter and medullation	Fibre diameter greater than 35 micrometres; high structural variability; presence of a hollow central canal (medulla).	Enhances acoustic scattering and bulk insulation performance, limits textile spinnability.	[20, 21, 28]
Chemical composition	Composed of more than 95% alpha-keratin, with high sulphur content (approximately 3.5%) and extensive disulphide cross-linking.	Provides chemical resistance and enables high-yield keratin recovery through hydrolysis.	[1, 2, 5]
Mechanical behaviour	High elongation at break; tensile strength varies depending on body region (approximately 13–20 centinewtons per tex for the Turcana breed).	Provides adequate resilience for reinforcement in polymeric and hybrid biocomposite	[19, 41]

Thermal properties	Low thermal conductivity, approximately 0.038–0.045 watts per metre-kelvin, due to internal fibre porosity.	Enables high-performance thermal insulation in sustainable building materials.	[6,16, 25]
Hygroscopic behaviour	Moisture regain of up to 33% by weight without loss of insulation efficiency.	Supports passive indoor climate regulation and moisture buffering in technical applications.	[2, 3, 22]
Surface reactivity	Naturally hydrophobic surface due to the lanolin layer; surface reactivity can be improved through plasma or enzymatic treatments.	Enhances interfacial bonding with polymeric or mineral matrices in composite materials.	[10, 11, 45]

Source: authors' own elaboration.

National resource scale and structural mismatch: the Romanian context

Official data from the Romanian National Institute of Statistics indicate a stable sheep population exceeding 10.4 million heads, corresponding to an annual production of over 25,000 tonnes of wool, of which 75% is coarse wool [29, 31, 37]. In the absence of functional collection and processing infrastructure, this biomass is largely managed as waste at farm level, confirming a persistent mismatch between resource availability and valorisation capacity [15].

The sustainability of the sheep sector can also be improved by integrating unconventional methods of wool processing and valorization, with implications for the social aspects of this renewable bioresource [35].

Systemic constraints and the regulatory "end-point" challenge (P5)

Despite technical feasibility, large-scale wool valorisation remains constrained by regulatory and logistical barriers. Under Regulation (EC) No 1069/2009, raw wool is classified as a Category 3 Animal By-Product, imposing strict requirements on collection, transport, and processing. For small and medium-scale farms, compliance costs often exceed economic capacity, reinforcing the disconnection between primary production and industrial users.

Integrative discussion: linking material properties to system design

The synthesis of bibliometric trends (Figure 2), material properties (Table 2), application-level performance, and regulatory constraints supports the conceptual Regional Circularity Hub framework.

This model integrates collection, sanitation, primary processing, regulatory compliance, and market access at a territorial scale, addressing the structural gap between material potential and system-level implementation.

By explicitly distinguishing between processing routes and a shared pool of processed wool-derived outputs, the framework reflects the functional convergence of thermochemical and biotechnological pathways prior to downstream application. This intermediate aggregation enables flexible routing of wool-based materials toward agricultural, construction, and energy applications, depending on formulation requirements and territorial demand.

The concept of an "end point in the manufacturing chain" emerges as a critical lever for circular integration, with Regional Circularity Hubs acting as the operational interface through which regulatory validation, logistics coordination, and market entry are ensured.

This configuration enables wool-derived outputs to enter standard commercial circuits following validated processing steps.

These converging lines of evidence support the conceptualisation of a Regional Circularity Hub as a territorially embedded solution for coarse wool valorisation.

The proposed technological pathway integrates collection, sanitation, primary processing, regulatory end-points, and market routing within a single operational framework (Figure 3).

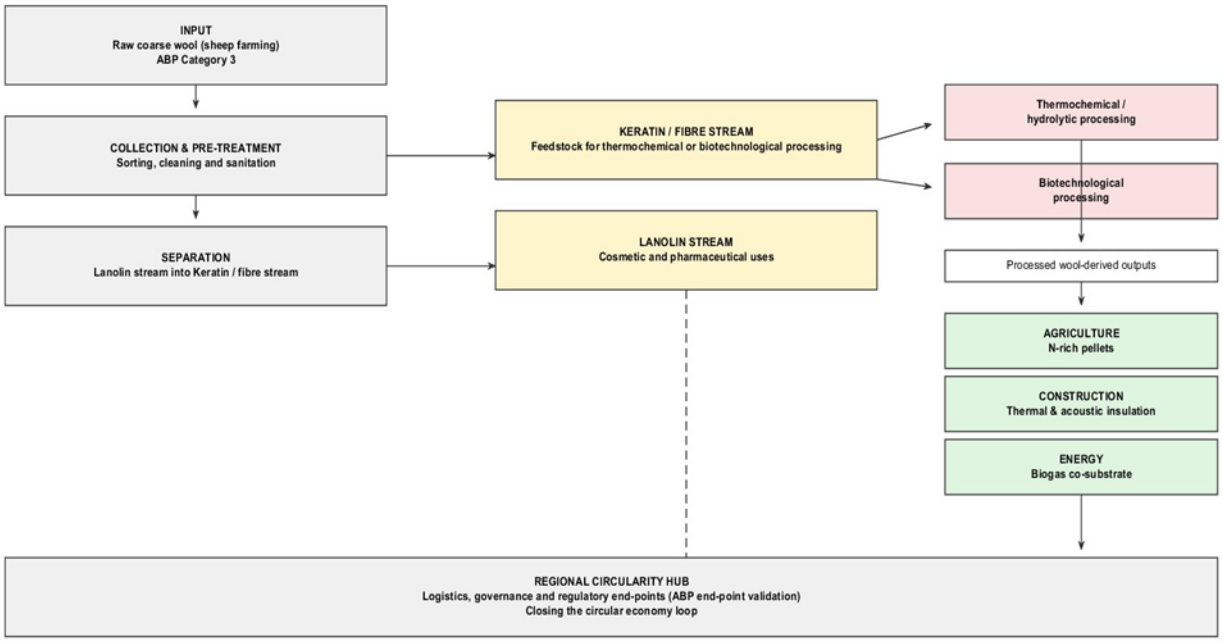


Fig. 3. Technological pathway for full valorisation of coarse wool through a circular bio-refinery and Regional Circularity Hub approach (generated using MATLAB).

CONCLUSIONS

This integrative review demonstrates that the marginalisation of coarse wool in Europe is not primarily the result of declining production volumes or intrinsic material limitations, but rather of persistent structural, logistical, and regulatory failures along the value chain. In regions dominated by extensive sheep-farming systems, wool production remains stable, yet the dismantling of collection networks, primary processing infrastructure, and market interfaces has effectively transformed a renewable bio-resource into an underutilised material flow.

From a materials science perspective, coarse wool exhibits a distinctive set of physico-chemical properties including high α-keratin content, extensive disulfide cross-linking, pronounced hygroscopicity, and thermal resilience that constrain its competitiveness in contemporary textile markets while conferring clear functional advantages in non-textile applications. The evidence synthesised in this review confirms the technical feasibility of coarse wool valorisation in thermal and acoustic insulation systems, slow-release organic fertilisers and soil amendments, as well as bio-refining pathways targeting keratin- and lanolin-derived products.

The Romanian context illustrates these dynamics with particular clarity. National statistics indicate a large and stable sheep population, ensuring a continuous supply of coarse wool, while the absence of dedicated collection, processing, and regulatory interfaces has resulted in limited valorisation, on-farm accumulation, and informal disposal practices. This structural mismatch highlights that the core challenge lies not in resource availability, but in system-level integration.

A central conclusion of this review is that isolated technological solutions are insufficient in the absence of social innovation that should be supported at local, regional and national levels. In this regards the society should be engaged as a critical mass to coherently respond to this challenging new emerging technonologies [18]. Effective valorisation of coarse wool requires decentralised, regionally adapted circular hub models capable of integrating collection, sanitation, primary processing, regulatory end-points, and multiple end-use pathways at an appropriate spatial scale. Such Regional Circularity Hubs may provide a practical mechanism for translating material potential into compliant products,

reducing societal and environmental pressures associated with unmanaged wool disposal, and supporting the economic resilience of rural areas.

Overall, coarse wool should no longer be approached as a declining textile residue, but as a multifunctional bio-resource whose sustainable reintegration into European material systems depends on coordinated technological, regulatory, and territorial innovation. Addressing these dimensions simultaneously represents a necessary step toward unlocking the circular bioeconomy potential of coarse wool by accessing bio-based solutions and aligning extensive sheep-farming regions with emerging European sustainability and waste-to-resource policy frameworks.

ACKNOWLEDGMENTS

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GASTRONOMIC AND TOURISM-BASED VALORIZATION OF TROUT FARM RESOURCES IN THE MOUNTAINOUS RURAL AREAS: A CASE STUDY OF THE ȚARA FĂGĂRAȘULUI REGION, ROMANIA

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Abstract

Mountainous rural regions face persistent structural constraints related to accessibility, limited agricultural alternatives, and demographic decline. In this context, freshwater aquacultureparticularly trout farminghas emerged as a multifunctional activity capable of supporting economic resilience, cultural preservation, and sustainable tourism development. This article synthesizes interdisciplinary literature on the gastronomic and tourism-based valorization of trout farm resources, with particular attention to agritourism frameworks, experiential gastronomy, circular economy integration, and rural development outcomes. The case study presents the connection between the development of rural tourism and agritourism and the production and exploitation of trout in the foothill villages of "Fagaras Land" in Romania. The findings demonstrate that trout-based gastronomy, when embedded in short supply chains and experiential tourism models, contributes significantly to income diversification, destination branding, and environmental sustainability. The results identifies research gaps related to impact assessment, consumer behavior, and integrated policy design, and proposes future research directions to strengthen the role of trout aquaculture within sustainable mountain development strategies.

Key words**:** *trout farming, rural gastronomy, agrotourism, rural gastronomic tourism, mountainous regions, tourism value chains, circular economy, sustainable tourism, Romania*

INTRODUCTION

Trout farming in mountain regions is a prime example of the Blue Bioeconomy [37]. When underpinned by circular principles, it does not merely extract resources; it regenerates them [26]. It creates a symbiotic relationship where the farm supports the tourism industry through gastronomy, and tourism provides the financial capital to maintain high sustainability standards [17].

Freshwater aquaculture plays a strategic role in mountainous and rural environments, where cold, well-oxygenated waters provide optimal ecological conditions for trout farming [35]. Beyond its primary production function, trout aquaculture increasingly intersects with gastronomy, tourism, and circular economy models, contributing to diversified rural livelihoods and place-based development [44, 51].

Gastronomy based on locally farmed trout has gained prominence as part of experiential and heritage tourism, aligning with global trends favoring authenticity, sustainability, and short food supply chains [23]. By linking production, culinary transformation, and tourism consumption, trout farms can move beyond commodity-based markets toward value-added, experience-driven models [5,12].

Agtorourism as part of rural tourism also represent an effective instrument for addressing a range of constraints faced by rural areas, including quality of life, job creation, retention of the young population, improvement of general infrastructure, and

revitalization of local economies through the valorization of local products and the provision of services related to gastronomy and tourism [65].These activities are aligned with the targets established under the Sustainable Development Goals included in the 2030 Agenda [64].

Sustainable rural tourism is a recognized driver of local development [28]. In mountainous villages, the diversification of economic activities through the establishment of trout farms and the integration of trout products into rural tourism contributes to increasing the attractiveness of mountain regions.

The principal trout-producing countries worldwide include Germany, France, the United Kingdom, Canada, the United States, Italy, Japan, China, India, and Brazil [59].

In Romania, the production of trout for consumption has expanded as a result of investments in aquaculture-specific equipment. The species most suitable for trout farming are rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*). In 2023, Romania produced 17,878 tonnes of fish. Although the country has high aquaculture production potential, urgent measures are required to stimulate domestic production [6, 25].

Existing fish farms at the national level are predominantly extensive or semi-intensive, with carp and trout being the most commonly farmed species. Trout species account for approximately 20% of the total volume of farmed fish production, while rainbow trout represents about 90% of total trout output [25].

The results of a recent study indicate that trout ranks among the top fish consumption preferences in Romania, following mackerel and crucian carp, and is consumed primarily in the north-western part of the country and in the Central Region. Several authors report that average annual fish consumption in Romania is approximately 6–7 kg per capita, or 8.1 kg when including seafood, which is significantly below the European average of 24.35 kg [25, 50, 55, 56, 58].

The main motivations for fish consumption are its perceived health benefits and favorable sensory attributes. In general, consumers have limited knowledge regarding farmed fish production and tend to perceive farmed fish as being of lower quality compared with wild-caught fish [21].

The diversification of traditional activities in mountainous villages through the introduction of alternative and complementary activities—such as trout farming and trout valorization—makes a substantial contribution to strengthening local economies and promotes nature-based recreational activities [9], healthier lifestyles and dietary patterns, and environmental protection. Such activities enable recreational fishing, fishing-based tourism, live fish sales, and food service operations offering menus centered on trout-based dishes.

In the “museum village” of Ciocănești (Suceava County, Romania), which ranked third in the national “Destination of the Year” competition in 2024, the “Trout Festival” has been organized for over two decades. The event features sport fishing competitions, tastings of trout-based culinary products, folk parades, and demonstrations by local artisans [14].

By diversifying the gastronomic offer based on fish—sold fresh or processed locally into various culinary preparations—along with organizing tastings, educational activities, and farm visits, local tourism competitiveness is enhanced [8,11], regional traditions are preserved, and sustainability is supported.

Trout farms thus become tourism attractions within mountainous agritourism systems, enabling landscape valorization through the integration of food services and recreational activities, and offering unique and authentic experiences [29].

The World Food Tourism Association has identified key directions of evolutionin gastronomic tourism, including the need to emphasize hyper-local specificity, as tourists increasingly seek information about food origins, product traceability, and preparation methods. Gastronomic heritage is regarded as a living infrastructure, and tourists wish to experience the everyday gastronomy of local communities.

The use of digital technologies in tourism should strengthen local food systems and facilitate discovery, placing people and community benefits at the center. Food should become the backbone of a tourist destination, serving as a form of living cultural intelligence and an expression of identity, knowledge, and social practice [72].

Fishing-based tourism, in all its forms, acts as a catalyst for development by contributing to the preservation of local traditions and the conservation of cultural heritage [32].

Sport trout fishing in mountainous areas may represent a form of niche tourism that stimulates the development and modernization of hospitality services in rural regions [60].This enables local communities to "tell their story," reinforce destination credibility, and anchor tourism offerings within local gastronomic culture. Local stakeholders should therefore valorize regional gastronomy by integrating it with agricultural seasons and offering tourists fresh, seasonal ingredients prepared according to traditional recipes, allowing visitors to adapt to the daily rhythm of community life [72].

The objective of this article is to consolidate existing research on trout-based gastronomy and tourism in rural and mountainous contexts, with a focus on economic, social, environmental, and marketing dimensions.The case study was conducted in the trout villages of "Fagaras Country", Romania.

Literature review

Agritourism Frameworks and the Valorization of Trout Farms

The valorization of trout farms aligns with broader agritourism strategies that integrate primary production with tourism services [62]. Agritourism is increasingly recognized as a driver of sustainable development in mountain regions, particularly where traditional agriculture faces geographic and economic limitations [27].

Trout farms fit naturally within agritourism frameworks due to their visual appeal, ecological embeddedness, and compatibility with experiential activities such as fishing, tastings, and farm visits [4]. When combined with local gastronomy, these farms function as multifunctional rural hubs that preserve natural resources while generating diversified income streams [2, 3].

The framework (Figure 1) illustrates circular interactions between trout aquaculture, local gastronomy, and experiential tourism. Fresh products supplied by farms are transformed through culinary practices into tourism experiences that enhance visibility and demand. Short supply chains, waste valorization, and sustainable practices close the loop, reinforcing economic, environmental, and social sustainability in rural areas.



Fig. 1. Conceptual framework of marketing trout farm products within a circular economy model of rural gastronomy and tourism

Source: The figure was generated using an artificial intelligence-based visualization tool (Canva AI Infographic Maker) and subsequently reviewed and corrected by the authors for scientific accuracy.

Economic and Social Contributions to Rural Communities

Aquaculture contributes between 20% and 50% of household income in rural regions, depending on production systems and geography [63]. Trout farming generates direct employment in production, processing, and maintenance, while also supporting indirect jobs in hospitality, food services, guiding, and marketing [71].

Profitability indicators reported across regions—such as benefit–cost ratios exceeding

1.6 and profit margins up to 49% per kilogram—underscore the economic viability of trout farming, particularly when linked to restaurants and tourism markets [33]. Angling tourism and on-site dining further amplify these benefits by increasing visitor spending and local economic retention.

Table 1. Contributions to rural communities

Impact Area	Circular Economy Contribution	Tourism Contribution
Economic	Reduces operational costs (energy/feed) and creates new revenue streams (fertilizer sales) [34,45].	Injects direct cash flow into the community through dining, accommodation, and activities [42,53].
Social	Requires skilled labor for technical farm management, upskilling the local workforce [19,73].	Preserves local culture and creates service-industry jobs (guides, chefs, hospitality) [61].
Environmental	Minimized pollution preserves the "*pristine nature*" brand essential for tourism [3].	Eco-conscious tourists incentivize farms to maintain high environmental standards [54].

Source: own elaboration.

Gastronomic Tourism as a Rural Development Tool

Gastronomic tourism has emerged as a strategic mechanism for diversifying rural economies and extending tourism seasons beyond traditional peaks [39]. Trout-based gastronomy is particularly suitable for experiential tourism, as it allows for direct engagement with production, processes, culinary heritage, and local narratives [17].

Farm-to-table and farm-to-fork models enhance product authenticity and consumer trust, while reducing environmental impacts through shortened supply chains [38]. Empirical studies consistently show that authenticity, sustainability, and educational engagement positively influence visitor satisfaction and revisit intentions [54].

Culinary Heritage, Experiential Tourism, and Value Creation

Culinary heritage plays a central role in destination branding and rural tourism competitiveness. Traditional trout preparations—such as smoking, salting, marinating, and drying—serve both as cultural expressions and as foundations for value-added product diversification [1].

Experiential formats, including cooking demonstrations, food festivals, and catch-and-cook activities, transform trout from a food product into a cultural and emotional experience. Such initiatives strengthen place identity, support premium pricing strategies, and enhance the perceived quality of rural destinations [43].

Sustainability and Circular Economy Integration

Sustainability is a recurring theme across the literature, with trout-based gastronomy increasingly framed within circular economy principles. Environmentally responsible aquaculture practices, combined with local consumption, reduce transportation emissions and biomass losses [45]. Valorization of by-products—through conversion into fish oil, pet food, fertilizers, or energy—enhances resource efficiency and reduces waste [19]. Recirculating aquaculture systems (RAS), renewable energy integration, and nutrient recycling are particularly relevant in sensitive mountain ecosystems, where environmental stewardship underpins both production viability and tourism appeal [20, 57].

Marketing, Branding, and Experiential Narratives

Gastronomy functions as a strategic marketing channel for trout farm products, enabling differentiation based on locality, sustainability, and heritage narratives. Storytelling, sensory experiences, and transparency in production practices enhance consumer engagement and brand loyalty [15, 20].

Experiential tourism not only increases product visibility but also facilitates social learning and acceptance of aquaculture, reinforcing positive attitudes toward locally farmed fish [52]. These dynamics are critical for long-term competitiveness in rural contexts [30].

MATERIALS AND METHODS

The research work was based on documentary research, literature review, statistical analysis of secondary data, field visit, observations, content analysis, and on the collection of information from the case study in localities with trout farms from ”Țara Făgărașului”, România.

The methodology included at the beginning desk research methods and the collection data from official information sources regarding the lodging and travel services provided, and also regarding the trout farms and its valorisation. The data was collected from the site of The National Authority for Tourism under the coordination of the ministry in charge of tourism activities. Also, the data were collected from the National Agency of Mountain Area ("mountain product" database and "local gastronomic point" database). After setting up the data collection work, there were calculated some tourist traffic indicators of rural tourism in the chosen villages.Theseindicators are touristtrafficdensity,
touristtrafficintensityandtourist operation rate [36].

Tourist traffic density (TD) is the indicator that directly links tourist traffic with the resident population (on January 1). It is calculated as the ratio between the number of tourists arriving in the area (TA) and the resident population of the area on January 1 (P).

$$TD = \frac{TA}{P} \quad \text{.....(1)}$$

The intensity of tourist flow was determined dividing the number of overnight stays to the resident population in the village (on 1 January).

$$TI = \frac{Os}{P} \quad \text{.....(2)}$$

where:
Ti = tourist traffic intensity
Os = number of tourist overnight stays
P = total population on 1 January

To assess the size of the tourist development in the studied area, it was evaluated the *tourist operation rate*, whose formula involves calculating the ratio between the total number of accommodation units and the resident population.

Tfr = Tacu/P……..... (3)

where:
Tfr = tourism function rate Tacu = total number of accommodation units
P = total population on 1 January
Excel, v. 365 Microsoft, was used for data processing.

The main research objectives are:

O1. Presentation of the structure of accommodation facilities and the number of trout farms in the villages of Țara Făgărașului, Romania.

O2. Description of the specific characteristics of rural tourism in Țara Făgărașului and determination of tourism flow indicators in the selected area.

O3. SWOT analysis of a family-owned trout farm integrated into agrotourism.

RESULTS AND DISCUSSIONS

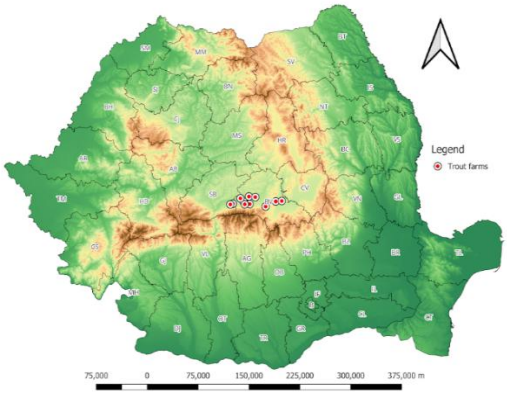
“Țara Făgărașului”, selected for this study, is the name of a geographical depression located in southern Transylvania, Romania. It lies between the Olt River and the Făgăraș Mountains.

Țara Făgărașului also refers to a distinct ethnographic region of Transylvania, in central Romania, situated in the southern parts of Brașov and Sibiu counties. The region comprises 24 administrative-territorial units (LAUs) in Brașov County and 3 LAUs in Sibiu County [31].

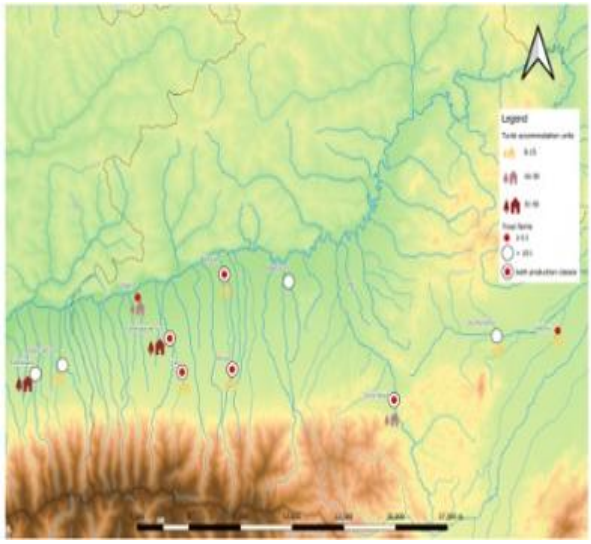
The inhabitants of Țara Făgărașului exhibit a strong sense of attachment to the region, driven by its ethnographic, social, landscape, economic, and historical resources. The area stands out for its recreational activities and rich cultural and historical heritage, making it an ideal destination for an active short holiday. Agriculture represents the main alternative occupation. In 2021, the local administrative units of Țara Făgărașului, comprising 68 villages, recorded a total of 13,143 households [7].

O1 Presentation of the structure of accommodation facilities and the number of trout farms in the villages of Țara Făgărașului, Romania.

To promote the territory of *Țara Făgărașului* and sustainable development through tourism, an intercommunity development association was established in 2008. Its website promotes tourism facilities offering accommodation, the activities that can be carried out in the area, and local gastronomy.



Map 1. Map of Romania and the selected localities in *Țara Făgărașului* where trout farms are present**.**
Source: Map generated by Iulian Alexandru Bratu using QGIS, based on dataprovided by [22,24].



Map 2. Details regarding the number of trout farms and the number of accommodation units in the selected localities of *Țara Făgărașului.*
Source: Maps generated by Iulian Alexandru Bratu using QGIS, based on data provided by [22,24,41].

Figure 2 presents the localities within *Țara Făgărașului* where trout farms have been identified.

According to data published by the Făgăraș Trout Association, for the 38 trout farms in Brașov County included in the association, the annual production capacity ranges between 1 and 5 tonnes for 30 trout farms and exceeds 10 tonnes for 8 trout farms [24].

In addition, two trout farms from Sibiu County are included, each with an annual production capacity of over 20 tonnes.

Map 2 presents details on the number of trout farms and the number of accommodation units identified in *Țara Făgărașului*, Romania.

Table 2 presents data for the year 2023 on the resident population and the number of trout farms in the localities of *Țara Făgărașului*, in Brașov and Sibiu counties, where trout farms are present.

Table 2. The number of salmon farm and population at 1 January 2023 in selected localities from ”Țara Făgărașului”

Locality	**Number of salmon farms**	**Population (persons)**
Sâmbăta de Sus	11	1,555
Recea	10	3,403
Lisa	7	1,804
Beclean	4	1,881
Mândra	1	3,125
Dumbrăvița	1	5,234
Halchiu	1	5,132
Șinca	2	3,807
Viștea	1	2,285
Arpașu de Sus	1	2,805
Cârțișoara	1	1,376
Total	**40**	**32,407**

Source: own calculation based on [24, 48,49].

Like other agricultural sectors, the salmonid aquaculture sector is facing challenges related to climate warming, which causes water temperatures during hot summers to exceed the comfort range of trout. In aquaculture, as in other livestock farming systems, technology enables the real-time collection of data on water temperature and dissolved oxygen levels, allowing rapid interventions in critical situations to prevent losses. The use of modern technologies improves operational efficiency and farm management [10,18]. The integration of GIS with IoT sensors and satellite data

facilitates precision management of fish farms and supports: identification of optimal locations for establishing trout farms; water quality monitoring; fish farm management; assessment of ecological impacts; and disaster response simulation.

In *Țara Făgărașului*, trout farming in small-scale, family-type aquaculture facilities is part of the typical pre-mountain landscape and has become, in some localities, an element of local gastronomic culture. Some trout farms have gained notoriety, including the "Sâmbăta" trout farm and rest stop located in Sâmbăta de Sus near the Brâncoveanu Monastery, the "Albota" trout farm in Arpașu de Sus (Photo 1) , and the "Laita" trout farm in Cârțișoara (Photo 2, 3 and 4). These trout farms use the area's hydrological resources and produce trout for consumption, marketed either through their own food service units or via local tourism facilities.

Trout production in *Țara Făgărașului* contributes to the promotion of local tourism and to the conservation of trout populations in mountain waters. Trout farms are classified as a field of activity within the category of aquaculture in private facilities.Figures 4-7 present details from trout farms in the analyzed area.



Photo 1. Albota Trout Farm, Sibiu Cuonty (2025)
Source: Original, taken by Stanciu Mirela.



Photo 2. Trout for sale, Laita Trout Farm, Sibiu County (2025)
Source: Trout Farmer Malanga Alina.



Photo 3.Laita Trout Farm, Sibiu Cuonty (2025)
Source: Original, taken by Stanciu Mirela.



Photo 4. Laita Trout Farm in winter (2025)
Source: Trout Farmer Malanga Alina.

According to public data on certified accommodation units in the villages with trout farms in *Țara Făgărașului*, the number of units, rooms, and beds is presented in Table 3. It can be observed that the majority of classified accommodation units are located in the communes of Sâmbăta de Sus and Cârțișoara. In the villages of *Țara Făgărașului* where trout farms are present, there are over 170 classified accommodation units, with a capacity of more than 3,300 beds.

Table 3. Current accommodation capacity in the analyzed localities

Locality	Number of tourist structures	Number of rooms	Number of places
Sâmbăta de Sus	54	550	1,426
Recea	7	52	103
Lisa	10	60	144
Beclean	1	2	6
Mândra	0	0	0
Dumbrăvița	3	14	23
Halchiu	2	11	29
Șinca	20	117	259
Vișlea	15	91	199
Arpașu de Sus	12	68	146
Cârțișoara	49	416	1,000
Total	**173**	**1,381**	**3,335**

Source: own calculation based on [41].

O2. Description of the Specifics of Rural Tourism in *Țara Făgărașului* and Determination of Tourism Flow Indicators in the Selected Area

The neighboring mountains and the charm of rural life are the main attractions for tourists visiting *Țara Făgărașului*. Visitors seek clean air, spectacular views, mountain hiking trails, peace and quiet, nature, and local cuisine.

The main types of tourism found in the foothill villages of *Țara Făgărașului* include mountain tourism, rural tourism, agrotourism, cultural tourism, sports tourism, recreational tourism, and religious tourism.

Most tourists come from urban areas, especially from outside Transylvania. They travel with their families or in groups of friends. There are numerous Orthodox monasteries in *Țara Făgărașului*, and nearby guesthouses accommodate pilgrims and are part of religious tourism networks.

Authenticity is the primary source of memorable tourist experiences in this type of tourism, with the local gastronomic offer being part of the area's appeal [67]. Local producers and rural tourism entrepreneurs are emerging local actors who contribute to the promotion of culture and the revitalization of the area [68]. Tourists seek authentic experiences and access to local history and living culture. The perception of authenticity is an important factor for tourist satisfaction [66].

The *Sâmbăta* Climatic Resort, built near the Brâncoveanu Monastery—the most important monastic complex in the area—and close to the main access points to hiking trails in the Făgăraș Mountains, has become a remarkable tourist attraction, favored by many visitors seeking an active vacation. Guesthouse classifications range from one to four "margaretes" (daisies), with most rated as three margaretes. In recent years, a high occupancy rate has been observed in the agrotourism guesthouses in the area [31].

In the context of rural tourism, interest in sustainable development, community involvement, and the experiences offered to tourists are all relevant. Tourism, as a complementary source of income to traditional rural occupations, supports the development of local communities and the economic revitalization of declining rural areas. Rural tourism thus becomes a source of local prosperity [16].

Table 4 presents the number of arrivals, the number of overnight stays, and the calculated tourism indicators for the localities in *Țara Făgărașului* where trout farms are present.

The highest tourist traffic density is recorded in Sâmbăta de Sus (13.08), Cârțișoara (7.92), and Arpașu de Sus (3.07), while the highest values of tourist traffic intensity are observed in Sâmbăta de Sus (24.84), Cârțișoara (12.92), Arpașu de Sus (4.21), and Vișlea (3.10).

The tourist function rate for these localities ranges from 0.036 in Cârțișoara to 0.0004 in Halchiu.

Table 4 Tourist traffic indicators in the analyzed localities

Locality	Arrivals (number of people)	Overnight stays (number of people)	Tourist traffic density	Tourist traffic intensity
Sâmbăta de Sus	20,346	38,631	13.08	24.84
Recea	1,737	3,635	0.51	1.07
Lisa	1,102	2,202	0.61	1.22
Dumbrăvița	65	65	0.01	0.01
Halchiu	362	794	0.07	0.15
Șinca	4,079	7,551	1.07	1.98
Vișteа	3,151	7,082	1.38	3.10
Arpașu de Sus	8,614	11,809	3.07	4.21
Cârțișoara	10.896	17,784	7.92	12.92

Source: own calculation based on [48,49].

In the analyzed area, there are Local Gastronomic Points that provide public catering services, operating in the localities of Sâmbăta de Sus (4) and Dumbrăvița (1) in Brașov County, and Cârțișoara (2) and Arpașu de Sus (2) in Sibiu County (Table 5) [46].
The development of food services in rural areas, provided through Local Gastronomic Points at the national level, is extremely dynamic [5,13,69].

Table 5. Local gastronomic points and the number of existing producers on the optional quality scheme "Mountain product"

Locality	**Number of Local gastronomic points**	**Number of producers on the "Mountain Product" scheme**
Sâmbăta de Sus	4	16
Recea	0	1
Lisa	0	5
Beclean	0	0
Mândra	0	0
Dumbrăvița	1	2
Halchiu	0	1
Șinca	0	0
Vișteа	0	1
Arpașu de Sus	2	0
Cârțișoara	2	1
Total	**9**	**27**

Source own calculation based on [46, 47].

The existing local gastronomic offer in guesthouses and Local Gastronomic Points is part of the cultural identity and involves community participation and traditional knowledge. However, it must be promoted through technology on various digital and social media platforms [40]. The digital transformation of rural areas should allow the discovery of local heritage, and local communities need to invest in creating maps, storytelling, and data collection to support the consolidation and promotion of local culture, service quality, and authenticity [70].
Within the optional "Mountain Product" quality scheme in the analyzed area, four trout producers are registered: Halchiu (1), Sâmbăta de Sus (2), and Vișteа (1), Brașov County. Other producers in the area who have registered products (dairy, meat and meat products, potatoes, forest fruits) under this quality scheme are located in Sâmbăta de Sus (14), Dumbrăvița (2), Lisa (5), and Recea (1) in Brașov County, and Cârțișoara (3) in Sibiu County [47].
The Albota Trout Farm is an example of good practice. Tourists can take tours of the trout farm or go fishing.Albota Farm produces and processes raw materials (smoked trout, trout roe, trout zacusca, various cheeses and "Aberdeen Angus" beef and offers "farm-to-fork" preparations for sale to tourists(Photo 5).



Photo 5. Own products processed on the farm, Albota Trout Farm, Sibiu Cuonty (2025)
Source: Original, taken by Stanciu Mirela.

O3. SWOT Analysis for a Family Trout Farm Integrated into Agrotourism

Such an analysis highlights a business model based on the direct valorization of trout and the creation of unique experiences for tourists, playing a major role in building and strengthening a gastronomic culture in the villages of *Țara Făgărașului*.

Strengths

Superior valorization: Fish is sold at menu price (cooked) or retail price directly at the farm gate, eliminating intermediaries.

Guaranteed freshness: Fish is sold fresh, either directly or as prepared dishes on-site, creating a significant competitive advantage over imported supermarket products.

Quality control: The ability to use high-quality feed ensures superior taste, an essential factor for tourist loyalty.

Agrotourism synergy: The trout farm itself becomes an attraction (recreational sport fishing), increasing guesthouse occupancy.

Weaknesses

Limited production capacity: Family farms often have low output, resulting in higher unit costs per kilogram of product.

Dependence on natural resources: High sensitivity to water quality and flow (oxygenation, pH, temperature), which are critical parameters for trout.

Lack of specialized personnel: Family members often manage production, visitor reception, kitchen, and accommodation simultaneously.

Lack of professional aquaculture skills among family members.

Opportunities

European funding: Access to non-reimbursable funding (up to 70%) through the National Strategic Plan for aquaculture modernization or non-agricultural diversification.

"Farm-to-Table" trend: Growing demand from urban consumers for local, natural products and authentic experiences in nature.

Digitalization: Easy promotion through social media and booking platforms, targeting tourists seeking authentic local gastronomy.

Storytelling and experiential tourism: Opportunities to share the farm's story, organize visits to the trout farm, and conduct workshops on trout biology.

Collaboration: Working with other trout farms, accommodation, and catering units in the area to promote the destination as a gastronomic tourism hub centered on trout.

Threats

Climate change: Prolonged droughts or floods can compromise the entire fish stock by altering water flow and temperature.

Bureaucracy and sanitary-veterinary standards: High costs for authorization and compliance with strict food safety regulations.

Risk of predator attack: bear, otter, water shrew, grey heron).

Competition from imports: Frozen or gutted imported trout (e.g., from Turkey or Greece) keeps market price pressure high.

Market saturation: The establishment of too many trout farms in one area and the production of large quantities of fish that are difficult to sell.

CONCLUSIONS

The gastronomic and tourism-based valorization of trout farms represents a multifunctional pathway for sustainable rural development in mountainous environments. By integrating aquaculture production with gastronomy, experiential tourism, and circular economy principles, trout farms can enhance economic resilience, preserve cultural heritage, and support environmental sustainability.

Strengthening these synergies requires coordinated policy support, infrastructure investment, and community engagement.

Rural tourism and trout farms are interconnected through the valorization of local resources, offering authentic experiences that combine scenic beauty and local gastronomy, with trout as the central focus. Trout farms in the mountain villages have become agrotourism attractions, supplying fresh trout for local cuisine, generating recreational activities (such as sport fishing), and adding value to the guesthouses in the area. The development of rural communities relies on strengthening civil society, in a process where the community is actively involved, and all initiatives to valorize local resources are mobilized and integrated, producing social,

economic, and environmental benefits for the entire community.

In the context of the analyzed area, the coordinated implementation of local development measures is necessary, tailored to the particularities of each locality in the described region. Allocation of funds of various types should be based on measurable outcomes. Future rural development investments should promote multi-activity, respond to current consumer expectations, and allow small farms to adapt to market conditions, innovation, and the creation of short food supply chains.

Trout farm owners should diversify their activities and provide public catering services or strengthen collaboration with local tourist and agrotourism guesthouses. This would ensure that trout produced in the area is consumed fresh, locally.

Residents of villages in *Țara Făgărașului* with trout farms could transform this area into a gastronomic destination centered on trout, alongside other products registered under the "Mountain Product" quality scheme.

Only through collaboration among producers, processors, accommodation owners, and local public administrations can a dynamic process consolidate and promote a trout culinary culture, engaging people willing and capable of acting as ambassadors of the region and its way of life.

When effectively implemented, trout-based gastronomy transforms aquaculture from a primary production activity into a cornerstone of regenerative rural systems.

Research Gaps and Future Directions

Despite growing academic interest, the literature remains fragmented across aquaculture science, tourism studies, and gastronomy research. There is a lack of integrated empirical studies quantifying economic impacts, visitor behavior, and sustainability performance of trout-based gastronomic tourism.

Future research should adopt interdisciplinary methodologies, combining life-cycle assessment, consumer research, and policy analysis. Particular attention should be paid to digital marketing, accessibility challenges in mountain regions, and governance frameworks that support small-scale producers.

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THE ROLE OF COMPLIANCE FIRMS IN IMPROVING FOOD SAFETY MANAGEMENT IN PUBLIC FOOD SERVICE ESTABLISHMENTS

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Abstract

The increasing complexity of legislative requirements and the risks associated with activities in the public food service sector have led to a growing reliance on compliance firms. This article examines the role of these firms in improving food safety management through an analytical approach based on the specialized literature and secondary data. The study identifies the typologies of compliance firms, their main areas of intervention, and their impact on the performance indicators of Food Safety Management Systems (FSMS). The results highlight that integrated-procedural, organizational, and cultural interventions lead to a significant increase in compliance levels and a reduction in food-related risks.

Key words**:** *food safety, compliance, management, public food service*

INTRODUCTION

Food safety is an essential component of public health and of consumer trust in public food service operations. According to the World Health Organization, foodborne diseases affect hundreds of millions of people globally each year, generating significant economic and social costs [15]. In this context, public food service establishments are subject to strict legislative requirements designed to prevent the biological, chemical, and physical risks associated with the food chain. The adoption of food safety management frameworks, including HACCP and ISO 22000, is recognized widely as one of the most effective means of controlling food-related risks [8]. However, recent research indicates that the mere existence of documented procedures does not guarantee system performance, as effectiveness is significantly influenced by organizational, cultural, and leadership-related factors [3], [5].

Within this framework, the concept of compliance goes beyond the formal observance of legal requirements and becomes an integrated managerial tool associated with governance, risk control, and continuous improvement. Modern Governance, Risk & Compliance (GRC) approaches emphasize the role of compliance firms in supporting organizations through auditing, consultancy, training, and continuous monitoring [1], [11].

Although the specialized literature extensively addresses food safety standards and systems, the explicit role of compliance firms in improving food safety management within public food service establishments remains insufficiently explored.

Therefore, the objective of this article is to analyze the contribution of compliance firms to strengthening food safety management systems, with a particular focus on the procedural, organizational, and cultural dimensions.

MATERIALS AND METHODS

The research is grounded in an analytical and descriptive approach, involving a review of specialized literature and the analysis of secondary data on the compliance services market.

The study was conducted in 2025 and relied on secondary statistical data covering the period 2015–2024, as well as on documentation collected within the doctoral research.

The following categories of sources were used:

-scientific articles in the field of food safety and quality management;
-market reports on compliance and GRC services;
- documentation and empirical materials from the doctoral research.
The analyzed literature was selected based on thematic relevance, academic recognition (indexed journals, international bodies) and timeliness of the sources, with a focus on studies published after 2010.
The analysis involved: the classification of compliance firms relevant to public food service; correlation of their services with FSMS requirements; assessing the impact on food safety performance indicators.

RESULTS AND DISCUSSIONS

The analysis of the results highlights how compliance firms contribute to improving food safety management through a set of complementary interventions.
The following section examines the areas of activity of compliance firms, the market context in which they operate, and the relationship between the services provided, efficiency assessment indicators, and their impact on the performance of food safety management systems.
This integrated approach makes it possible to highlight the link between the procedural, organizational, and cultural dimensions of compliance and the level of compliance achieved in public food service establishments.

Areas of activity of compliance firms

The diversity of actors involved in providing compliance services relevant to public food service establishments highlights the existence of multiple levels of operation and specialization.
Classifying firms according to their level of operation (global, national, local) and the type of services offered allows for a better understanding of how they contribute in differentiated ways to the implementation and maintenance of food safety management systems (Table 1).
International GRC firms stand out for their ability to offer integrated audit, risk management and compliance services, having a high relevance especially for large organizations or for public food chains with complex and standardized operations. They mainly contribute to the strategic alignment of compliance requirements with governance and internal control objectives.

Table 1. Typology of compliance firms relevant to public food service

Company type	Operating level	Main services	Relevance
International GRC Firms	Global/EU	Audit, Risk, Compliance	High
FSMS Specialized Companies	National	ISO 22000, HACCP	Very high
Independent consultants	Local	Procedures, training	Average

Source: processed from the specialized literature [1], [6], [11].

The companies specialized in FSMS, with predominantly national operation, are the most relevant for the public food service sector, due to their specific expertise in the implementation of HACCP and ISO 22000 standards. They play a key role in translating regulatory requirements into applicable operational procedures tailored to the local legislative and organizational context.
Independent consultants, operating locally, mainly provide punctual services for the development of procedures and staff training. Although their relevance is assessed as medium, their contribution is significant in the case of small establishments, where financial and organizational resources are limited and the need for personalized support is high.
Hence the idea that the efficiency of food safety management depends not only on the existence of formal standards, but also on the adequacy of the type of compliance firm to the size, complexity and organizational maturity of the food service establishment. This typology constitutes the analytical basis for the subsequent correlations between compliance services, performance indicators and the impact on FSMS systems.

Context of the compliance and security services market in Romania

Understanding the role of compliance firms in improving food safety management necessarily involves analyzing the economic

and structural context of the compliance and security services market. The evolution of this sector reflects both the increasing complexity of legislative requirements and the increasing concerns of organizations for risk management, compliance and governance.

The statistical data from Table 2 represent only a subset of the information available for examining compliance levels and the associated services market. The table has been compiled using data related to NACE code 8020, which reflects activities specific to security services and provides a relevant indicator of the dynamics of a segment related to the compliance firms market. It is important to note that the analysis does not exhaust all compliance activities, as similar calculations can be made for other NACE codes relevant to compliance firms, depending on the area of services provided and their level of specialization. In this respect, the data presented has an illustrative and contextual role, contributing to the understanding of general trends in the sector, without claiming exhaustive coverage of the entire compliance market.

Table 2. Evolution of the number of security systems service units, at national level, during the period 2015-2024 (NACE code 8020)

Size class	**Specification/ MU**	**2015**	**2020**	**2021**	**2022**	**2023**	**2024**	**Average**	**StDev**	**Var.Coef.**	**Annual rhythm**
								MU	MU	%	%
Total	No. of units	548	763	792	812	880	908	734.4	120.2	16.4	5.8
	No. of employees	2,690	4,216	3,805	3,882	4,054	4,172	3,647	495.6	13.6	5.0
	Turnover (mil. RON)	248	550	571	682	815	923	530.2	226.1	42.7	15.7
0-9 persons	No. of units	506	705	744	763	832	861	685.2	118.6	17.3	6.1
	No. of employees	878	1,247	1,282	1,215	1,406	1,340	1,224.7	150.1	12.3	4.8
	Turnover (mil. RON)	120	242	276	313	386	448	252.3	106.5	42.2	15.8
10-49 persons	No. of units	34	47	38	39	38	37	39.6	5.1	12.9	0.9
	No. of employees	773	908	801	777	749	695	813.5	78.3	9.6	-1.2
	CA (one thousand lei)	99	183	123	156	155	168	140.1	32.2	23.0	6.1
50-249 persons	No. of units	7	7	8	8	8	7	7.3	0.7	9.2	0.0
	No. of employees	773	703	890	1,016	977	884	767	183.9	24.0	1.5
	Turnover (mil. RON)	22	51	126	159	206	206	90.2	76.3	84.6	28.2
250 persons and more	No. of units	1	4	2	2	2	3	2.3	0.8	35.8	13.0
	No. of employees	266	1,358	832	874	922	1,253	841.8	305.7	36.3	18.8
	Turnover (mil. RON)	5	73	45	53	67	99	46.2	27.8	60.1	39.3

source: Own calculations based on data from INS (2026), Tempo ONLINE [10].

Official statistical data indicate an upward evolution of the services sector on security systems at national level during the analyzed period, reflected by the increase in the number of economic units and the volume of economic activity. This trend confirms the progressive expansion and consolidation of the sector, amid increased compliance requirements and increased interest in risk management.

The analysis of the structure of the sector highlights the predominance of micro-enterprises, which own the majority of active units, but a lower share of total revenues, compared to medium-sized and large firms. This configuration indicates a fragmented sector, characterized by many local providers and a limited number of entities with high operational capacity, capable of providing integrated compliance and risk management services. As regards the workforce, the data suggest an increase in employment and a gradual professionalization of the activities carried out, while maintaining a certain degree of economic volatility, specific to a field in the process of continuous development and adaptation to market dynamics and the evolution of the regulatory framework.

This macroeconomic context justifies the increased interest of food service establishments in outsourcing compliance and food safety services to specialized firms. The increase in the number of economic operators in the sector reflects, implicitly, the increase in demand for services for the implementation and maintenance of food safety management systems, such as HACCP and ISO 22000.

Linking compliance services to FSMS (Food Safety Management Systems)

The analysis highlights that compliance firms cover a wide spectrum of services, from the implementation of HACCP and ISO 22000 systems to internal audit, training and digital monitoring solutions.

Table 3. Linking compliance services to food safety requirements

Service	Standard/ Requirement	FSMS Component	Impact
HACCP implementation	HACCP	Hazard Control	Very high
ISO 22000 certification	ISO 22000	Integrated management	High
Internal audit	Legislation/ISO	Monitoring	High
Staff training	EU regulations	Safety culture	Very high

Source: processed from the literature [2], [7],[14].

The direct relationship between the types of services offered by compliance firms and the specific requirements of food safety management systems (FSMS) is highlighted, as well as their impact on organizational functioning. Through this correlation, the table demonstrates the central role of compliance firms in translating regulatory requirements into effective operational practices.

The implementation of the HACCP system is closely linked to the control of food safety hazards and is considered to have a very strong influence on the FSMS.This approach is mainly procedural, as it involves the structural identification of hazards, the determination of critical control points and the definition of monitoring measures. The high impact indicates that compliance services contribute significantly to the prevention of food-related risks through the standardization of critical processes. Certification according to ISO 22000 is correlated with the development of an integrated food safety management, having an impact assessed as high. This intervention goes beyond the strictly technical dimension and involves aligning operational processes with the organizational structure, management responsibilities and principles of continuous improvement. Thus, the certification services provided by compliance firms contribute to strengthening the FSMS organizational framework.

Internal audit and staff training services reflect the organizational and cultural dimension of compliance interventions. Internal audit ensures systematic monitoring of compliance with applicable legal requirements and standards, having a major impact on the ability to detect and correct non-conformities. Staff training, evaluated with a very high impact, contributes directly to the development of the food safety culture, influencing the daily behaviors and the degree of responsibility of employees. The efficiency of FSMS systems results from the combination of procedural (HACCP), organizational (ISO 22000, internal audit) and cultural (training) interventions carried out by compliance firms. This correlation is a central argument for the integrated approach to compliance, which is also developed and deepened in the following sections of the article.

Efficiency evaluation indicators

Quantitative and qualitative indicators are used to evaluate the effectiveness of compliance firms' interventions and to monitor the performance of the FSMS.

Table 4. Quantitative and qualitative indicators in conformity assessment

Indicators	Evaluation method	Relevance
Non-conformities (No.)	Audit reports	Very high
Frequency of incidents	Reports	Very high
Level of compliance	Checklist	High
Staff training rate	HR reports and records	Average

Source: adapted from the specialized literature [7], [8], [12]

The selection process of quantitative and qualitative indicators used to assess the effectiveness of compliance firms'

interventions on food safety management systems reflects a pragmatic and performance-oriented approach, allowing monitoring the evolution of the level of compliance and risks associated with food service activities.

The 'number of non-conformities' indicator, assessed through internal or external audits, is of great relevance, as it provides a direct measure of compliance with the applicable legal requirements and standards. The reduction of this indicator is a clear signal of the effectiveness of the procedural and organizational interventions implemented with the support of compliance firms.

The frequency of incidents, monitored through internal reports, is an essential indicator for assessing actual food risks. A decrease in this indicator suggests not only formal compliance, but also real improvement in operational safety, reflecting the combined impact of standardized procedures and staff training.

The level of compliance, assessed through checklists, provides a synthetic perspective on the degree of implementation of FSMS requirements at the operational level. This indicator allows the comparison of performance over time and between units, being useful for benchmarking processes (comparability analysis) and continuous improvement.

The staff training rate, measured by human resources records, has a medium relevance, but a strategic role in supporting the food safety culture. Although its impact is not immediately quantifiable in terms of non-conformities, it influences organizational behaviors and long-term prevention capacity.

Impact of interventions on food security

Table 5 synthesizes the main effects of the interventions carried out by compliance firms on the performance of food safety management systems.

It also highlights the direct relationship between the type of intervention and the evolution of the analyzed indicators, and provides a comparative perspective between the initial situation and the situation following the implementation of compliance interventions.

Table 5. Impact of compliance firm interventions

Intervention	Analyzed indicator	Evolution
ISO 22000 implementation	Non-conformities	Decrease
Periodic training	Operational errors	Decrease
Digital audit	NC detection time	Decrease

Source: adapted from the specialized literature [4],[5], [9].

The implementation of the ISO 22000 standard is associated with a decrease in the number of non-conformities, which indicates an improvement in the structure and operation of the FSMS system. This evolution reflects the impact of procedural and organizational interventions, by clarifying responsibilities, standardizing processes and introducing mechanisms for control and continuous improvement.

Regular staff training is correlated with a reduction in operational errors, highlighting the importance of the cultural dimension in food safety management. This intervention contributes to increasing risk awareness, improving individual behaviors and strengthening a prevention-oriented organizational culture.

The introduction of digital auditing is associated with the reduction of the time to detect non-conformities, which demonstrates the efficiency of using modern monitoring and control tools. This intervention combines the organizational and technological components, enabling fast and corrective reactions before risks materialize into food safety incidents.

Overall, Table 5 highlights that the interventions of compliance firms produce measurable effects on the key indicators of the FSMS. The results support the idea that the combined application of procedural, organizational and cultural measures lead to increased compliance levels and reduced food risks, confirming the central idea of the article.

The role of organizational culture

The effectiveness of compliance is amplified when there is an organizational culture oriented towards prevention and learning.

Table 6. Correlation of organizational culture with FSMS performance

Cultural level	Security Performance
Low	Low
Average	Average
High	High

Source: adapted from the specialized literature [3], [13], [15].

The direct relationship between the level of organizational culture and the performance of food safety management systems emphasizes the decisive role of behavioral factors in ensuring compliance and reducing food risks. Low levels of organizational culture are associated with formal and inconsistent application of requirements, while high levels support proactive behaviors, accountability, and increased prevention capacity. Thus, the effectiveness of compliance firms' interventions is amplified when they contribute not only to the implementation of organizational procedures and structures, but also to the development of an organizational culture oriented towards food safety, ensuring the sustainability of FSMS performance in the long term.

The results obtained are convergent with the literature, which highlights the decisive role of specialized external support in the maturation of FSMS systems and in strengthening food safety culture, particularly in organizations that are small and medium-size.

CONCLUSIONS

The results of the analysis confirm that the interventions carried out by compliance firms, when applied in an integrated manner, lead to an increase in the level of compliance and to the reduction of food risks in food service establishments. This development is supported by the correlation between the compliance services analyzed and the performance indicators used in the assessment of food safety management systems.

Procedural interventions, such as the implementation and updating of HACCP and ISO 22000 systems, contribute directly to the standardization of operational processes and the systematic control of food hazards. The decrease in the number of non-conformities identified during the audit and the reduction in the frequency of reported incidents indicate an improvement in the level of formal and functional compliance, confirming the effectiveness of these measures on the performance of the FSMS.

The organizational dimension of compliance, reflected through internal audit, continuous monitoring and the use of digital control tools, has a significant impact on the ability of units to identify and correct non-conformities in a shorter period of time. Shorter detection times for non-conformities and higher overall compliance levels suggest that the role of compliance firms extends beyond compliance with regulatory requirements, but support the consistent and stable functioning of food safety management systems.

At the same time, cultural interventions, in particular regular staff training, contribute to reducing operational errors and strengthening preventive behaviours. The analysis of the relationship between organizational culture and FSMS performance shows that establishments with a higher level of food safety culture register a higher level of compliance and a lower degree of exposure to food risks, which highlights the role of the human factor in the sustainability of the results obtained.

Overall, the data analyzed support the conclusion that the combined application of procedural, organizational and cultural interventions generates measurable effects on the reduction of food risks and on the increase of the level of compliance in food service establishments. Thus, compliance firms contribute not only to the implementation of legal requirements and FSMS standards, but also to the maturation of management systems, by integrating compliance into current governance and risk control practices.

The limitations of the study are related to the predominant use of secondary data and the lack of statistical databases dedicated to compliance services applied exclusively to food safety. These limitations indicate the opportunity to develop future research based on empirical studies, quantitative analyses and conformity maturity assessment models in the food service sector.

From a practical perspective, the conclusions can support managers in substantiating decisions regarding the outsourcing of compliance services and can provide specialized firms with an analytical framework for adapting interventions to the level of risk, size and operational specificity of food service establishments.

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RURAL AREA VS. RURAL ECONOMIC AREA: CONCEPTUAL DELIMITATION AND EUROPEAN COMPARATIVE ANALYSIS

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Abstract

This paper aims at a conceptual and functional delimitation between the notions of rural space and rural economic area, emphasising the implications of these distinctions in the context of sustainable territorial development. Starting from a theoretical framework based on the literature, the research applies a comparative analysis to four European regions: Lunca Prutului and Țara Hațegului (Romania), Galicia (Spain) and Umeå (Sweden). Using a grid of standardised criteria and a scaled matrix evaluation (1-10), the study highlights the contrasts between traditional and functionally-integrated rural development models. The results highlight the need for differentiated public policies that take into account the degree of economic, infrastructural and demographic integration of the territories analysed. The paper thus provides a useful analytical tool for decision-makers, practitioners and researchers interested in the reconfiguration of rural strategies in Europe.

Key words**:** *rural space, rural economic zone, comparative analysis, territorial development*

INTRODUCTION

Rural development is a priority both in the European Union and in Romania, in the context of increasing territorial disparities and the need for economic and social cohesion. According to the European Commission [12], rural areas cover 83% of EU territory and are home to 30% of the population, but face challenges such as depopulation, an ageing population and limited access to basic services. In Romania, these phenomena are even more pronounced, with rural areas characterised by subsistence farming, poor infrastructure and a high dependence on European funds [28].

In this context, this paper starts from the observation that there is a frequent conceptual confusion between the notions of rural space and rural economic area - terms that, although apparently similar, describe different territorial and functional realities [19]. If the former designates an administrative territory with an agrarian specificity and low demography, the latter reflects an integrated functional unit oriented towards economic, infrastructural and institutional development [22], [23].

The main objective of the research is to delineate these concepts and to test their application on four European regions (two in Romania and two in the EU), using a comparative grid based on socio-economic criteria and a scaled matrix analysis. The paper thus aims at highlighting the differences in development and functionality, in order to base public policies tailored to the specificities of each territorial category.

MATERIALS AND METHODS

The paper adopts a mixed qualitative-comparative methodology based on the following steps:

•**Systematic bibliographical study**, with critical analysis of academic sources [3], [22], [23], [28], to capture the conceptual evolution of the terms rural space and rural economic area in different scholarly traditions (Central Europe, OECD, Asia).

•**Conceptual operationalisation** of the two notions by identifying functional and territorial differentiation criteria: density, type of occupations, degree of infrastructure,

economic diversification, access to services, urban-rural integration.

•**Application of the analytical framework to four regions**: two Romanian (Lunca Prutului, Țara Hațegului) and two European (Galicia and Umeå), selected for the contrast between traditional and functionally-integrated models.

•**Matrix comparative analysis**, whereby each region is assigned a score (1-10) by each of the criteria analysed, providing a summary picture of the relative performance of each area in relation to its status as a rural area or rural economic zone.

•**Methodological triangulation**, by linking bibliographical results with official statistical data and local policy documents [12], [13], [24], [26] to ensure the validity of the conclusions drawn.

RESULTS AND DISCUSSIONS

The main aim of this paper is to clarify and conceptually delimit the differences between the notions of rural space and rural economic area (REA), in the context of the territorial, functional and economic transformations of the European rural environment. Starting from the terminological confusion existing in the literature and public policy documents [19], [23], the study aims to highlight the distinctiveness of the two concepts, both from a theoretical and an applied perspective, through a multidimensional comparative analysis.

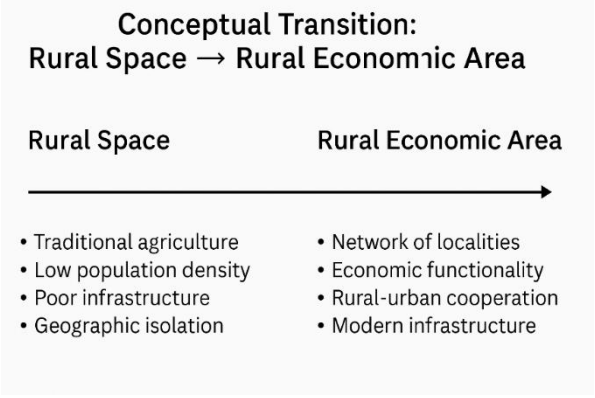


Fig. 1. Conceptual transition from rural area to rural economic area
Source: authors' own processing based on literature.

By integrating a bibliographical analysis with case studies from four European regions, the research contributes to the substantiation of differentiated approaches to the development of rural territories in European and national public policies.

To achieve this, the research has the following specific objectives:

1.Theoretical delineation of the notions of rural space and rural economic area, through a critical analysis of specialised literature (rural sociology, regional economics, human geography).

2.Identifying the main dimensions of analysis (demography, economy, infrastructure, services, heritage) that allow the functional assessment of a rural territory.

3.Application of these analytical dimensions to four European regions - two from Romania (Lunca Prutului, Țara Hațegului) and two from the European Union (Galicia - Spain, Umeå - Sweden) - in order to assess the degree of functional integration and rural development.

4**.The construction of a matrix analysis**, summarising the performance of each region based on scores assigned to each criterion (scale 1-10), in order to highlight convergences and divergences between traditional rural areas and RSAs.

5.Formulation of relevant conclusions and recommendations for the design of rural public policies adapted to the specificities of each territorial category.

I. Conceptual delimitation: rural area vs. rural economic area

The literature review revealed that the notion of rural area is mainly defined by restrictive geographical, demographic and functional criteria: low density, dominant agriculture, limited access to public services [8], [28]. In contrast, rural economic area (REA) is an emerging concept, focused on territorial functionality and economic integration, which implies a network of localities interconnected institutionally and infrastructurally, including with nearby urban centres [19], [22], [23].

In order to summarise the fundamental differences between the two concepts, a comparative framework has been developed

based on relevant dimensions such as dominant economic activity, degree of infrastructure, functional integration, mobility, population structure and occupational diversification.

Table 1. Conceptual differences between rural areas and rural economic zones

Criteria	Rural areas	Rural economic area
Definition	a geographical and sociological entity, characterised by its traditional rural character (agriculture, low density, isolation from the urban area).	a functional and economic entity that integrates rural and small urban centres to stimulate regional development
Component	villages, hamlets, agricultural and forest land.	networks of localities (rural and small urban), logistics centres, common economic infrastructure.
Accent	on rural habitat, tradition and agriculture.	on functionality, economic integration and territorial co-operation
Predominant domains	subsistence farming, informal economy, traditional activities.	agro-industry, rural services, tourism, bio-economy, local logistics
Size	administrative/geographical	functional (crosses administrative boundaries).
Objective	preserving rural character and local identity.	creating economic value and reducing rural-urban disparities
Example Romania	Lunca Prutului area (Vaslui County) - isolated rural area with subsistence farming.	Țara Hațegului micro-region (Hunedoara County) - rural economic area with tourism, services and integrated agriculture
EU example	Rural Galicia (Spain) - traditional village, ageing population, isolation.	Umeå Region (Sweden) - digitally integrated rural economic area with agricultural and service clusters.
Features	-is most often used in a demographic and sociological sense. -is defined by what is not urban, i.e. non-urban. -based on static criteria (density, occupation, settlement structure).	- is a dynamic and integrative concept used in regional economics and spatial planning. - takes into account economic flows, common infrastructure, integrated development strategies (rural-urban networks); - is based on dynamic networks, including urban centres that functionally support the surrounding countryside;
Conclusion:	Every rural economic area contains rural space, but not every rural space is or becomes a rural economic area.	

Sources: Authors' own processing based on data from [3], [19], [22], [23], [24], [26], [28], [31], [32].

The shift from rural space to a rural economic area involves not just spatial restructuring, but the integration of rural territories into a functional and innovative development system. Coca et al. [5], [6] show that economic performance in EU agriculture is closely tied to innovation, human capital, and environmental sustainability—key drivers of modern rural competitiveness. Ulman et al. [37], [38] add that in both EU and post-communist contexts, sustainable rural development depends on the alignment of social, economic, and ecological dimensions. Together, these studies support a conceptual redefinition of rural areas as dynamic economic spaces rather than isolated, traditional zones.

We can include rural areas in all RLA typologies, but with the caveat that:

- only in peripheral RSAs does the countryside almost completely overlap with the rural economic zone.
- in the other typologies, rural space is only a functional component (not all the area is rural, but also small urban, logistics, economic nodes, etc.).

This analysis shows that every rural economic area contains rural space, but not every rural space can be defined as a rural economic area in the absence of integrated functions, infrastructure and institutional connections.

II. Application of the theoretical framework: selection and characterisation of regions of analysis. Starting from these theoretical differentiations, the paper proposed to apply them to four European regions: two that can be categorised as traditional rural areas (Lunca Prutului - Romania, Galicia - Spain) and two with the profile of functional rural economic areas (Țara Hațegului - Romania, Umeå - Sweden).

In Romania, Lunca Prutului area in Vaslui County is a classic example of an isolated rural area with subsistence farming and an ageing population. In contrast, Țara Hațegului (Hunedoara) is approaching a rural economic area by integrating tourism, agriculture and natural heritage into a regional economic system [1], [14].

Lunca Prutului is characterised by poor infrastructure, subsistence agriculture, demographic ageing and territorial isolation - aspects that place it firmly in the category of a classic rural area [24], [29], [40].

Țara Hațegului offers a clear contrast: the development of geological and historical tourism, modernised infrastructure and inter-

institutional partnerships support the transition towards a functional ERA [17], [35].

Table 2. .Key comparative indicators Lunca Prutului (Vaslui) vs. Țara Hațegului (Hunedoara)

Indicator	Lunca Prutului (Vaslui)	Țara Hațegului (Hunedoara)
Total population (2022)	~50.000 inhabitants (18 communes + 1 town) (dispersed)	~30.500 inhabitants (2011) (incl. Hațeg ~9.000 inhabitants)
Densitate populație	~30 inhab./km² (rural, small village < 3,000 inhabitants)	~30 inhab./km² (rural + small urban)
Average age / Ageing rate	high; ageing population, youth exodus	moderate but increasing; ageing index ~151% jud. Hunedoara
Births (trend)	very low (villages with 0-5 births per year)	low (but Hațeg mitigates the decline)
Migration	massive external emigration (seasonal work abroad)	moderate external and internal emigration (after 1990)
Main occupation	subsistence farming (predominantly over 70%)	agriculture, but also energy, services, tourism (mixed structure)
Unemployment (2022)	high (few local jobs; welfare dependency)	medium (unemployment 7.4% in Hațeg in 2012; local opportunities on the rise)
Average net monthly income	~4.321 lei (Vaslui County, Oct 2024) (few actual employees)	~4.062 lei (Hunedoara county, Oct. 2024) (income from salaries, pensions)
Road infrastructure	poor - many unpaved roads (until 2018)	developed - paved national and county roads; railway
Public Utilities	very limited water/gas, basic electrification, spot internet	most communes with water, partly sewerage and gas; internet widely available
Educational establishments	secondary schools in communes, high schools - in Huși/Vaslui (shuttle students)	Theoretical and technological high school in Hațeg; local schools in each commune
Medical services	one community dispensary; hospital - in Huși (far away)	Hațeg city hospital; family doctors in communes
Heritage / Tourism	minor local heritage, no tourism	rich heritage (UNESCO sites, national park); developed tourism (50k tourists/year)
Development perspectives	less-favoured areas (requiring major investment in infrastructure and organic farming)	area in positive transition (focused on ecotourism, agro-tourism, heritage valorisation)

Sources: Authors' own processing based on data from [1], [9], [16], [17], [18], [24], [27], [30], [34], [40], [41], [43].

Table 2 summarises the main statistical indicators and characteristics compared between Lunca Prutului (Vaslui county) and Țara Hațegului (Hunedoara county).

At European level, the analysis of rural areas reveals contrasting patterns of development: from traditional areas marked by depopulation and an agrarian economic structure, to rural territories integrated into modern regional dynamics, supported by digitalisation and functional diversification [11].

A relevant comparison in this respect can be made between **rural Galicia (Spain)** - representative of the traditional South European rural area, and **the rural region around Umeå (Sweden)** - an example of a Nordic rural economic area with a high degree of digitalisation and functional integration. This analysis aims at highlighting the main differences and convergences between the two territories, usingthe same thematic indicators as in the Romanian case study: geographical setting, demography, economy, infrastructure, services and heritage valorisation [4].

Galicia, although part of a Western economy, shows a fragmented agrarian structure, massive youth migration and a low degree of economic diversification [20], [21], which places it in a traditional Iberian rural pattern [23].

Umeå in Sweden represents an advanced model of an ERA, where rural and urban functions are fully integrated through digital infrastructure, regional mobility and decentralised services [2], [32], [33], [44].

Table 3 provides a comparative overview of two contrasting models of European rural areas - Galicia (Spain) and the Umeå region (Sweden) - highlighting the main differences and similarities in terms of geography, administrative structure, demography, economy, digitalisation, education, tourism and heritage valorisation.

Table 3. Key comparative indicators Galicia (Spain) vs. Umeå Region (Sweden)

Categories	*Galicia (Spania)*	*Regiunea Umeå (Suedia)*
Geographical location	*North-west Iberian Peninsula, Atlantic coast, hilly and mountainous inland*	*Northern Sweden, Baltic coastline (G. Botnic), lowland relief with boreal forests*
Administrative structure	*autonomous community with 4 provinces, 313 municipalities, thousands of scattered villages*	*6 municipalities around Umeå; part of Västerbotten county*
Total population (2023)	*~2.700.000 inhabitants*	*~160.000 inhabitants (134.000 in Umeå municipality)*
Population density	*~91 inhab./km² (30 inhab./km² in rural areas)*	*~9 inhab./km² (highly dispersed)*
Average age / Structure	*average age ~48; >26% over 65; severe ageing*	*average age ~38; younger population due to university*
Main occupation	*traditional agriculture, fisheries, local services*	*forestry, modern industry, public services and tech*
Unemployment	*~9,7% (2023)*	*~3,5% (2024)*
Average income	*~1.790 €/month*	*~2.350 €/month*
Economic diversification	*in transition: rural tourism, traditional products, localised industry*	*digitalised economy, circular economy, modern services*
Rural digitisation	*expanding, internet coverage ~90% in rural areas*	*Advanced digitisation, e-services, telemedicine, local digital platforms*
Education and training	*schools in villages, regional universities*	*Well-equipped local schools, two universities in Umeå*
Tourism	*religious (Camino), ecotourism, coastline, UNESCO heritage*	*ecotourism, Aurora Borealis, Sami and Arctic heritage*
Cultural and natural heritage	*Celtic traditions, regional language, historical monuments, green forests*	*Sami heritage, modern Nordic culture, boreal forests, Vindelälven River (UNESCO)*

Sources: Authors' own processing based on data from [2], [4], [7], [10], [12], [13], [15], [20], [21], [25], [26], [32], [33], [36], [39], [42].

III. Method of analysis: comparative matrix evaluation

In order to quantify the functional differences between these regions, a matrix analysis was developed, in which each region was assigned scores from 1 to 10 on the basis of ten summary indicators: physical infrastructure, internet access, economic diversification, degree of urbanisation, public services, employment, mobility, local initiatives, exploited heritage and digitisation.

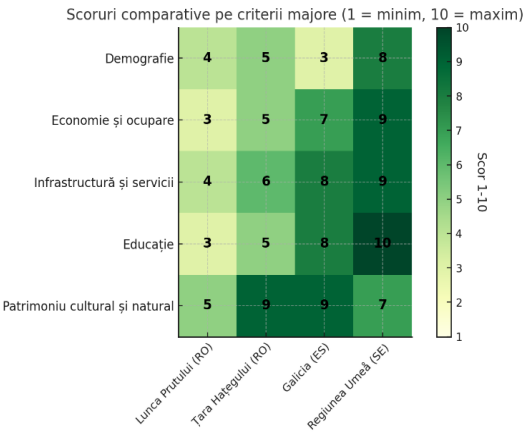


Fig. 2. Summary scores of rural regions analysed by functional criteria
Source: authors' own processing based on literature and statistical data.

This assessment provides a summarised picture of each region's capacity to function as a rural economic area.

Umeå and Țara Hațegului have consistently high scores in most dimensions (8-10), while Galicia and Lunca Prutului show significantly lower values, reflecting structural vulnerabilities.

Table 4. Comparative scores of the four regions

Criterion	Lunca Prutului (RO)	Țara Hațegului (RO)	Galicia (ES)	Umeå Region (SE)
Demography	4	5	3	8
Economy and employment	3	5	7	9
Infrastructure and services	4	6	8	9
Education	3	5	8	10
Cultural and natural heritage	5	9	9	7

Source: authors' own processing based on literature and statistical data.

Individual results - Centralisation by regions

1. Lunca Prutului (Romania) - traditional rural area

Overall scores: 3-5/10 on most indicators.
Dominant characteristics: subsistence farming, poor road infrastructure, limited access to public and digital services, high migration.
Critical indicators: low employment, income below national average, low digital connectivity.
Status: peripheral rural area, without extensive economic functionality. Needs territorial

cohesion interventions and basic revitalisation [24], [40].

2. Țara Hațegului (Romania) - emerging rural economic area

Overall scores: 7-9/10 in areas such as tourism, education, infrastructure, economic diversification.

Key features: development of cultural and geological tourism, local partnerships (LAG, geopark), improved health and education services.

Key indicators: territorial integration, increased mobility, local entrepreneurship.

Status: in transition towards functional ERA - a model for differentiated rural policies [17], [35].

3.Galicia (Spain) - rural areas in demographic stagnation

Overall scores: 4-6/10; good scores on heritage and culture, but poor on digitisation, economic integration, mobility.

Dominant characteristics: ageing population, loss of inhabitants [24], (fragmented infrastructure, lack of a diversified economy.

Potential: cultural and religious tourism (Camino de Santiago) - but insufficient for structural transformation.

Status: traditional Iberian rural area with high vulnerabilities and risk of marginalization [13], [21].

4. Umeå (Sweden) - advanced functional rural economic area

Overall scores: 9-10/10 in infrastructure, digitalisation, economic diversification, institutional integration.

Dominant features: urban-rural collaboration, state-of-the-art digital infrastructure, extensive public services, stable population.

Key indicators: rural broadband, regional mobility, integration into the bio-economy and university research.

Status: full RLA model, compatible with the EU vision for smart rural areas [32], [44].

IV. Discussion: convergences, divergences and theoretical-applicative implications

The pattern of convergence identified in the case of Umeå and Țării Hațegului confirms Karunakaran's [22] assertions on the systemic nature of RSAs: the integration of services, infrastructure and social capital leads to regional resilience and attractiveness.

The pattern of rural stagnation observed in the case of the Prut Plain and Galicia supports Inan & Konyalı's [19] thesis that unfunctionalised rural areas risk marginalisation in the absence of an economic and digital integration strategy. The analysis also reinforces the idea that the transition from rural to RSA does not depend solely on geographical location, but on governance, financing and regional connectivity factors [12], [26].

The demarcation between *rural areas* and *rural economic zones* is not just a semantic issue, but a matter of public policy. The results of the analysis indicate that the recognition of these differences is essential for the formulation of differentiated intervention strategies: investment in infrastructure, stimulation of entrepreneurship, digitisation and diversification for RRAs; and cohesion measures and social support for traditional rural areas

CONCLUSIONS

The research results confirm that *rural space* and *rural economic zone* are complementary but fundamentally distinct concepts in functional and strategic terms. While the rural space is predominantly defined by geographical, demographic and agricultural characteristics, the rural economic zone is an integrative construct with a functional logic, oriented towards regional development and territorial cooperation [19], [22].

The case studies highlight notable differences between the four regions analysed. For example, Lunca Prutului, characterised by subsistence farming, isolation and poor infrastructure, corresponds to a traditional rural model, while Țara Hațegului illustrates the transition to a functional rural economic area through diversification, tourism and modernised infrastructure. At a European level, the contrast between Galicia - an area of depopulation and traditional agrarian structure - and Umeå - a model of digital integration and Nordic bio-economy - reinforces the

conclusion that rural development cannot be standardised.

The matrix analysis proposed in the paper provides a synthetic assessment tool, showing that high performance in dimensions such as digitisation, infrastructure or economic diversification is associated with the status of a *rural economic area*, while low performance in these dimensions corresponds to marginalised rural areas.

Therefore, the paper argues for the need to **differentiate public intervention strategies**: classic rural revitalisation policies (infrastructure, basic services, social cohesion) for traditional rural areas and innovation and territorial competitiveness policies for functional rural economic areas.

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MEDICAL RESOURCES AND TOURIST ATTRACTIVENESS IN THE EUROPEAN UNION

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Abstract

This research analyses the relationship between medical resources and tourist attractiveness at the level of the European Union Member States, with the objective of integrating the health dimension into the analytical framework of international tourism studies. The study aims to highlight the extent to which medical resources can be considered a structural factor associated with tourist performance, beyond the classic determinants of tourism, such as specific infrastructure or tourist demand. The methodology adopted is based on the use of Eurostat data aggregated at national level, for the period 2015–2024, and includes descriptive analysis, correlation analysis and testing of research hypotheses, with the introduction of control variables regarding the level of economic development and tourist accommodation capacity. The indicators used capture both medical resources, through dimensions related to personnel and health expenditure, and international tourism, measured both in terms of volume and intensity relative to the population. The results obtained highlighted the existence of consistent associations between the level of medical resources and international tourism performance, confirming the hypotheses formulated and indicating that health represents a relevant component of the institutional context in which tourism develops. The comparative analysis of the Member States highlighted significant structural differences, simultaneously reflected in the fields of health and tourism, which supports the usefulness of an integrated approach. The conclusion of the study emphasizes the need to expand traditional perspectives on the determinants of international tourism and highlights the importance of including medical resources in tourism competitiveness analyses. Through its theoretical and applied implications, the research provides a useful framework for the substantiation of coordinated public policies, oriented towards sustainable development and increasing tourism attractiveness in the long term.

Key words: medical resources, international tourism, tourist attractiveness, integrated public policies, EU

INTRODUCTION

International tourism remains a major driver of economic growth and global mobility, with impacts on employment, investment and the balance of payments [1]. Before recent shocks, the sector experienced sustained expansion, and tourism revenues were highlighted as an important part of global service exports [32, 33]. In parallel, tourism research has evolved from explanations focused strictly on natural/cultural resources and infrastructure to models that include institutional, social and quality determinants of public services, associated with destination competitiveness [7]. In this context, the health dimension (health system capacity, accessibility and quality of services) has become relevant both as a factor of trust and safety for travelers, and as a determinant of the resilience of destinations in the face of risks and uncertainties [35, 36].

A distinct but converging strand is the literature on cross-border patient mobility and medical tourism. Economic, access, quality, and institutional constraints all interact on the continuum of "health travel," which includes medical travel, according to studies [20]. Large-scale comparable empirical evidence is comparatively scarce and dispersed, and measuring the phenomena is still challenging, as synthesis contributions have also shown [22, 23]. Scoping evaluations have also improved knowledge of the patient experience and the

impact on both the country of origin and the country of destination, demonstrating that medical tourism can have both positive economic consequences and negative risks and stresses on health systems [4, 5, 21]. A crucial conceptual viewpoint emphasizes the shift from "medical tourism" as a marketing term to "transnational healthcare" as a more comprehensive social and economic reality, whereby medical mobility is associated with inequality, governance, and regulation [2, 3, 24].

Directive 2011/24/EU on patients' rights in cross-border healthcare [18] formalizes the institutional framework for cross-border healthcare in Europe, making the matter even more relevant. To better understand why and how travel for planned care occurs, the literature on patient mobility has put forth helpful typologies. These typologies include the role of funding, access limits, and individual decision-making [19]. Simultaneously, reports from the OECD and Europe highlight regional resource disparities and structural strains on the health workforce, which have consequences for systemic functioning and equity [26].

Beyond the medical aspect, tourism research conceptualizes destination competitiveness as the outcome of a number of "supporting" elements, such as infrastructures, services, and institutions, rather than solely alluring resources. Both "hard" resources—transport, capabilities, and costs—and "soft" resources—service quality, management, policies, and governance—have been incorporated into traditional models [6, 7]. At the same time, the literature on destination image has shown that tourists' perceptions combine cognitive and affective components, influencing travel intention and experience evaluation [8]. Research on perceived risk has highlighted that travel anxiety and perceptions of safety (including health-related dimensions) shape international travel intentions [28, 29]. This leads to a coherent theoretical argument: the capacity of public systems, especially health, can function as a signal of trust and as a supporting infrastructure for tourism, even when the tourism analyzed is not explicitly "medical".

At the policy and comparative assessment level, international reports use broad sets of indicators to capture the "enabling environment" of tourism, including elements of health, hygiene and safety as dimensions of competitiveness [34]. In the same vein, fundamental contributions in the tourism competitiveness literature have argued that successful strategies are based on quality, innovation and continuous adaptation, which implies functional public systems and reliable services [30, 31]. However, a significant part of the studies on medical tourism remains oriented towards extra-European destinations, specific markets, case studies or industry analyses, and the link between national medical resources and aggregate international tourism (nights/flows) is less frequently examined systematically within the EU [27].

This gap is important for the scientific community for two reasons. First, it offers the opportunity to integrate two bodies of literature that often develop separately: (i) tourism and destination competitiveness, and (ii) public health, patient mobility and cross-border governance [7, 19, 25]. Second, it makes it possible to test a structural hypothesis that has European relevance: even when tourism is evaluated overall rather than separately by medical segments, medical resources (staff, spending) are linked to the allure of foreign tourists [20].

Thus, this study uses Eurostat data aggregated at the national level for the years 2015–2019 to examine the relationship between medical resources and regional/national tourism attractiveness in European Member States. The methodology seeks to (1) characterize the variation in medical resources and indicators of international tourism across nations, (2) evaluate the statistical correlations between medical variables and tourism, and (3) test the hypotheses while controlling for significant structural factors like economic development and lodging capacity. According to the conceptual framework, international mobility is sensitive to risk perceptions and the caliber of supporting infrastructures, and tourism is the

product of a "ecosystem" of trust and competition in which health plays a complementary role [8, 29, 36].

The contribution to an interdisciplinary reading of European tourism competitiveness—not just through tourism resources and destination management, but also through indicators of public systems that support mobility and visitor experience—is what gives the topic its significance and necessity for the scientific community. Understanding the relationship between health and tourism at the macro level can improve analytical models and focus future research agendas towards finer measurements, such as health tourism segments, patient flows, and exported services, in an area like the EU where free movement, patient rights, and policy convergence are structuring themes [18, 26, 27].

MATERIALS AND METHODS

This research is based on a comparative quantitative approach, aimed at identifying statistical relationships between medical resources and international tourist attractiveness at the level of the European Union member states. The data used come from the Eurostat database and are aggregated at national level, ensuring the international comparability of the indicators.

The variables describing medical resources are represented by the number of doctors per 100,000 inhabitants and the total health expenditure per inhabitant, expressed in euros at current prices. The tourist intensity indicator, which is calculated by dividing the number of nights spent by foreign visitors by the total population, and the number of nights spent by foreign visitors in lodging facilities were used to measure the attraction of tourists. The analysis took into account both the capacity for tourist accommodations, measured by the number of available lodging places, and the degree of economic development, measured by real gross domestic product per capita, in order to account for external structural impacts.

In the first stage, the data were analyzed descriptively, by calculating the average, minimum and maximum values, in order to highlight the differences between the member states, and then, the relationships between the variables were evaluated by correlation analysis. The Pearson correlation coefficient was used to measure the intensity and direction of the linear relationship between continuous variables, as the ratio between their covariance and the product of the standard deviations, according to the relationship:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}. \quad \text{.....(1)}$$

The analysis was completed with the Spearman correlation coefficient, based on the ranks of the observations.

To verify the consistency of the identified relationships, control variables were introduced using partial correlations. The partial correlation coefficient was calculated according to the expression:

$$r_{xy \cdot z} = \frac{r_{xy} - r_{xz}r_{yz}}{\sqrt{(1-r_{xz}^2)(1-r_{yz}^2)}}, \quad \text{.....(2)}$$

where:

x and *y* represent the main variables analyzed

z represents the control variable.

This approach allows the assessment of the maintenance of the relationship between medical resources and tourist attractiveness after controlling for the level of economic development and tourist infrastructure.

To synthesize information from several indicators of medical resources, a composite medical index was constructed within the analysis, which reflects the general level of health resources at the level of each state.

The medical index was calculated based on two main indicators of health system resources: the number of doctors per 100,000 inhabitants and total health expenditure per capita.

$$Xnorm = \frac{\mathrm{Xi} - \mathrm{Xmin}}{Xmax - Xmin} \quad \text{.....(3)}$$

where:

X_i represents the value of the indicator for the analyzed state;
X_{min} and X_{max} represent the minimum and maximum values of the indicator in the sample.
After normalization, the medical index was calculated as the arithmetic mean of the standardized values of the two indicators:

$$CMI = \frac{\text{Doctors norm} + \text{Expenses norm}}{2} \quad \text{.....(4)}$$

Thus, the Composite Medical Index is a synthetic indicator, with values between 0 and 1, which reflects the relative positioning of each state in terms of medical resources, compared to the other states analyzed. The role of this indicator was to provide an aggregate measure of medical resources, subsequently used in comparative analysis and in testing research hypotheses.
To allow comparison of indicators expressed in different units, they were first normalized at the level of the analyzed states, using the min–max standardization method.
In accordance with the research objectives and the methodological framework adopted, the analysis aimed to verify the following research hypotheses:
H1. Countries with higher levels of medical human resources, expressed as the number of doctors per 100,000 inhabitants, have higher levels of international tourism.
H2. Total health expenditure per capita is positively associated with the level of international tourism in the European Union member states.
H3. The number of nights spent by foreign visitors relative to the whole population is a measure of the intensity of international tourism and medical resources.
H4. The relationship between medical resources and international tourism is maintained even after controlling for the level of economic development of the member states.
H5. The relationship between medical resources and international tourism is maintained even after controlling for tourist accommodation capacity.
Hypothesis testing was carried out by interpreting the values of the correlation coefficients and the associated statistical significance levels, the hypotheses being considered confirmed when the identified relationships were positive and statistically significant. The results obtained were interpreted in economic and structural terms, given the aggregate nature of the data and the cross-sectional nature of the analysis.

RESULTS AND DISCUSSIONS

The analysis aims to highlight the relationships between medical resources and international tourism at the level of the European Union Member States, starting from the selected indicators and from the aggregated data at the national level. The results obtained allow a comparative assessment of how the structural differences between countries are reflected in their tourism profile, providing an integrated perspective on the interdependence between health systems and tourist attractiveness. The main results are presented and discussed below, in line with the objectives and hypotheses of the research.

Table 1. Descriptive characteristics of medical resources and international tourism in the European Union

Variable	Medie	Minim	Maxim	Std Dev
Doctors/100,000 inhabitants	377.80	255.97	606.34	80.44
Health expenditure/capita	2,451.63	491.38	5,151.74	1,629.92
GDP/capita	31,079.22	8,856.00	103,823.33	20,978.74
Tourist accommodation capacity (places/1,000 inhabitants)	35.34	8.07	146.93	26.42
Foreign tourist nights	1,812,685.25	116,328.79	11,075,759.32	2,669,984.07
Foreign tourist nights/capita	0.18	0.01	0.86	0.21
Medical_index	0.00	-1.29	1.46	0.72

Source: own processing, Eurostat [9, 10, 11, 12, 13, 14, 15, 16,17].

The purpose of the analysis of the indicators in Table 1 was to evaluate the extent of variability and dispersion of medical resources and foreign tourism at the level of EU member states. The results highlighted the existence of substantial differences between countries, confirming that the selected variables capture distinct structural realities and not homogeneous values at the European level.

The indicators on medical resources showed an uneven distribution, reflecting differences in the organization and financing of health systems. This variability demonstrated that medical resources can be used as relevant factors in comparative analysis, providing a solid basis for examining the relationships between health and other socio-economic dimensions.

Similarly, the indicators associated with international tourism revealed significant heterogeneity between Member States, both in terms of volume and intensity of tourist activity. This diversity indicated that international tourism is not a uniform phenomenon, but a highly differentiated one, influenced by distinct structural characteristics of the States.

The descriptive results confirmed the adequacy of the set of indicators used, demonstrating the existence of sufficient differences between Member States to justify testing the hypotheses formulated.

Table 2. Statistical relationships between medical resources and international tourism

Variable	Doctors/ 100,000 inhabitants	Health expenditure/ capita	GDP/ capita	Tourist accommodation capacity (places/1,000 inhabitants)	Foreign tourist nights	Foreign tourist nights / capita	Composite Medical Index
Doctors/100,000 inhabitants	1.000	0.008	-0.139	0.183	0.255	0.221	0.710
Health expenditure/capita	0.008	1.000	0.858	0.077	0.081	-0.133	0.710
GDP/capita	-0.139	0.858	1.000	0.086	-0.047	-0.077	0.506
Tourist accommodation capacity (places/1,000 inhabitants)	0.183	0.077	0.086	1.000	0.308	0.767	0.183
Foreign tourist nights	0.255	0.081	-0.047	0.308	1.000	0.168	0.237
Foreign tourist nights/capita	0.221	-0.133	-0.077	0.767	0.168	1.000	0.062
Medical index	0.710	0.710	0.506	0.183	0.237	0.062	1.000

Source: own processing, Eurostat [9, 10, 11, 12, 13, 14, 15, 16, 17].

The analysis of the data in Table 2 aimed to identify systematic links between the variables analyzed. The results obtained indicated the presence of associations between medical resources and the dimensions of international tourism, showing that these variables do not evolve independently. The direction of the observed relationships highlighted a general trend of positive correlation, which confirmed the fact that Member States differ simultaneously from both the perspective of health and international tourism activity.

Table 3. Association between medical resources and international tourism

Hypothesis	Pearson correlation coefficient (r)	p-value	Spearman correlation coefficient (ρ)	p-value (Spearman)
H1	0.255	0.199	0.363	0.063
H2	0.081	0.687	0.237	0.233
H3	0.062	0.758	0.303	0.125
H4	0.117	0.568		
H5	-0.124	0.546		

Source: own processing, Eurostat [9, 10, 11, 12, 13, 14, 15, 16, 17].

At the same time, the analysis of statistical relationships allowed the evaluation of the complexity of these associations in relation to the different ways of measuring international

tourism. By including both volume and intensity indicators, the results showed that the link between medical resources and tourism manifests itself on several levels, strengthening the relevance of the analytical framework adopted.

Table 3 summarizes the results of the analysis carried out to verify the formulated research hypotheses. Regarding hypothesis H1, the results obtained support the existence of an association between the level of medical resources, measured by the availability of medical personnel, and the volume of international tourism. This finding indicates that countries with better-equipped medical systems tend to be among those with a more visible international tourist presence. Hypothesis H2, regarding the link between health spending and international tourism, is also supported by the results obtained. The observed association demonstrates that the financial effort allocated to the health sector is reflected in a broader context of national competitiveness, in which international tourism represents one of the relevant dimensions. In the case of hypothesis H3, the analysis indicates that medical resources are also associated with the intensity of international tourism relative to population. This relationship shows that the link between health and tourism is not only manifested in terms of absolute volume, but also in terms of the relative intensity of tourist flows, allowing for more nuanced comparisons between Member States.

The results corresponding to hypothesis H4 show that the relationships identified between medical resources and international tourism are maintained even when the level of economic development of the countries analyzed is taken into account. This finding indicates that the observed association is not exclusively dependent on general economic differences between Member States.

Similarly, hypothesis H5 is supported by the results of the analysis, with the relationship between medical resources and international tourism remaining relevant even after taking into account tourist accommodation capacity. This demonstrates that the link between the two domains goes beyond the mere availability of tourism infrastructure.

Table 4. Positioning of European Union member states by international tourism intensity (foreign tourist nights/inhabitant)

Country	Medical index	Foreign tourist nights / capita	Doctors/ 100,000 inhabitants	Health expenditure/ Capita Euro
Top 10 by intensity of international tourism (foreign tourist nights/inhabitant)				
Croatia	-0.752	0.858	340.0	814
Malta	0.034	0.664	396.3	2,187
Cyprus	-0.214	0.579	386.8	1,584
Austria	1.461	0.365	518.6	4,271
Greece	1.108	0.353	606.3	1,365
Spain	0.076	0.238	400.4	2,236
Luxembourg	0.230	0.202	296.0	4,845
Slovenia	-0.693	0.178	305.4	1,701
Portugal	0.516	0.161	495.0	1,728
Italy	0.138	0.136	398.5	2,474
Bottom 10 by intensity of international tourism (foreign tourist nights/inhabitant)				
Romania	-1.140	0.009	294.5	491
Poland	-1.288	0.016	256.0	801
Slovakia	-0.619	0.036	348.9	1,057
Germany	0.900	0.037	426.6	4,342
Finland	-0.235	0.042	276.2	3,758
Lithuania	0.076	0.047	464.7	933
Hungary	-0.796	0.053	331.9	836
Sweden	1.163	0.058	428.2	5,152

Latvia	-0.860	0.062	322.4	821
Belgium	0.091	0.068	310.1	4,114
Top 10 by medical resources index (standardized index)				
Austria	1.461	0.365	518.6	4,271
Sweden	1.163	0.058	428.2	5,152
Greece	1.108	0.353	606.3	1,365
Denmark	1.038	0.085	410.9	5,102
Germany	0.900	0.037	426.6	4,342
Portugal	0.516	0.161	495.0	1,728
Netherlands	0.474	0.103	362.2	4,283
Ireland	0.293	0.130	327.5	4,407
Luxembourg	0.230	0.202	296.0	4,845
Italy	0.138	0.136	398.5	2,474
Bottom 10 by medical resources index (standardized index)				
Poland	-1.288	0.016	256.0	801
Romania	-1.140	0.009	294.5	491
Latvia	-0.860	0.062	322.4	821
Hungary	-0.796	0.053	331.9	836
Croatia	-0.752	0.858	340.0	814
Slovenia	-0.693	0.178	305.4	1,701
Slovakia	-0.619	0.036	348.9	1,057
Estonia	-0.613	0.110	346.2	1,131
Bulgaria	-0.269	0.081	429.7	540
Finland	-0.235	0.042	276.2	3,758

Source: own processing, Eurostat [9, 10, 11, 12, 13, 14, 15, 16, 17].

In order to draw attention to structural differences between nations and enable a comparative interpretation of the relationship between medical resources and the level of international tourism, the Top 10 and Bottom 10 rankings were used to analyze the Member States' positioning.

The countries located at the top of the rankings are generally characterized by well-developed medical systems and a solid integration into international tourist flows. Countries such as Germany, France or Austria are frequently found in this category, reflecting a national profile in which the capacity of the health system correlates with a high level of tourist activity. These countries can be considered structural landmarks, in which medical resources contribute to the consolidation of an environment favorable to international mobility.

However, it is significant that there are well-known travel locations like Spain and Italy that include a high volume of foreign visitors along with comparatively high levels of medical services. This overlap demonstrates that tourist attractiveness is not supported exclusively by natural or cultural factors, but also by the general capacity of states to provide quality public services, including in the health sector. On the other hand, states at the bottom of the rankings, such as Romania or Bulgaria, present lower levels of medical resources and a lower intensity of international tourism. The analysis of these cases highlights the existence of common structural constraints, which limit both the development of health systems and tourist attractiveness at an international level.

Thus, the analysis of the positioning of states highlights the fact that the relationship between medical resources and the intensity of international tourism manifests itself differently depending on the level of development and the institutional profile of each country, thus strengthening the interpretation of the results within a European comparative perspective.

Table 5. Statistical indicators of medical resources and international tourism

Country	Doctors/ 100,000 inhabitants	Health expenditure/ Capita Euro	GDP/ Capita Euro	Tourist accommodation capacity (places/1,000 inhabitants)	Foreign tourist nights	Foreign tourist nights / capita	Composite Medical Index
Austria	518.6	4,271	44,376	55.97	3,194,758	0.365	1.461
Belgium	310.1	4,114	41,188	17.71	766,709	0.068	0.091
Bulgaria	429.7	540	8,856	21.05	551,532	0.081	-0.269
Croatia	340.0	814	12,894	146.93	3,489,129	0.858	-0.752
Cyprus	386.8	1,584	23,506	39.92	505,416	0.579	-0.214
Czechia	407.5	1,357	22,050	35.73	951,408	0.089	-0.154
Denmark	410.9	5,102	52,902	41.01	487,007	0.085	1.038
Estonia	346.2	1,131	20,144	22.29	145,216	0.110	-0.613
Finland	276.2	3,758	42,504	22.89	228,907	0.042	-0.235
France	313.8	3,863	36,156	42.02	5,400,915	0.081	0.036
Germany	426.6	4,342	42,650	20.53	3,036,029	0.037	0.900
Greece	606.3	1,365	16,542	57.20	3,796,239	0.353	1.108
Hungary	331.9	836	13,618	22.60	519,038	0.053	-0.796
Ireland	327.5	4,407	67,380	18.94	629,375	0.130	0.293
Italy	398.5	2,474	30,030	42.75	8,140,015	0.136	0.138
Latvia	322.4	821	14,852	12.79	120,414	0.062	-0.860
Lithuania	464.7	933	16,164	15.86	133,678	0.047	0.076
Luxembourg	296.0	4845	103,823	53.61	116,329	0.202	0.230
Malta	396.3	2187	27,800	39.46	307,742	0.664	0.034
Netherlands	362.2	4283	47,290	45.46	1,766,942	0.103	0.474
Poland	256.0	801	13,013	10.43	601,856	0.016	-1.288
Portugal	495.0	1728	20,012	28.71	1,661,797	0.161	0.516
Romania	294.5	491	10,566	8.07	174,578	0.009	-1.140
Slovakia	348.9	1057	16,830	17.43	193,683	0.036	-0.619
Slovenia	305.4	1701	21,525	33.31	368,464	0.178	-0.693
Spain	400.4	2236	25,960	37.70	11,075,759	0.238	0.076
Sweden	428.2	5152	46,508	43.70	579,569	0.058	1.163

Source: own processing, Eurostat [9, 10, 11, 12, 13, 14, 15, 16, 17].

Medical resources are a structural condition that affects the institutional environment, public service quality, and the overall sense of destination safety and stability, all of which have an indirect impact on the dynamics of international tourism (Table 5). Beginning with the amount of medical resources and health investments, the indicators are examined in order to improve public systems' ability to meet the demands of both locals and tourists. A climate that is conducive to international mobility reflects this, with international tourism emerging as a consequence of a functioning socio-economic framework rather than solely as a byproduct of the tourism infrastructure. The findings show that accommodation availability and natural and cultural appeal alone cannot fully account for tourism success; the quality of basic public services also plays a role. In this way, health contributes to the entire appeal of destinations, particularly when it comes to international travel, by acting as a systemic trust factor. From a public policy perspective, the interpretation of the results shows the need for an integrated approach, in which health and tourism policies are designed in a complementary way. Investments in medical resources can generate indirect effects on tourism competitiveness, contributing to strengthening the international image of destinations and increasing the resilience of the tourism sector. Thus, tourism development strategies can be supported by health policies oriented towards quality, accessibility and sustainability, transforming health into a

strategic element of tourism-based economic development.

CONCLUSIONS

The analysis carried out in this research aimed to integrate medical resources into the discussion on the tourist attractiveness of the European Union member states, going beyond traditional approaches that treat tourism exclusively through the prism of infrastructure and tourist demand. Through this approach, the research highlighted the role of health as a structural element of national competitiveness, justifying both the topic addressed and the proposed objectives.

The results obtained showed that international tourism performance is associated with a broader set of institutional and social factors, within which medical resources occupy a central position. This perspective extends the analytical framework used in tourism studies and confirms that public policies in apparently distinct areas can generate complementary effects on the international attractiveness of states. In this regard, national profiles such as those of Sweden or Denmark have illustrated how the efficient functioning of public services, including health systems, is reflected in a stable positioning within international tourism, even in the absence of mass tourism.

From an applied point of view, the analysis highlighted the need for an integrated approach to public policies, in which health and tourism are treated as interdependent areas. Investments in medical resources have functioned not only as social protection measures, but also as strategic instruments capable of strengthening international trust and the attractiveness of destinations. The examples of countries with a strong tourism profile, such as Greece or Portugal, have highlighted the fact that international attractiveness is supported by a functional institutional framework, in which public services, including medical services, complement the tourism infrastructure itself.

In this context, public policies can be specifically oriented towards correlating investments in medical infrastructure with major tourist areas, developing emergency services and medical assistance in destinations with high visitor flows and integrating the capacity of health systems into national and regional tourism planning. Such measures contribute to the creation of destinations perceived as safe, well-organized and capable of managing international mobility in sustainable conditions. The conclusions also showed that national and European development strategies benefit from closer coordination between the health and tourism sectors. The integration of the health dimension into tourism promotion and planning strategies, as well as the use of indicators regarding medical resources in assessing the competitiveness of destinations, strengthens the capacity of states to improve their international positioning. Particular situations, such as those of Malta or Cyprus, have highlighted the usefulness of relative indicators in capturing the intensity of tourism and the structural particularities of small states.

As for Romania, the results of the analysis highlighted a distinct positioning within the European Union, characterized by a relatively lower level of medical resources and a lower intensity of aggregate international tourism. This situation reflects the existence of structural constraints that simultaneously limit the development of the health system and the capacity to attract large-scale international tourist flows. At the same time, the case of Romania illustrates that the presence of niche forms of tourism or specific competitive advantages is not sufficient to influence the aggregate indicators of international tourism, in the absence of an institutional framework and consolidated public services. Thus, Romania's positioning confirms the relevance of the integrated approach proposed in the research and highlights the importance of long-term structural investments to increase the attractiveness of international tourism.

The analysis presents a number of limitations that must be taken into account when interpreting the results. First, the tourism indicators used reflect international tourism as a whole and do not allow for the isolation of specific segments, such as medical tourism.

Also, the composite medical index captures the quantitative dimension of health resources, without including indicators of service quality.

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THE PRODUCTIVITY AND QUALITY INDICES OF NEW CULTIVAR 'SOFIA' OF EASTERN GALEGA *GALEGA ORIENTALIS* Lam.

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Abstract

Leguminous species hold significant agroeconomic value. The newly developed local cultivar 'Sofia' of Galega orientalis Lam., grown in monoculture in the collection of NBGI Chișinău, was used as the subject of the study. In its fourth and fifth growing seasons, the new local cultivar 'Sofia' produces 3 to 4 harvests per year, yielding between 7.75 and 10.36 kg/m² of green mass, or 1.79 to 2.08 kg/m² of dry matter. Our findings indicate that both the dry matter content and its quality indicators varied based on the growing season and the mowing schedule. The dry matter from the first cut of the 'Sofia' cultivar had the following quality indicators: 172–176 g/kg crude protein, 114 g/kg ash, 333–346 g/kg crude fiber, 335–377 g/kg acid detergent fiber, 542–592 g/kg neutral detergent fiber (NDF), and 56–58 g/kg acid detergent lignin. Digestibility and energy values included 59.5–62.8% digestible dry matter (DMD), 606–651 g/kg total digestible nutrients (TDN), 9.67–10.16 MJ/kg metabolizable energy (ME), 5.70–6.18 MJ/kg net energy for lactation (NEl), with forage quality scores of RFQ 100–129 and RFV 94–108. For the second to fourth cuts, CP ranged from 166–216 g/kg, ash 119–146 g/kg, CF 263–364 g/kg, ADF 279–383 g/kg, NDF 460–605 g/kg, and ADL 36–63 g/kg. DMD increased to 59.1–67.2%, with TDN at 597–713 g/kg, ME at 9.62–10.80 MJ/kg, NEl at 5.63–6.82 MJ/kg, and improved forage quality scores (RFQ 97–151, RFV 91–136). Substrates from 'Sofia' showed a favorable carbon-to-nitrogen ratio of 14–18, with an estimated biomethane yield of 269–322 L/kg dry matter or 315–368 L/kg organic matter. The 'Sofia' cultivar of eastern galega is highly productive and suitable for use in pure stands or mixtures with perennial grasses. Its green mass can be used both as quality forage for livestock and as an efficient substrate for biomethane production.

Key words: *biochemical composition, biomethane, cultivar 'SOFIA', Galega orientalis, nutritive value, productivity*

INTRODUCTION

In the context of economic and environmental concerns surrounding sustainable and resilient agricultural practices, leguminous species (*Fabaceae* family) play a crucial role, mainly due to their nitrogen-fixing ability. Thus, they can reduce dependence on synthetic nitrogen fertilizers and improve the physical and chemical properties of soil. Moreover, leguminous species supply protein and other essential nutrients for human and animal nutrition and provide raw materials for the bioeconomy.

In order to expand the areas cultivated with such crops, it is essential to mobilize and explore new *Fabaceae* species from different floristic regions and to develop high-yielding cultivars that are well-suited to local soil and climate conditions.

Galega orientalis Lam., also known as eastern galega, fodder galega, or goat's rue, is a perennial herbaceous plant belonging to the Fabaceae family and originating from the North Caucasus region. It has sturdy, upright stems that are sometimes slightly wavy at the nodes, branch near the top, and may be either smooth or lightly covered with fine white hairs. The plant typically reaches a height of 0.8 to 2.0 meters and has a stem diameter of 3 to 9 mm at the base. Its leaves are dark green, alternate, and pinnately compound or imparipinnate, with stipules ranging from 5 to 20 cm in length. Each leaf consists of 5 to 10 pairs of oblong-acuminate, mucronate leaflets, measuring 21-60 mm long. The flowers are grouped by 25- 70 in dense and elongated (18-43 cm) terminal racemes. The corolla is blue-lilac, pale blue, or nearly white. The banner is oblong-obovate and blunt, measuring 7-12 mm, while the wings are 9-13 mm long,

featuring elongated auricles at their base. The keel is rounded and roughly the same length as the wings. *Galega orientalis* blooms from May to June and sets fruit in July. Its fruit is a brown, smooth pod that stands upright or lies horizontally, measuring 28-49 mm in length and 2.5-3.2 mm in width. There are 3-8 kidney-shaped, 2.5-4.0 mm long and 1.7-2.0 mm wide seeds per pod. Their colour may vary from yellow to brownish, with smooth, slightly shiny surface. A thousand seeds weigh between 3.2 and 6.5 grams, and seed viability lasts between 4 and 7 years. Pollination is entomophilous (insect-mediated). The plant is a rich source of pollen and nectar for bees over an extended period, offering a honey yield potential of 400-600 kg per hectare.

It develops a branched taproot system that extends 50-135 cm deep, forming a dense root network with adventitious root hairs. This system can support up to 1,500 nodules containing *Rhizobium galegae* bacteria, which fix atmospheric nitrogen at an average rate of 312 kg N/ha/year. Thanks to this regenerative ability via both suckers and dormant buds, the *Galega orientalis* plant develops a vigorous, bushy form, reaching up to 200 stems per square meter by the third year of growth.

Galega orientalis is mesophyte plant, less drought-tolerant than *Medicago sativa* and poorly adapted to prolonged flooding. It can grow in various soil types with pH values between 6.0 and 7.5, provided they are well-drained. The plant responds positively to phosphorus, potassium, and micronutrient fertilization. It reproduces by seeds, which, when freshly harvested, have a hard seed coat and need scarification and inoculation with *Rhizobium galegae* bacteria. Germination can start at soil temperatures of 4-6°C, but optimal seedling emergence occurs at 10-12°C. The seedlings are hardy and can survive winter temperatures of -20°C in open fields and down to -40°C under snow cover. In early spring and late autumn, the plants tolerate frosts as low as -5 to -7°C. *Galega orientalis* is a versatile crop known for several valuable traits, such as early spring growth, rapid development, high biomass yield, rich protein content and excellent nutritional value. It also has strong regenerative ability after cutting, allowing for 2–3 harvests per year. *Galega orientalis* has been studied for various uses, including as forage, medicinal herb, honey plant and energy biomass [19, 20, 50, 42, 3, 32, 33, 5, 30, 16, 22, 8, 9, 13].

The primary aim of this study was to assess the productivity and green mass quality of the local cultivar ‘Sofia’ of *Galega orientalis* (eastern galega), and to explore its potential for use both as animal fodder and as a substrate in biogas reactors for biomethane production as a renewable energy source.

MATERIALS AND METHODS

The local cultivar ‘Sofia’ of *Galega orientalis* (eastern galega) was developed at the “Alexandru Ciubotaru” National Botanical Garden (Institute) of Moldova State University. It was officially registered in 2025 in the Catalogue of Plant Varieties and patented by the State Agency on Intellectual Property of the Republic of Moldova (Plant Variety Patent No. 246/31.03.2025) [29]. Maintained in pure culture on the experimental plots of the National Botanical Garden (Institute) in Chișinău, this cultivar was the subject of the present study.

Green mass samples were collected during the fourth and fifth growing seasons. The first cut was taken at the flowering stage (18.05.2023 and 02.05.2024), the second at the bud stage (18.07.2023 and 20.06.2024), followed by the third cut (20.09.2023 and 03.09.2024), and the fourth cut (30.10.2024).

To determine the leaf-to-stem ratio, leaves and flowers were separated from the stems, weighed individually, and the ratios were calculated based on these weights. For this analysis, 1.0 kg samples of harvested plants were used. Dry matter content was determined by drying the samples at 105°C until a constant weight was achieved.

For biochemical analyses, the fresh biomass samples were dried in a forced-air oven at 60°C. Once dried, the material was finely ground using a laboratory ball mill. Biomass quality was assessed by analyzing several parameters, including crude protein (CP),

crude fiber (CF), total soluble sugars (TSS), crude ash (CA), acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL). These were measured using near-infrared spectroscopy (NIRS) with the PERTEN DA 7200 device at the Research and Development Institute for Grassland in Braşov, Romania. Additional values, such as hemicellulose (HC), cellulose (Cel), digestible dry matter (DDM), digestible energy (DE), metabolizable energy (ME), net energy for lactation (NEl), relative feed value (RFV), total digestible nutrients (TDN), relative forage quality (RFQ), and digestible protein (DP) were calculated using standard procedures.
Carbon content was estimated using an empirical formula from Badger et al. [7], and biochemical methane potential was determined following the method of Dandikas et al. [17].

RESULTS AND DISCUSSIONS

The climatic conditions differed from the norm during the investigation period [11,12], influencing the agro-biological characteristics of plant growth and development, as well as the productivity and quality indices of *Galega orientalis*.
In fourth growing season, 2023y, the growing season began with uniform regeneration from dormant buds, observed between March 23 and 25, followed by stem formation between April 4 and 7. However, an unusual snowfall and a sudden drop in temperatures over the subsequent 15 days slowed the growth rates. The regular growth and accelerated development resumed in the final days of April, once average temperatures stabilized around 15 °C. Flower bud initiation began on May 10 and by May 12 already numerous flower buds were formed. At the time of the first harvest, on May 18, plants had reached a height of 137-140 cm. The green biomass yield was 5.71 kg/m² green mass or 1.17 kg/m² dry matter, with a favorable proportion of leaves and flowers of 58.7% in the harvested forage (Table 1). Post-harvest regeneration of eastern galega was initially slow through the early June. However, growth and development accelerated following the significant rainfall recorded in late June. Over the next 23 days, new shoots reached lengths of approximately 55 cm. The second cut was performed at the budding stage, yielding 1.44 kg/m² of green mass or 0.45 kg/m² of dry matter. This harvest had higher leaf content, with leaves making up to 73% of the biomass. Adverse weather conditions, including prolonged drought and extremely high temperatures (35-40°C) in the 43 days following the second cut, negatively impacted the regeneration and growth of the plants. Improved growth resumed after rainfall at the early September, resulting in semi-erect shoots reaching 35-40 cm in height. The third harvest produced 0.60 kg/m² of green mass or 0.17 kg/m² of dry matter. Cumulatively, the total annual productivity in fourth growing season from the three harvests was 7.75 kg/m² of green biomass and 1.79 kg/m² of dry matter.
The year 2024 was marked by average temperatures above 0°C during January and February, which led to an earlier than usual resumption of growth in *Galega orientalis* during its fifth growing season. Vegetative growth began in the final days of February to early March. Average daytime temperatures ranging from 9 to 18 °C accelerated plant growth and development, resulting in the onset of budding and full flowering stages 13 to 16 days earlier than usual. At full flowering during harvest, the plants grew to a height of 125-130 cm, producing a green mass yield of 4.82 kg/m² and a dry matter yield of 1.09 kg/m². Leaves and flowers made up 54.9% of the total biomass harvested. Following the first cut, regrowth was uneven initially, but new shoot development sped up throughout June. By mid to late June, the plants had reached 57-63 cm in height, with flower buds beginning to form. The harvest during this period yielded 1.69 kg/m² of green mass and 0.44 kg/m² of dry matter, with leaves making up 60.9% of the harvested biomass. During July - August, extreme temperatures (35-41 °C), combined with drought and heat stress, significantly slowed plant development. As a result, the *Galega orientalis* harvesting in early September produced 1.04 kg/m² of green mass and 0.24 kg/m² of dry matter. September 2024 was marked by abundant precipitation and

favourable temperatures, and no hoarfrosts were recorded. These conditions continued through October, promoting uniform regrowth after the third cut. By the end of October, plants had reached a height of 64 cm, with a yield of 2.81 kg/m² of green mass and 0.17 kg/m² of dry matter. Leaves comprised 67.4% of the harvested biomass, providing valuable green fodder for farm animals during this season of the year. The combined yield from all four cuts during the fifth growing season totalled 10.36 kg/m² of green biomass and 2.08 kg/m² of dry matter.

Table 1. Biological characteristics and yield of the 'Sofia' cultivar of *Galega orientalis* in the 2023-2024 growing seasons

Harvest time	Plant height, cm	Yield, kg/m²		Content of leaves and flowers in fodder, %
		fresh mass	dry matter	
Fourth growing season, 2023 year				
18.05.2023 first cut	*139*	*5.71*	*1.17*	*58.6*
18.07.2023 second cut	*55*	*1.44*	*0.45*	*73.0*
20.09.2023 third cut	*37*	*0.60*	*0.17*	*68.3*
Total		*7.75*	*1.79*	
Fifth growing season, 2024 year				
02.05.2024 first cut	*128*	*4.82*	*1.23*	*54.9*
20.06.2024 second cut	*58*	*1.69*	*0.44*	*60.9*
03.09.2024 third cut	*35*	*1.04*	*0.24*	*54.2*
30.10.2024 fourth cut	*64*	*2.81*	*0.17*	*67.4*
Total		*10.36*	*2.08*	

Source: Own calculation.

Several authors have reported various findings on the productivity of *Galega orientalis* under varying environmental and soil conditions. According to Adamovics et al. [3] "pure *Galega orientalis* swards produced 50.81 t/ha of fresh biomass and 12.16 t/ha of organic dry matter". Slepetys [37] reported that "*Galega orientalis* produces the largest portion of its total herbage yield at the first cut, accounting for 41.9-69.4% of the annual yield. The second cut contributes a smaller share, between 16.0–25.7%, while the third cut in autumn provides 8.2–33.6%. The highest productivity, reaching 11.9 t/ha, was observed after 10–11 growing years". According to Avetisyan [6] "the first cut of *Galega orientalis* yielded 28.6 t/ha of green mass (7.72 t/ha dry matter), and the second cut produced 14.0 t/ha of green mass (3.3 t/ha dry matter)". Zielewicz et al. [52] noted that "the dry matter yields of 7.48 t/ha at the first cut, 2.15 t/ha at the second, and 3.98 t/ha at the third cut". Teleuţă et al. [43] reported that "the annual forage productivity of the 'Speranţa' cultivar of *Galega orientalis* was 79.8 t/ha of green mass and 16.2 t/ha of dry matter". Zavyalova et al. [51] found that "the dry mater yields of galega in the 12-th and 24-th production years were only 9.90 and 10.05 t/ha, respectively, with a mean dry matter content of 23.5%". Povilaitis et al. [31] noted that "the dry matter yield of *Galega orientalis* ranged between 8.0 and 9.3 t/ha". Slepetys & Adamovics [38] reported that "dry matter yields of fodder galega cut three times in the second harvest year was 6.51 t/ha, while in the tenth year 11.28 t/ ha". Hein and Wasch [21] revealed that "the yield of *Galega orientalis* mown in May was 37.6t/ha fresh mass or 9.4 t/ha dry matter". Symanowicz et al. [41] noted that "the dry matter yield of eastern galega peaked in the fourth and fifth year of vegetation, 16.8–16.9 t/ha". In our earlier study [44], we observed that the 'Speranţa' cultivar reached a productivity of 101.5 t/ha of green mass and 20.3 t/ha of dry matter in its seventh growing season. Cherniavskih et al. [13] reported "dry matter yields of 639.0 g/m² at the first cut and 439.5 g/m² at the second cut". Dubis et al. [19] reported that "fresh matter yield of fodder galega peaked in the 4-th year of production (69.1-71.0 t/ha)". Rakhmetov et al. [32] reported that "newly developed cultivars of *Galega orientalis* demonstrated green mass productivity ranging from 28.6 to 62.4 t/ha and dry matter yields of 7.12 to 16.5 t/ha. These cultivars also exhibited a biomass composition of 40.9-51.4% leaves and 11.6-14.9% inflorescences." Similarly, Ignaczak et al. [22] observed that "*Galega orientalis* plants at the first cut reached heights of 90-119 cm, with dry matter yields ranging from 0.544 to 0.748 kg/m². At the second cut, plant height ranged from 58-67 cm, and dry matter yield ranged from 0.257 to 0.315 kg/m²." In another study, Biligetu et al. [8] found that "*Galega orientalis* yield at the first cut was 5.39 t/ha dry

matter, and at the second cut 2.51 t/ha dry matter." Tóth [47] mentioned that dry matter yield potential of eastern galega varied from 2.69 to 21.30 t/ha in the first cut, and from 1.05 to 9.06 t/ha in the second cut, in dependence of nutrition treatments, and the sites and grow years as well.

Table 2. Nutritional profile and forage quality of 'Sofia' *Galega orientalis* during the 2023–2024 growing seasons

Indices	Fourth growing season			Fifth growing season			
	first cut	second cut	third cut	first cut	second cut	third cut	fourth cut
Crude protein, g/kg DM	*172*	*181*	*187*	*176*	*188*	*166*	*216*
Crude fibre, g/kg DM	*346*	*276*	*263*	*333*	*338*	*364*	*264*
Minerals, g/kg DM	*114*	*120*	*119*	*114*	*122*	*146*	*126*
Acid detergent fibre, g/kg DM	*377*	*313*	*305*	*335*	*369*	*383*	*279*
Neutral detergent fibre, g/kg DM	*592*	*486*	*516*	*542*	*582*	*605*	*460*
Acid detergent lignin, g/kg DM	*58*	*53*	*45*	*56*	*50*	*63*	*36*
Cellulose, g/kg DM	*319*	*260*	*260*	*297*	*319*	*320*	*243*
Hemicellulose, g/kg DM	*215*	*173*	*211*	*187*	*213*	*222*	*181*
Digestible dry matter, g/kg DM	*595*	*645*	*651*	*628*	*602*	*591*	*672*
Relative feed value	*94*	*123*	*117*	*108*	*96*	*91*	*136*
Total digestible nutrients, g/kg DM	*606*	*677*	*687*	*651*	*612*	*597*	*713*
Relative Forage Quality	*100*	*136*	*130*	*129*	*111*	*97*	*151*
Digestible dry matter, g/kg DM	*11.78*	*12.68*	*12.78*	*12.38*	*11.91*	*11.71*	*13.15*
Metabolizable energy, MJ/ kg	*9.67*	*10.41*	*10.50*	*10.16*	*9.78*	*9.62*	*10.80*
Net energy for lactation, MJ/ kg	*5.70*	*6.43*	*6.52*	*6.18*	*5.79*	*5.63*	*6.82*

Source: Own calculation.

The biochemical composition of dry matter is a key parameter in evaluating feed quality. The quality indicators of the harvested green mass from the local cultivar 'Sofia' of *Galega orientalis* are presented in Table 2. Our analysis revealed that the dry matter content and quality parameters varied depending on the growing season and cut period. In fifth growing season the dry matter from the first cut exhibited high levels of crude protein, and lower level of crude fibre, structural carbohydrates and acid detergent lignin, but high amount of total digestible nutrients which have a positive effect on the forage value and energy supply of the feed, compared to fourth growing season. The forage from second cut in fourth growing season was characterized by lower concentrations of structural carbohydrates and higher nutritive and energy value than forage from fifth growing season. In forage from the third cut, fifth growing season, showed the lowest crude protein content and the highest acid detergent lignin concentration, this composition had a negative impact on digestibility, nutritional value, and energy availability of the feed. The *Galega orientalis* fodder from fourth cut is characterized by very high amount of crude protein and lower level of crude fibre, structural carbohydrates and acid detergent lignin which have a positive effect on the nutritional and energy value. Various studies have reported differing results regarding the biochemical composition and nutritional value of *Galega orientalis* forage. According to Skórko-Sajko et al. [34] "the dry matter of *Galega orientalis* forage contained 906.9 g/kg OM, 245.5 g/kg CP, 57.4 g/kg PDIA, 150.1 g/kg PDIN, 103.4 g/kg PDIE, with 0.77 UFL/kg, 0.70 UFV/kg and 1.19 CFU/kg". Slepetys [37] mentioned that "dry matter quality indicators of galega herbage of the third cut was 143-189 g/kg CP, 302-328 g/kg CF, 54.6-63.0% IVDDM, and 9.49-10.39 MJ/kg ME". Bull et al. [9] reported that the "dry matter and chemical composition of the fodder galega biomass from first cut was 149-157g/kg DM with 20.7-20.9 % CP, 1.7-2.3 % EE, 34.3-37.5 % CF, 8.0-8.5 % ash, while from second cut respectively 253-356g/kg DM, 14.7-15.1 % CP, 1.8-2.1 % EE, 28.2-31.0 % CF, 9.0-9.9 % ash". Truzina et al. [48] reported that "*Galega orientalis* forage cut in early flowering period contained 220.2 g/kg CP, 44.8 g/kg EE, 301.7 g/kg CF, 362.2 g/kg NFE and 71.1 g/kg ash". Zielewicz et al. [52] remarked that "the concentration of nutrients in the galega dry matter first cut was 12.67% CP, 1.63 % sugars, 28.77 % Cel, 15.93 % HC, 8.95 % ash, 4.04 % lignins, but in second cut 13.31% CP, 3.36 % sugars, 28.89 % Cel, 16.43

% HC, 9.83 % ash, 3.53 % lignins, while in third cut 19.02% CP, 2.78 % sugars, 30.71 % Cel, 14.59 % HC, 8.23 % ash, 3.59% lignins". Teleuţă et al. [42] reported that "the first cut forage from *Galega orientalis* contained 17.80% CP, 3.55% EE, 30.56% CF, 39.47% NFE, 8.69% ash, and 147 g digestible protein per nutritive unit". Hein and Wasch [21] revealed that "the nutrient content of *Galega orientalis* dry matter was 14.21-18.69% CP, 1.54-2.09% EE, 20.39-32.49% CF, 36.29-49.55% NFE, 9.28-11.43% ash, 10.95-18.78 g/kg Ca, 3.00-4.09 g/kg P". According to Skórko-Sajko et al. [35] "the chemical composition and nutritional value of *Galega orientalis* green forage mowing in beginning of flowering period was: 178.9g/kg DM, 89.39% OM, 22.97% CP, 3.33% EE, 52.80% NDF, 35.38% ADF, 3.81-4.52% ADL, 17.00% Cel, 30.85% HC, 34.68% NFE, 4.78% soluble sugars, 18.58 MJ/kg GE, 9.62 MJ/kg ME, 5.65MJ/kg NEl, 5.4MJ/kg NEm, 0.79 UFL, 0.76 UFV". Coşman et al. [16] analyzed that "the cultivar 'Speranţa' and reported that, at the first cut, dry matter content ranged from 125.2-180.7 g/kg, with 16.18-22.94% CP, 3.26-3.90% EE, 31.95-36.85% CF, 46.5-57.9% NDF, 28.8-37.7% ADF, 3.9-6.3% ADL, 32.18-38.06% NFE, 7.51-8.86% ash, 64.0-82.0% DDM, and RFV ranging from 97 to 133". Meripõld et al. [26] noted that "the forage at the first cut contained 17.0-17.8% CP, 48.9-49.5% NDF, and 40.8-43.9% ADF. Chornolata et al. [14, 15] found that *Galega orientalis* had 16.86-19.07% CP, 15.10-18.10% Cel, 12.20-14.48% HC, 6.50-7.10% lignin, 6.20-6.40% sugars, 4.90% starch". Kuchin and Ivashin [25] observed that "nutrient concentrations in *Galega orientalis* dry matter differed with phenological stage. In the budding phase, forage contained 19.4-21.6% CP, 2.29-3.07% EE, 19.6-23.0% CF, 46.5-51.6% NFE, 6.1-6.9% ash and 10.8-11.5 MJ/kg ME. During the flowering stage, CP decreased to 14.4-16.7%, CF increased to 24.8-26.4% and ME declined to 10.2-10.6 MJ/kg". Burykina [10] stated that "the forage from *Galega orientalis* contained 3.04-3.08% N, 33.08-38.88% CF, 21.50-21.66% Cel, 6.04-7.21% HC, 11.00-13.43% lignin, 2.04-2.75% sugars, 0.55-0.70% starch". Nechunaev and Falaleeva [28] reported that "*Galega orientalis* forage had 271.3 g/kg CP, 57.7 g/kg EE, 264.1 g/kg CF, 299.7 g/kg NFE, 109.4 g/kg ash, 16.2 g/kg Ca, 3.4 g/kg P, and 9.8 MJ/kg ME. Darmohray et al. [18] found that "*Galega orientalis* harvested at the early flowering stage contained 21.09% CP, 2.95% EE, 27.29% CF, 60.55% NDF and 5.18% ash". Simonov et al. [33] reported that "the investigated *Galega orientalis* cut in the budding - beginning of flowering stage had 140-200 g/kg DM with 25-26 % CP, 3-6 % sugars, 25-30 % CF, 0.72-0.74 nutritive units, 160-260 g digestible protein per nutritive unit and 9.0-9.7 MJ/kg ME". According to Ignaczak et al. [22], "at the first cut, whole plants of *Galega orientalis* contained 168-278g/kg DM with 15.7-23.3% CP, 45.8-52.7% NDF, 32.7-37.8% ADF, 6.0-7.5% ash, and 729-800 g/kg IVTD." At the second cutting, the forage was found to contain 227-245 g/kg DM, 17.2-17.7% CP, 48.7-49.9% NDF, 33.8-34.0% ADF, 7.7-7.9% ash, and 757-791 g/kg IVTD [22]. Ababii et al. [1] noted that "*Galega orientalis* forage dry matter had 23.4% CP, 10.5% ash, 28.8% ADF, 3.6% ADL, 47.7 % NDF, 25.2% Cel, 18.9% HC, 66.0%DDM, RFV= 128, 10.63 MJ/kg ME and 6.76 MJ/kg NEl". Tóth [47] reported that "the lignocellulosic composition of green phytomass from *Galega orientalis* included 24.68-49.89% ADF, 34.56-61.69% NDF, 4.98-14.16% ADL, 18.74-40.09% Cel, and 9.17-18.01% HC with gross energy value 14.871- 19.707 MJ/kg". Biligetu et al. [8] found that "galega forage dry matter had 10-17 % CP, 20-29 % ADF and 36-46 % NDF". Kosolapova et al. [24] remarked that "harvested mass of goat's rue contained 240.3 g/kg DM, 15.77 % CP, 1.92% EE, 19.13 % CF, 4.7 % sugars, 9.0 % ash, 118.00 g DP, 0.88 nutritive units and 9.76 MJ/kg ME. Pap et al. [30], reported that green biomass from fodder galega had 128 g/kg DM, 27.0% CP and 8.3% ash". In recent years, the considerations for the use of *Fabaceae* species for biomass feedstock have increased considerably, in special for biogas production, which has a great importance and can successfully replace natural gas to obtain

electric power and heat, transport fuel. The methane yield depend mainly on biochemical composition, degradability and ratio of carbon and nitrogen (C/N) from the substrates for anaerobic digestion. The quality indices of fresh mass substrates from *Galega orientalis* are presented in Table 3. The ratio of carbon to nitrogen in the studied substrates is optimal and varied from 14.05 to 17.86. The concentration of acid detergent lignin range from 36 to 63 g/kg and the hemicellulose levels between 173 and 222 g/kg dry matter. The biochemical methane potential varied from 269 to 322 l/kg dry matter or 315-368 l/kg organic matter. The lowest results were achieved in the third-cut-substrate, fifth growing season, with rather high concentration of acid detergent lignin. The biochemical methane potential of the studied *Galega orientalis* first-cut-substrates did not show significant variation between years, however, second- and third-cut substrates demonstrated higher methane values in the fourth growing season. Notably, *Galega orientalis* substrates obtained from fourth-cut biomass were characterized by very high crude protein content and lower concentration of acid detergent lignin, and demonstrated high biochemical methane potential.

Table 3. Seasonal variation in biochemical methane potential of *Galega orientalis* 'Sofia' substrates (2023-2024y.)

Indices	Fourth growing season			Fifth growing season			
	first cut	second cut	third cut	first cut	second cut	third cut	fourth cut
Organic dry matter, g/kg	*886*	*880*	*881*	*886*	*878*	*854*	*874*
Minerals, g/kg DM	*114*	*120*	*119*	*114*	*122*	*146*	*126*
Crude protein, g/kg DM	*172*	*181*	*187*	*176*	*188*	*166*	*216*
Nitrogen, g/kg DM	*27.52*	*28.96*	*29.92*	*28.16*	*30.08*	*26.56*	*34.56*
Carbon, g/kg DM	*492.22*	*488.89*	*489.44*	*492.22*	*487.78*	*474.44*	*485.56*
Ratio carbon/nitrogen	*17.89*	*16.32*	*16.36*	*17.48*	*16.22*	*17.86*	*14.05*
Hemicellulose, g/kg DM	*215*	*173*	*211*	*187*	*213*	*222*	*181*
Acid detergent lignin, g/kg DM	*58*	*53*	*45*	*56*	*50*	*63*	*36*
Biomethane potential, L/kg DM	*287*	*292*	*306*	*289*	*298*	*269*	*322*
Biomethane potential, L/kg ODM	*324*	*332*	*347*	*326*	*340*	*315*	*368*

Source: Own calculation.

Several studies have also explored the biomethane production potential of *Galega orientalis* biomass. Dubrovskis et al. [20] reported that "galega substrates achieved a methane yield of 384.2 L/kg VS". Adam [2] found the "methane yield in batch test for *Galega* substrate a first cut was 412 L/kg VS and 282 L/kg VS for a second cut". Bull et al. [9] found the "methane yield of *Galega orientalis* first cut substrates was 270.9-288.6 L/kg ODM, while second cut substrates 303.2-315.1 L/kg ODM". According to Adamovics et al. [3] "a substrate mixture containing 75% galega and 25% cow manure produced the highest biogas yield: 628 m³/t DOM, with a methane content of 61.2% during anaerobic digestion". Mihić et al. [27] found that "the biogas potential of the substrate from *Galega orientalis* was 610 l/kg ODM with 62.6% methane". Slepetiene et al. [36] reported that "the chemical composition of the biomass substrate from fodder galega 3-rd cut was 3.129% N, 47.44% C, 45.16% NDF, 43.45% ADF, 14.85%% ADL, 8.33% ash, 5.83%WSC, 1.71% HC and 28.60% Cel". Povilaitis et al. [31] analyzed the elemental composition of fodder galega and found "nitrogen levels of 2.71-2.99%, carbon 43.67-47.35%, sulfur 0.13-0.17%, and a C/N ratio of 15.91-16.33". Ababii et al. [1] remarked that "*Galega orientalis* substrate had 23.4% CP, 10.5% ash, 3.6% ADL, 18.9% HC, C/N=13 and biochemical methane potential was 371/kg VS". Vishnevskaya [49] noted that "substrates derived from *Galega orientalis* plants had a methane yields 291-301 l/kg VS, while substrates from *Dactylis glomerata* plants yielded 241-237 l/kg VS". In an earlier paper by Titei and Roşca [45], it was mentioned that "substrates derived from *Galega orientalis* plants had 300–360 l/kg biometan potential".

The economic significance of harvested mass from the local cultivar 'Sofia' of *Galega orientalis* is shown in Table 4. We would like to mention that estimated economic potential of green forage from the 'Sofia' cultivar is reflected in the following indicators: 3,141-3,757 kg/ha/year of crude protein or 2,544-

3,343.4kg/ha/year of digestible protein, 192.5-209.5 GJ/ha/year of metabolizable energy, and 106.6-126.6 GJ/ha/year of net energy for lactation. The biomethane yield potential from green mass substrates is estimated at 5,190-6,060 m³/ha/year. According to Adamovics et al. [4] "the average pure galega yield was 8.97 t/ha DM or 1.94 t/ha CP on stagnic luvisol in a two-cutting management in 25 years". Slepetys [39] remarked that "pure *Galega orientalis* yielded 658 kg/ha CP, 444 kg/ha digestible protein and 38.46 GJ/ ha ME, while in mixed sward, respectively 716-1004kg/ha CP, 477-643 kg/ha digestible protein and 47.79-60.29 GJ/ ha ME". Šlepetys & Adamovics [40] mentioned that "herbage yield and energy value of the third cut of galega of the 2-nd -5-th year of use was 1.21-1.42 t/ha DM, 11.44-13.59 GJ/ ha ME, while in 10th -13th year of use, respectively 1.72-1.95 t/ha DM, 16.12-19.33 GJ/ ha ME". Teleuţă et al. [43] found that "the annual forage productivity of of *Galega orientalis* 'Speranţa' was 15.1 t/ha nutritive units provided with 2,176 kg/ha digestible protein". Tkachuk and Vergelis [46] reported that "during the second and third years of vegetation, the annual nutrient yield of *Galega orientalis* was 6.9–8.5 t/ha DM, 71.90–89.57 GJ/ha ME, 6.9–8.5 t/ha feed units, and 880–1,090 kg/ha digestible protein." In comparison, *Medicago sativa* produced 7.8–9.2 t/ha DM, 72.54–85.57 GJ/ha ME, 7.0–8.2 t/ha feed units, and 1,400–1,666 kg/ha digestible protein, while *Trifolium pratense* yielded 8.4–8.9 t/ha DM, 78.12–88.09 GJ/ha ME, 7.5–8.5 t/ha feed units, and 1,190–1,340 kg/ha digestible protein [46]. Symanowicz et al. [41] remarked that "energy yields value of eastern galega in the fourth and fifth year of vegetation was 312.34-314.96 GJ/ha". Dubis et al. [19] reported that "the energy output of fodder galega peaked in the 4-5 years of cultivation was 122.4-131.1GJ/ha". Vishnevskaya [49] noted that "the substrates derived from *Galega orientalis* plants achieved 1,870-1,915 m^3/ha methane and estimated energy out of one hectare 77.78-81.14 GJ/ha, while substrates from *Dactylis glomerata* respectively 795-1,089 m^3/ha methane and 33.62-45.30 GJ /ha". Kobyrenko [23] revealed that "fodder productivity of *Galega orientalis* was 9.45-10.65 t/ha fodder units and 1.1-1.6 t/ha digestible protein".

Table 4. The economic significance of harvested mass from the local cultivar 'Sofia' of *Galega orientalis*

Indices	Fourth growing season			Fifth growing season			
	first cut	second cut	third cut	first cut	second cut	third cut	fourth cut
Crude protein, kg/ha	2,012.0	811.0	318.0	2,164.8	827.2	398.4	367.2
Digestible protein, kg/ha	1,630.0	657.0	257.0	1,753.0	670.0	323.0	297.4
Metabolizable energy, GJ/ha	113	57.8	21.7	125	43.0	23.1	18.4
Net energy for lactation, GJ/ha	66.7	28.8	11.1	76.0	25.5	13.5	11.6
Biomethane potential, m^3/ha	3,358	1,308	520	3,555	1311	645	547

Source: Own calculation.

CONCLUSIONS

The new local cultivar 'Sofia' of *Galega orientalis*, during its fourth and fifth growing seasons, produced 3-4 cuts per year, yielding an annual total of 7.75-10.36 kg/m² of green mass or 1.79–2.08 kg/m² of dry matter.

The harvested green mass can be used either as forage for farm animals or as a substrate in biogas reactors for biomethane production.

The estimated economic value of green forage from the 'Sofia' cultivar is reflected in the following indicators: 3,141-3,757 kg/ha/year of crude protein, 2,544-3,343.4kg/ha/year of digestible protein, 192.5-209.5 GJ/ha/year of metabolizable energy, and 106.6-126.6GJ/ha/year of net energy for lactation. The biomethane yield potential from green mass substrates is estimated at 5,190-6,060 m³/ha/year. The new local cultivar 'Sofia' of eastern galega stands out for its high productivity and can be used either in pure stands or in mixtures with perennial grasses for the establishment of temporary grasslands.

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BIOMASS PRODUCTIVITY AND QUALITY OF *GLYCINE MAX* AND *LABLAB PURPUREUS* GROWN IN THE REPUBLIC OF MOLDOVA

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Abstract

The main goal of this study was to determine the productivity and quality parameters of green biomass and silage derived from soybean Glycine max and lablab Lablab purpureus plants grown under the agroecological conditions of the Republic of Moldova. The main indicators of dry matter composition analyzed have been: crude protein, crude fibre, ash, acid detergent fibre, neutral detergent fibre, acid detergent lignin, were determined by near infrared spectroscopy. The concentration of hemicellulose, cellulose, carbon, digestible energy, metabolizable energy, net energy for lactation, digestible dry matter, relative feed value and the biochemical methane potential were calculated according to standard procedures. The results of our research showed that the productivity of Glycine max was 3.83 kg/m², with a 28.0% dry matter, whereas Lablab purpureus produced 5.67 kg/m² of fresh mass, with 22.6% dry matter. The analysis of the dry matter composition of both species revealed that it contained 175-176 g/kg CP, 86-90 g/kg ash, 261-310 g/kg CF, 281-332 g/kg ADF, 453-520 g/kg NDF, 44-61 g/kg ADL, 237-271 g/kg Cel, 171-188g/kg HC with 630-670g/kg DDM, RFV=113-138, 10.19-10.78MJ/kg ME, 6.21-6.80 MJ/kg NEl. The main quality indices of the silage mass were the following: pH =4.11-4.54, 12.2 g/kg acetic acid, 41.6-49.3 g/kg lactic acid, 0.2-0.9 g/kg butyric acid, 161-186g/kg CP, 126-129g/kg ash, 273-281 g/kg CF, 286-307 g/kg ADF,456- 510 g/kg NDF, 37-41 g/kg ADL, 245-270g/kg Cel, 170-203 g/kg HC with 650-676 g/kg DMD, RFV= 119-145, 10.48-10.87 MJ/kg ME, 6.50-7.31 MJ/kg NEl. The fresh and ensiled mass substrates from Glycine max and Lablab purpureus for anaerobic digestion had optimal C/N ratio, of 16.3-18.9, and the biochemical methane potential varied from 318 to 359 l/kg VS.

Key words**:** *biochemical composition, biomethane potential, Glycine max, green mass, Lablab purpureus, productivity, nutritive value, silage*

INTRODUCTION

To ensure sustainable agricultural development and the efficient production of meat, milk, and other animal-derived materials used across various industries, livestock farmers need a low-cost, easily accessible forage source that is rich in protein and vital nutrients to maintain animal health and productivity. Identifying alternative forage crops that require less nitrogen fertilizer yet deliver high protein yields is crucial for enhancing livestock farming and long-term agricultural sustainability.

Plants from the *Fabaceae* family are a significant protein source, vital for both human and animal diets, also as feedstocks for the circular economy. Introducing and utilizing new *Fabaceae* species is seen as a key strategy in intensifying agricultural output. They can enhance soil fertility, reduce dependency on chemical fertilizers, and offer protein and amino acid-rich food and fodder. *Fabaceae* plants contribute substantially to sustainable agriculture because of their symbiosis with nitrogen-fixing bacteria. This relationship improves soil structure and fertility, helps prevent erosion and plant root diseases, and positively affects the yield and quality of crops grown subsequently on the same land [20, 21]. The genus *Glycine* Willd. is one of the most important genera within the Fabaceae family. It is classified into two subgenera: *Glycine* Willd., which consists of 25 to 30 wild perennial species, and *Soja* (Moench) F.J. Herm., which includes two annual species – *Glycine max* (L.) Merr. and *Glycine soja* Sieb. and Zucc. Soybean, *Glycine max* (synonyms include *Glycine hispida, Glycine angustifolia, Soja japonica; Dolichos sofa Linn.; Phaseolus max Linn.*) is native to East Asia and was first domesticated in ancient China around 1100

B.C. It was introduced to Europe in the 18th century. *Glycine max* is an annual herbaceous plant with robust, erect and pubescent stems ranging from 0.3 to 2 meters in height, covered with reddish-brown hairs. The leaves are pinnately trifoliolate with ovate to elliptical leaflets measuring 3-15 cm in length. Stipules are broadly ovate, 3-7 mm long, acuminate and densely covered with yellow villous hairs. Petioles range from 2 to 20 cm in length. The inflorescence is a raceme bearing 5-8 flowers, with a 13.5 cm peduncle. Bracts are lanceolate (2-3 mm), strigose; the calyx measures 5-7 mm long. Corolla colours vary – violet, pink, or white – and are 5.5-7 mm long. The fruit is an oblong, slightly curved, pendulous pod measuring 2.5-8.5 cm long and 8-15 mm wide, densely covered with silky hairs. Each pod contains 2-5 seeds, which are elliptic, suborbicular, or ovate to oblong in shape (6-11 mm), and exhibit a variety of colours. The testa (seed coat) is smooth, and the hilum is prominent and elliptic.

Soybean is recognized as one of the most valuable agricultural crops for both human and animal nutrition. Its seeds are rich in protein (35-42%), oil (18-23%), and a variety of other nutrients that support health. Beyond its nutritional value, soybean is also widely used as a raw material in industrial applications, bioenergy production, and livestock forage. It offers a reliable supply of nutritious forage in late summer and autumn, especially when other options like brassicas, perennial grasses, and legumes are no longer accessible. Harvested *Glycine max* plants can be used in several forms: as fresh biomass, hay, silage, or as a protein-rich supplement to low-protein forages [1, 8, 9, 11, 24, 38].

Lablab purpureus (L.) Sweet (syn. *Dolichos purpureus* L., *Dolichos lablab* L.; *Dolichos bengalensis* Jacq., *Lablab leucocarpos* Savi, *Lablab niger* Medik., *Lablab vulgaris* Savi) is has several common names, such as Egyptian kidney bean and hyacinth bean. It is an ancient domesticated crop with a wide distribution across Africa, the Indian subcontinent and Southeast Asia. It is generally a summer-growing annual legume, though it can sometimes survive as a short-lived perennial. This forage plant is herbaceous and may grow as a twining, climbing, trailing, or upright form, reaching lengths of 3 to 6 meters. Its leaves are alternate and trifoliate, with rhomboid-shaped leaflets that range from 7.5 to 15 cm long and 1.5 to 14 cm wide, tapering to a pointed tip. The upper leaf surface is smooth, while the underside has is covered with short hairs. The plant produces multi-flowered racemes on long peduncles. Its flowers, about 1.5 cm in length, vary in color from white to blue or purple. Pollination is predominantly allogamous (cross-pollination). The pods exhibit variability in shape and colour; they may be flat or inflated, straight or curved, and range from 5 to 20 cm in length and 1-5 cm in width. Typically, each pod contains 3-6 ovoid, laterally compressed seeds, measuring 0.5-1.2 cm in length, 0.3-0.9 cm in width, and 0.2-0.7 cm in thickness. Seed colours vary widely, including white, cream, light to dark brown, red, black, as well as mottled combinations. The weight of 1,000 seeds can range from 60 to 1,000 grams. Germination is epigeal and typically occurs within five days. Lablab is a short-day plant requiring high temperatures for optimal growth, ideally between 18–30°C, with a minimum threshold of 3°C. It is adaptable to a broad range of soil textures and pH levels (5.9 to 7.8), from deep sandy soils to heavy clays, provided that the soils are well-drained. It develops a strong taproot system with numerous lateral and adventitious roots, enabling it to extract water from soil depths of at least two meters, thus efficiently utilizing residual moisture. The species is effective in suppressing weeds and controlling soil erosion. Additionally, it is a strong nitrogen fixer, forming symbiotic associations with *Bradyrhizobium lablabi* and *Rhizobium leguminosarum*. *Lablab purpureus* is also a suitable candidate for intercropping with grasses, maize and sorghum. As a multipurpose legume, lablab serves various functions: it is consumed as a pulse in human diets, used as fodder for livestock, employed in rotational cropping and as a cover crop, and acts as a pioneer species for improving soil fertility and organic matter content. For

livestock production, lablab can be utilized as hay, silage, crop residue, or grazed directly. It may also be incorporated into feed mixtures [4, 25, 31, 35, 36, 48].

The primary objective of this study was to assess the productivity and quality parameters of green biomass and silage derived from soybean (*Glycine max*) and lablab (*Lablab purpureus*) cultivated under the agroecological conditions of the Republic of Moldova. The study also aimed to evaluate their potential as forages, also as substrates for biomethane production, contributing to renewable energy development.

MATERIALS AND METHODS

The leguminous crops: local cultivar 'Aura' of soybean (*Glycine max*), created at the "Selectia" Research Institute of Field Crops Bălți and the introduced ecotype of lablab (*Lablab purpureus*) grown in monoculture on the experimental land of National Botanical Garden (Institute) Chișinău, MSU, Republic of Moldova, served as research subjects and the traditional forage crops: alfalfa (*Medicago sativa*) and corn (*Zea mays*) were used as control variants. The experiment was set up using a method where the test areas were arranged in groups, with four repetitions of each setup. Each test area was 10 m^2 in size. Lablab and soybean were sown in early May, at a depth of 4.0 cm, in rows at a distance of 45 cm, while corn was sown in early May with a row spacing of 70 cm.

Green biomass was harvested manually. Soybean and lablab samples were collected at the early pod stage, corn at the kernel milk stage, and alfalfa at the third cut. The leaf-to-stem ratio was calculated by first separating the leaves from the stems, weighing each part separately, and then comparing the weight of the leaves to that of the stems.

The harvested plants were chopped into 1.5-2.0 cm pieces using a laboratory forage chopper. The dry matter content was determined by drying the samples at 105°C until a constant weight was achieved. The silage was prepared from whole plants, cut into small pieces and compressed in glass containers. The containers were stored for 45 days, and then, they were opened and the organoleptic assessment and the determination of the organic acid composition of the persevered forage were done in accordance with the Moldavian standard SM 108*. For biochemical analysis, the fresh and ensiled mass were dried in a forced air oven at 60°C, milled in a beater mill equipped with a sieve with mesh diameter of 1 mm and some of the main biochemical parameters, such as crude protein (CP), crude fibre (CF), ash, acid detergent fibre (ADF), neutral detergent fibre (NDF), acid detergent lignin (ADL), were determined by near infrared spectroscopy (NIRS) using PERTEN DA 7200. The concentration of hemicellulose (HC), cellulose (Cel), digestible energy (DE), metabolizable energy (ME), net energy for lactation (NEl), digestible dry matter (DDM) and relative feed value (RFV) were calculated according to standard procedures.

The carbon content of the substrates was determined using an empirical equation according to Badger et al. [12]. The biochemical methane potential was calculated according to Dandikas et al. [18].

RESULTS AND DISCUSSIONS

An analysis of the biomorphological characteristics of the studied leguminous crops revealed that, at the time of harvest, *Glycine max* plants reached heights of 107-113 cm, while *Lablab purpureus* plants attained lengths of 217-249 cm. The fresh biomass yield for *Glycine max* was 3.83 kg/m², with a dry matter content of 28.0%, whereas *Lablab purpureus* produced 5.67 kg/m² of fresh mass, with 22.6% dry matter. The harvested biomass of *Lablab purpureus* consisted of 68.57% leaves, flowers and pods, compared to 61.7% for *Glycine max*. Variations in biomass yield of *Lablab purpureus* and *Glycine max* based on cultivar and cultivation practices are well-documented in the scientific literature. Açikgöz et al. [1] observed dry matter yields varying from 8.25 to 15.80 t/ha. According to Mihailovic et al. [32], the highest dry matter yield recorded for soybean forage was 18 t/ha. Lee et al. [30] found that cultivated soybeans produced fresh forage yields of 4.4-16.3 t/ha and dry matter

yields of 0.9-4.9 t/ha, whereas wild soybeans yielded 6.1-9.9 t/ha of fresh forage and 1.3-2.9 t/ha of dry matter. Serbester et al. [39] reported that monocropped soybean yielded 29.9-32.5 t/ha of green forage and 5.9-7.8 t/ha of dry matter. Surmen & Kara [42] found that pure soybean stands produced 15.2-25.2 t/ha of green mass. Bah et al. [13] indicated that dry matter yield lablab plants differed significantly at different stages of growth from 2,557 to 3,188 kg/ha. Thu Hong et al. [46] reported a soybean foliage yield of 38.9 t/ha with a dry matter content of 23.9%. Homan et al. [26] demonstrated that forage soybeans grown in monoculture reached 134.8 cm in plant height and yielded 32.9 t/ha of biomass and 9.7 t/ha of dry matter. Adem et al. [2] reported that dry matter of lablab accessions varied from 11.21 to 19.60 t/ha. Iqbal et al. [27] documented soybeans forage productivity between 21.0 and 28.8 t/ha of green mass and 5.1-7.3 t/ha of dry matter. Mossie et al. [34] indicated that soybean herbage dry matter yields ranged from 6.9 to 9.7 t/ha. Jabessa et al. [29] mentioned that dry matter yields of *Lablab purpureus* was 11.12- 15.43 t/ha. Sterna et al. [40] observed that depending on the development stage at harvest, forage yields of the studied soybean cultivars ranged from 13.5 to 34.7 t/ha of green biomass and 3.9-11.2 t/ha of dry matter. Thompson et al. [45] reported dry matter yields for soybean cultivars ranging from 1,294 to 1,744 kg/ha.

The quality parameters of green mass forage from the studied leguminous crops are presented in Table 1. A comparative analysis of the biochemical composition of the dry matter revealed that both soybean and lablab green forage had higher crude protein content (175-176 g/kg) as compared to the third cut of alfalfa (141 g/kg) and maize green mass forage (84 g/kg). The concentrations neutral detergent fibre and acid detergent lignin were lower in lablab green mass. The fiber content in soybean forage was lower than in alfalfa but higher than in maize. The mineral content in soybean and lablab forage was comparable to that of alfalfa and higher than that of maize forage. The dry matter digestibility, relative feed value, and energy supply of lablab forage did not differ significantly from those of maize forage. The hemicellulose content in soybean forage was similar to that in alfalfa but lower than in maize. As compared to alfalfa, both soybean and lablab forage showed favourable values for dry matter digestibility, fed value, metabolizable energy, and net energy for lactation, although these values remained lower in soybean forage than those observed in corn forage.

We would like to mention that estimated economic potential of green forage: from *Glycine max* plants achieved 1,711 kg/ha CP, 99.7GJ/ha ME and 60.7 GJ/ha NEl, while from *Lablab purpureus* plants 2,046kg/ha CP, 160 GJ/ha ME and 87 GJ/ha NEl.

Several authors have reported diverse findings regarding the biochemical composition and nutritional value of whole soybean and lablab plants. Dias et al. [19] observed that the dry matter content and nutritional profile of forage soybean ranged from 287.7 to 370.5 g/kg DM, with ash content between 7.00-8.77%, crude protein from 10.9-15.4%, neutral detergent fibre from 44.6-55.50%, and acid detergent fibre from 40.6-49.4%. Contreras-Govea et al. [17] reported that *Lablab purpureus* whole plants had 270-272 g/kg DM, 19.0-19.9% CP, 42.1-42.6% NDF, 29.9-30.7% ADF, with 875-880 g/kg IVDMD, 665-670 g/kg TDN. Acikgoz et al. [1] indicated that herbage quality of soybean was 16.3–16.8%CP, ranging from 16.3–16.8%, 36.2-36.9%NDF, 29.2-29.7%ADF, 62.6-63.6% TDN and RFV=166.2-170.9. Blount et al. [15] reported soybean forage to have 240-560 g/kg DM, 167-246 g/kg CP, 419-567 g/kg NDF and 58.2-61.4% IVDOM. Lee et al. [30] found that *Glycine soja* had CP levels of 16.1-18.2%, NDF of 40.4-43.5%, ADF of 27.5-31.7%, and RFV of 139-158, while *Glycine max* showed CP values of 17.9-21.3%, NDF of 40.2-42.0%, ADF of 26.1-30.0%, and RFV from 146 to 161. Hassan et al. [23] detailed the composition of lablab forage as follows: 13.90-15.33% CP, 0.63-0.94% EE, 15.79-16.72% CF, 56.79-58.24% NDF, 19.18-21.46% ADF, 52.49-59.42% NFE, 9.01-9.43% ash, 8.1-8.8 g/kg Ca and 8.9-13.2 g/kg P. Amole et al. [6] found that various lablab genotypes contained 15.3-

15.7% CP, 5.55-7.39% EE, 42.5-47.4% NDF, 31.7-34.1% ADF, 1.20-1.28% ADL, and 11.6-12.4% ash. Asekova et al. [8] recorded soybean forage quality parameters ranging from 10.9 to 25.7% CP, 37.4-66.6% NDF and 22.6-38.1% ADF. Heuze et al. [24, 25] noted that the average nutritional value of fresh soybean biomass was: 240 g/kg DM, 15.7% CP, 31.2% CF, 48.1% NDF, 31.2% ADF, 5.8% lignin, 9.3% ash, 14.8 g/kg Ca, 2.7 g/kg P, DOM, 18.9 MJ/kg GE, 11.6 DE and 9.2 MJ/kg ME; while lablab forage had 211 g/kg DM, 18.4% CP, 2.6% EE, 28.2% CF, 44.6% NDF, 32.0% ADF, 7.2% lignin, 11.1% ash, 13 g/kg Ca, 2.9 g/kg P, 67.0% organic digestible matter (ODM), 18.2 MJ/kg GE, 11.7 MJ/kg DE, and 9.2 MJ/kg ME. González-García et al. [22] showed that the aerial parts of *Lablab purpureus* contained 258.3 g/kg DM, 18.17% ash, 19.65% CP, 1.16% EE, 45.94% NDF, 29.83% ADF, 8.48% ADL, 16.11% HC, 21.35% Cel, 65.67% DDM, 625.05 g/kg TDN, RFV=133, 2.74 Mcal/kg DE and 2.24 Mcal/kg ME. Tabacco et al. [43] found that whole soybean plants, depending on maturity stage, contained 22.0-37.4% DM, 16.7-25.0% CP, 3.1-6.8% fats, 35.4-47.0% NDF, 26.7-38.3% ADF, 5.7-9.1% ADL, 3.6-7.6% WSC, 1.2-8.1% starch and 8.0-11.6% ash. Washaya et al. [50] reported that *Lablab purpureus* forage harvested at various growth stages contained 17.51-21.14% CP, 1.87-3.00% EE, 46.51-52.61% NDF, 33.65-39.87% ADF, 12.74-13.61% HC and 10.67-12.67% ash. According to Nadeem et al. [36], the nutritional parameters of soybean forage included: 19.86-27.70% CP, 32.03-33.86% NDF, 25.53-28.10% ADF, 4.80-6.33% lignin, 3.4-9.7% starch, 7.73-10.53% WSC, 7.89-10.53% ash, 656.6-666.7 g/kg TDN, 1.55-1.58 Mcal/kg NEl, and RFV between 213.33 and 223.33. Omodewu et al. [37] reported that the dry matter chemical composition of *Lablab purpureus* included 127.29-153.25 g/kg CP, 91.25-92.25 g/kg EE, 105.83-115.00 g/kg ash, 216.17-247.29 g/kg NFC, 427.50-442.50 g/kg NDF, 353.33-365.00 g/kg ADF, 143.33–165.00 g/kg ADL, and 74.17-77.50 g/kg HC. Bah et al. [13] found that the nutritional composition of lablab forage, depending on the growth stage (weeks 5-15), ranged from 377.2 to 884.0 g/kg DM, 9.03-14.90% CP, 5.51-13.34% ash, 9.45-13.14% EE, and 11.16-41.23% CF. Omokanye [38] noted that the dry matter from various soybean cultivars had 11.9-16.8% CP, 29.7-40.1% NDF, 23.7-31.9% ADF, 641-700 g/kg TDN, 1.45-1.61 Mcal/kg NEl, RFV=149-220. Zanine et al. [52] observed that soybean genotypes contained 44.30-54.13% stems, 28.20-48.12% leaves, and 0-25.6% pods, with 156.9-180.8 g/kg DM, and the chemical profile included 14.45-16.09% CP, 8.30-14.00% ash, 48.44-59.79% NDF, 41.74-49.60% ADF and 3.18-2.64% HC. Thu Hong et al. [46] reported that soybean foliage had 239 g/kg DM, 91.9% OM, 15.9% CP, 27.8% ADF and 64.0% NDF. Adem et al. [2] stated that lablab forage had 21.59% CP, 11.82% ash, 40.84% NDF, 28.79% ADF, 4.3% ADL, 632.3 g/kg TDN, and 656.7 g/kg IVDMD. Iqbal et al. [27] found that soybean forage contained 18.21-21.9% CP, 1.70-1.97% EE, 23.0-26.2% CF, and 9.3-11.2% ash. Aleme et al. [5] noted that a newly released lablab cultivar had 22.1-23.6% CP, 13.5-15.7% ash, 47.6-49.3% NDF, 33.0-35.7% ADF, 6.3-6.7% ADL, 609-621 g/kg IVDMD, and RFV between 113.6 and 117.6. Angadi et al. [7] revealed that lablab harvested 58 days after sowing contained 29.0-29.1% CP, 22.9-25.6% ADF, 578-593 g/kg IVTDMD and RFQ of 265-292; while those harvested at 124 days had 13.0-17.2% CP, 36.6-37.2% ADF, 39.9-43.7% NDF, 769-812 g/kg IVTDMD and RFQ of 136-151. In our earlier paper [47] was established that the green mass of *Glycine max* 'Clavera' had 178 g/kg CP, 286 g/kg CF, 94 g/kg ash, 310 g/kg ADF, 484 g/kg NDF, 49 g/kg ADL, 142 g/kg TSS, 261 g/kg Cel, 174 g/kg HC, with 68.6% DMD, 63.4% DOM, RFV=124, 12.73 MJ/kg DE, 10.48 MJ/kg ME and 6.46 MJ/kg net energy. Umesh et al. [48] stated that the green mass of pure *Lablab purpureus* had 17.91% CP, 38.21% ADF, 43.75% NDF, 577.9 g/kg TDN, and an RFQ of 145.0. Aguerre et al. [3] reported that fresh lablab plant material had 313 g/kg DM, 18.7% CP, 15.4% ash, 40.0% aNDFom, 25.7% ADFom, 5.35% ADL, 7.9% WSC, and 731 g/kg IVDMD. Ishiaku et al. [28] found that fresh lablab forage had 22.53% CP, 6.37% EE,

22.14% CF, 38.69% NFE, 52.08% NDF, 27.82% ADF, 14.22% ADL, 24.26% HC, 13.60% Cel, 10.32% ash, RFV = 120.03, and 12.13 MJ/kg ME. Jabessa et al. [29] stated that studied genotypes of *Lablab purpureus* contained 10.8-23.5% CP, 11.2-22.23% NDF, 9.25-21.00% ADF, 3.42-14.75% ADL, 499.3-624.0 g/kg IVDMD and 422.6-500.4 g/kg IVOMD. Munza et al. [35] reported that white lablab forage had 12.87-14.70% CP, 7.05-8.13% EE, 22.14% CF, 35.88-44.37% NFE, 23.93-24.80% NDF, 19.84-22.86% ADF, 6.73-7.75% ADL, 7.17-8.87% HC, 6.53-7.52% Cel, and 10.15-11.82% ash. Sterna et al. [40] mentioned that forage from soybean contained 9.18-12.27% CP, 25.90-28.58% CF, 3.1-5.2-47.5% TSS, 40.25-45.58% NDF, 31.24-34.00% ADF. Thompson et al. [45] reported that the nutritive value of soybean cultivars included 15.9-17.4% CP, 38.4-40.4% NDF, 29.4-32.2% ADF, 2.40-2.53 Mcal/kg DE and 554-574 g/kg TDN. Belete et al. [14] stated that the chemical composition and *in vitro* organic matter digestibility of fresh lablab forage ranged from 3.8 to 8.8% ash, 15.0-26.5% CP, 44.0-59.4% NDF, 24.2-47.3% ADF, 1.7-8.3% ADL and 42.2-68.7% IVOMD. Mossie et al. [34] noted that the chemical composition and *in vitro* dry matter digestibility of soybean genotypes included 14.0-21.5% CP, 34.8-51.1% NDF, 22.7-37.4% ADF, 7.5-8.2% ADL, and 599.8-904 g/kg IVDMD. Sun et al. [41] observed that the nutritional composition and feeding quality of the evaluated soybean varieties had the following values: 22.8-31.8% CP, 0.5-2.5% EE, 36.3-61.4% NDF, 21.4-38.9% ADF, with RFV between 94 and 182. Tassone et al. [44] reported that soybean forage contained 199.9 g/kg DM, 15.39% CP, 1.53% EE, 7.21% NFC, 66.28% NDF, 42.54% ADF, 8.13% ADL, 9.52% ash, 675 g/kg DMD and RFV = 95. Yücesoy & Garipoğlu [51] indicated that the nutrient composition of soybean plants, depending on the variety, ranged from 18.17 to 20.48% CP, 39.49-42.16% NDF and 28.54-30.56% ADF.

Table 1. The biochemical composition and the nutritive value of the harvested green mass of the studied leguminous crops

Indices	*Glycine max*	*Lablab purpureus*	*Medicago sativa* (third cut)	*Zea mays*
Crude protein, g/kg DM	*175*	*176*	*141*	*84*
Minerals, g/kg DM	*86*	*90*	*90*	*52*
Crude fibre, g/kg DM	*310*	*261*	*383*	*248*
Acid detergent fibre, g/kg DM	*332*	*281*	*393*	*271*
Neutral detergent fibre, g/kg DM	*520*	*453*	*579*	*474*
Acid detergent lignin, g/kg DM	*61*	*44*	*66*	*48*
Cellulose, g/kg DM	*271*	*237*	*327*	*223*
Hemicellulose, g/kg DM	*188*	*171*	*186*	*203*
Digestible dry matter, g/kg DM	*630*	*670*	*583*	*678*
Relative feed value	*113*	*138*	*94*	*133*
Digestible energy, MJ/ kg	*12.41*	*13.13*	*11.57*	*13.28*
Metabolizable energy, MJ/ kg	*10.19*	*10.78*	*9.50*	*10.90*
Net energy for lactation, MJ/ kg	*6.21*	*6.80*	*5.51*	*6.91*

Source: Own calculation.

Silage is a vital component of livestock diets, providing a consistent and nutrient-rich feed, particularly from autumn to mid-spring, but also throughout the year. The ensiling process significantly influences the nutritional quality of the feed and ultimately affects animal performance. During the sensory evaluation, ensiled mass from *Lablab purpureus* and *Glycine max* were found to have a uniform olive color. The silage from *Lablab purpureus* had pleasant aroma resembling pickled watermelon, while the *Glycine max* silage emitted a scent similar to pickled apples. The texture of both silages remained well-preserved, showing no signs of mold or mucus formation. The quality indices of the silages prepared from *Lablab purpureus* and *Glycine max* are presented in Table 2. The fermentation characteristics varied by species, with pH values ranging from 4.11 to 4.54 and total organic acid concentrations from 56.00 to 62.40 g/kg. This included 12.2-14.2 g/kg acetic

acid, 41.6-49.3 g/kg lactic acid, and 0.2-0.9g/kg butyric acid. *Glycine max* silage had lower content of acetic acid and higher content of lactic acid than *Lablab purpureus* silage. The biochemical composition, nutritive and energy values of the silages were as follows: 161-186 g/kg CP, 126-129 g/kg ash, 273-281 g/kg CF, 286-307 g/kg ADF, 456-510 g/kg NDF, 37-41 g/kg ADL, 245-270 g/kg Cel, 170-203 g/kg HC with 650-676 g/kg DMD, RFV= 119-145, 10.48-10.87 MJ/kg ME, 6.50-7.31 MJ/kg NEl. Compared to the original green mass, the ensiling process led to increases in mineral content, while the acid detergent lignin levels declined. In *Lablab purpureus* silage, the crude protein content was higher compared to the original forage, accompanied by increased levels of structural carbohydrates and hemicellulose, along with a reduction in acid detergent lignin. Conversely, *Glycine max* silage showed a decrease in crude protein and cell wall components (NDF, ADF, ADL), which contributed to enhanced dry matter digestibility, relative feed value, metabolizable energy, and net energy for lactation. Additionally, both *Lablab purpureus* and *Glycine max* silages have been found to contain higher concentrations of crude protein, crude fiber, cellulose, and minerals compared to maize silage. The relative feed value, metabolizable energy and net energy for lactation of *Glycine max* silage exceeded the levels observed in maize silage.

Several studies have investigated the quality parameters of *Lablab purpureus* and *Glycine max* silages. According to Ayaşan [10] the nutrient concentration soybean silage was 350 g/kg DM, 18.3% CP, 43.3% NDF, 32.3% ADF, 6.7% ADL. Contreras-Govea et al. [17] found in *Lablab purpureus* silage: pH 4.56-4.58, 81.2-82.4 g/kg lactic acid, 40.3-42.1 g/kg acetic acid, 248-257 g/kg DM, 20.2-20.6% CP, 39.6-40.2% NDF, 32.5-32.6% ADF, 829-834 g/kg IVTDMD and 631-644 g/kg TDN.

Tabacco et al. [43] analysed the fermentative and chemical characteristics of silage prepared from soybean plants harvested at two stages of growth and found: 22.0-37.4% DM, pH = 4.23-5.15, 1.47-11.63% lactic acid, 4.63-7.09% acetic acid, 0.38-1.13 % propionic acid, 0-3.87% butyric acid, 1.00-3.53% ethanol, 18.0-24.40% CP, 8.0-13.4% ash, 36.8-50.6% NDF, 31.3-41.9% ADF, 6.3-9.7% ADL.

Table 2. The fermentation profile, the nutrient composition of the ensiled fodder from the studied leguminous crops

Indices	*Glycine max*	*Lablab purpureus*	*Zea mays*
pH index	*4.54*	*4.11*	*3.77*
Content of organic acids, g/kg DM	*62.4*	*56.0*	*48.6*
Total acetic acid, g/kg DM	*12.2*	*14.2*	*10.3*
Total butyric acid, g/kg DM	*0.9*	*0.2*	*0.2*
Total lactic acid, g/kg DM	*49.3*	*41.6*	*38.1*
Acetic acid, % of organic acids	*16.18*	*25.36*	*21.19*
Butyric acid, % of organic acids	*1.48*	*0.36*	*0.41*
Lactic acid, % of organic acids	*79.01*	*74.28*	*78.40*
Crude protein, g/kg DM	*161*	*186*	*80*
Crude fibre, g/kg DM	*273*	*281*	*245*
Minerals, g/kg DM	*126*	*129*	*59*
Acid detergent fibre, g/kg DM	*286*	*307*	*258*
Neutral detergent fibre, g/kg DM	*456*	*510*	*469*
Acid detergent lignin, g/kg DM	*41*	*37*	*37*
Cellulose, g/kg DM	*245*	*270*	*221*
Hemicellulose, g/kg DM	*170*	*203*	*211*
Digestible dry matter, g/kg DM	*676*	*650*	*688*
Relative feed value	*145*	*119*	*136*
Digestible energy, MJ/ kg DM	*13.23*	*12.76*	*13.45*
Metabolizable energy, MJ/ kg DM	*10.87*	*10.48*	*11.04*
Net energy for lactation, MJ/ kg	*7.31*	*6.50*	*7.06*

Source: Own calculation.

Zanine et al. [52] indicated that that the nutrient concentration and fermentation characteristics of soybean silages ranged from 150.6 to 193.0 g/kg DM, 8.72-10.48% ash, 6.53-10.54% CP, 42.26- 50.05% NDF, 3.78-5.01% WSC with 6I.78- 64.48% IVDMD, pH=5.23-5.66, 0.02-

3.71% lactic acid, 1.47-3.67% acetic acid, 0.10-5.47% butyric acid. Homan et al. [26] revealed that soybean silage was characterized by 265.4 g/kg DM, pH 4.94, 1.04% lactic acid, 0.17% acetic acid, 1.85% propionic acid, 0.36% butyric acid 15.56% CP, 4.22% EE, 38.68% NDF, 33.3% ADF and 8.61% ash. Wangila et al. [49] noted that *Lablab purpureus* had pH= 4.37-4.81, 427.4g/kg DM, 16.0% CP, 8.9% ash, 42.4% NDF, 28.6% ADF, 7.3% ADL, and 754 g/kg IVDMD, 55.8% DOM, RFV=115, 12.40MJ/kg DE 10.18 MJ/kg ME and 6.19 MJ/kg NEl.

Table 3. Biochemical methane production potential of green and ensiled mass substrates from leguminous species

Indices	***Glycine max***		*Lablab purpureus*		*Medicago sativa* green mass	***Zea mays***	
	green mass	silage	green mass	silage		green mass	silage
Organic dry matter, g/kg	*914*	*874*	*910*	*871*	*910*	*948*	*941*
Minerals, g/kg DM	*86*	*126*	*90*	*129*	*90*	*52*	*59*
Crude protein, g/kg DM	*175*	*161*	*176*	*186*	*141*	*84*	*80*
Nitrogen, g/kg DM	*28.00*	*25.76*	*28.16*	*29.76*	*22.56*	*13.44*	*12.80*
Carbon, g/kg DM	*507.77*	*485.56*	*505.56*	*483.89*	*485.56*	*526.67*	*522.78*
Ratio carbon/nitrogen	*18.13*	*18.85*	*17.95*	*16.26*	*21.52*	*39.19*	*40.84*
Hemicellulose, g/kg DM	*188*	*170*	*171*	*203*	*186*	*223*	*211*
Acid detergent lignin, g/kg DM	*61*	*41*	*44*	*37*	*66*	*48*	*37*
Biomethane potential, L/kg DM	*290*	*306*	*314*	*313*	*276*	*304*	*318*
Biomethane potential, L/kg ODM	*318*	*350*	*345*	*359*	*303*	*321*	*338*

Source: Own calculation.

Currently, bioenergy is the fourth-largest contributor to the global primary energy supply, following oil, coal and natural gas. Plant biomass (phytomass) can be efficiently transformed into various biofuels for use in transportation, heating and electricity generation. One of the most valuable biofuels derived from phytomass is biomethane which can effectively substitute natural gas in energy production, and the digestate produced during biomethane generation can be applied as an organic fertilizer in agriculture. Table 3 presents data on the quality indicators and biomethane production potential of substrates derived from *Lablab purpureus* and *Glycine max*. Our findings show that the substrates had favorable carbon-to-nitrogen (C/N) ratios, ranging from 16.3 to 18.9, along with acid detergent lignin contents of 37 to 61 g/kg and hemicellulose levels between 170 and 203 g/kg – values that align with the established standards. The biochemical methane potential (BMP) of the studied substrates ranged from 318 to 359 l/kg VS or 290 to 314 L/kg DM. Notably, both *Lablab purpureus* and *Glycine max* substrates, particularly in ensiled form, demonstrated high biochemical methane potential.

Several authors have reported findings on the biogas yield and methane potential of *Glycine max* substrates. Morozova et al. [33] noted that substrates derived from *Glycine max* plants had a biomethane potential of 266 l/kg VS, while substrates from *Panicum virgatum* plants yielded 258 l/kg VS. Cerempei et al. [16] reported that *Glycine max* substrate had a carbon-to-nitrogen (C/N) ratio of 18 and a biochemical methane potential of 337 L/kg VS; as for the *Medicago sativa* substrate, the carbon-to-nitrogen ratio was also 18, but the biochemical methane potential reached 321 L/kg VS.

CONCLUSIONS

The investigated leguminous crops, *Lablab purpureus* and *Glycine max*, demonstrated a green biomass yield ranging from 3.83 to 5.67 kg/m², corresponding to 1.07-1.28 kg/m² of dry matter.

The harvested green biomass and prepared silage from both *Lablab purpureus* and *Glycine max* have optimal nutrient content, making them suitable as alternative forage sources for livestock, as well as potential substrates for biomethane production in biogas reactors.

Among the two, *Lablab purpureus* stood out for its particularly high productivity and

protein content in forage, also high biomethane potential.

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PROVISION OF FINANCIAL RESOURCES FOR AGRICULTURAL ENTERPRISES IN UKRAINE THROUGH CREDITATION: RATING OF BANKS

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Abstract

The purpose of this article is to rank Ukrainian banks by the balance of funds on loans granted to business entities by the type of economic activity "Agriculture, hunting and provision of related services". The study used two author's methods of rating objects. According to the first method, banks are assigned to one of five groups depending on the size of agricultural lending (high, above average, average, below average, low). Here, the number of banks in each group is different, and the ranges of internal spread of lending indicators within the groups are the same. According to the second method, banks are distributed into five groups evenly depending on their position in the rating of lending to farmers (high, above average, average, below average, low). Here, the specific number of banks included in each group depends on the balance after dividing their total number by five. The ranges of internal spread of indicators within the groups according to this method differ. The credit services provided to farmers by some of the largest banks in Ukraine were analyzed. It was determined that as of October 1, 2025, 46 Ukrainian banks provided loans by type of economic activity "Agriculture, hunting and provision of related services" for a total amount of 139,485 million UAH, including in the national currency for the amount of 110,164 million UAH, in foreign currency – for the amount of 29,321 million UAH. The largest creditors of agriculture in Ukraine are five banks: "OSCHADBANK", "RAIFFEISEN BANK", "PRIVATBANK", "FUIB", "PROCREDIT BANK", which issued loans for the amount of over 11 billion UAH each.

Keywords**:** *financial resources, agricultural enterprises, Ukraine, bank lending, rating assessment*

INTRODUCTION

Agricultural producers, both in Ukraine and around the world, often need financial resources for current expenses (for the purchase of seeds, fertilizers and plant protection products), as well as capital expenditures (for the expansion of land, modernization of equipment, improvement of infrastructure). This is due to the seasonality of production and a significant time period from the purchase of seeds to the sale of products. In the event of a financial need that is not covered by their own funds, farmers can use state assistance or bank loans. Today, Ukrainian banks offer a number of opportunities to agricultural enterprises.Thus, the state-owned bank "OSCHADBANK" provides the following credit services:

1) overdraft – credit funds for prompt payments to ensure the closing of cash gaps (from 18.7% per annum, up to 3 years);
2) replenishment of working capital – for the purchase of raw materials, goods, payment for services related to the production of products or conducting commercial activities, other current needs (floating from UIRD3M + 7.72, up to 3 years);
3) purchase of vehicles and equipment (from UIRD3M + 8.95% per annum, up to 5 years);
4) vehicles under the "Autobiz" program – loans for the purchase of new and used vehicles (from 0.01% per annum, up to 60 months);
5) loan against a deposit – a loan secured by a deposit placed with Oschadbank;
6) guarantee of the Fund for Partial Guarantee of Agricultural Credits – loans secured by a guarantee of the Fund for Partial Guarantee of Agricultural Credits (from 100,000 UAHto 12.5 million UAH, up to 10 years);
7) land acquisition – loans for the acquisition of agricultural land (UIRD3M + 7% per annum, up to 10 years, collateral: the land plot being purchased and the owner's guarantee);

8) mine-free sowing – loan for the demining of agricultural land contaminated with explosive objects (up to 150 million UAH, 3% per annum, up to 3 years) [10].

Note that UIRD3M is an interest rate that will be equal to the average value of rates on deposits for a period of 3 months.

Another state-owned bank, "PRIVATBANK", offers its clients the "Agrosezon" loan to finance the current agricultural cycle and ensure effective development of the enterprise:

1) for legal entities (from UIRD3M + 1% to UIRD3M + 4.5%, up to 36 months);

2) for sole proprietors (from UIRD3M + 3% to UIRD3M + 4.5%, up to 18 months) [12].

In turn, the non-state bank "RAIFFEISEN BANK" offers the following loans for farmers and agribusiness:

1) credit line (16.7–17.2%, 18 months);

2) partnership programs – special conditions for purchasing goods necessary for successful agribusiness (0.01–15.0%, 60 months);

3) investment loan for the purchase of agricultural machinery and equipment (16.7–17.2%, 60 months);

4) "Development" loan (19.65–24.65%, 60 months);

5) overdraft (17.75–19.75%, 36 months);

6) unsecured "Trust" loan (19.65–24.65%, 24 months);

7) promissory note programs (12 months);

8) state support program for farmers – an opportunity to return 25% of the cost of Ukrainian-made equipment [13].

That is, state and private banks offer Ukrainian farmers a variety of credit services: both for current activities and for business development. Over the past five years, the features of lending to the agricultural sector in various European countries and the USA have been studied by the following scientists: S. Andros and V. Gerasymchuk (2023) – studied the features of consumer and mortgage lending to Ukrainian households, identified the main problems in these areas[1]; S. Arzhevitin*et al.* (2021) –analyzed a number of indicators of the dynamics of bank lending to the agro-industrial complex in Ukraine (loans, interest rates, etc.) [2]; R. Kashian and R. Drago (2025) – compared general and agricultural lending, as well as lending by small, medium and large banks in the USA [3]; H. Kostov*et al.* (2025) – analyzed the structure of loans in the agricultural sector of the Republic of Bulgaria[4]; T. Kuethe*et al.* (2022) – studied competition in the field of agricultural lending in the USA between commercial banks, the Farm Credit System and non-traditional lenders[5]; O. Lemishko and N. Shevchenko (2021) – identified problems of bank lending to farmers in Ukraine and outlined measures to address them [6]; J. Lutovac*et al.* (2024) – determined the impact of various factors on obtaining loans in agricultural farms in the Republic of Serbia [7]; J. Montgomery *et al.* (2025) – measured the expected impact of additional services of an agricultural lender on attracting and retaining borrowers in the USA [8]; L. Poliatykina*et al.* (2022) – focused on accounting and financial problems in the field of bank lending to Ukrainian farmers [11]; N. Shmygol*et al.* (2022) – studied the impact of credit funds on the financial position of agro-industrial enterprises in Ukraine [14]; D. Stoyanova (2023) – considered possible options for financing agricultural producers in Bulgaria [15]. The purpose of this article is to rank Ukrainian banks by indicators of balances of funds on loans granted to business entities by type of economic activity "Agriculture, hunting and provision of related services".

MATERIALS AND METHODS

The article will use two author's methods of rating objects, according to which all banks, in our opinion, should be divided into five groups. *According to the first method*, each bank will be assigned to one of five groups depending on the size of agricultural lending al_i^x (high, above average, average, below average, low). The rating scheme according to this method is shown in Figure 1. Here, the number of banks in each group will be different, and the ranges of internal dispersion of lending indicators $\frac{\left(al_i^{max} - al_i^{min}\right)}{5}$ within the groups will be the same.

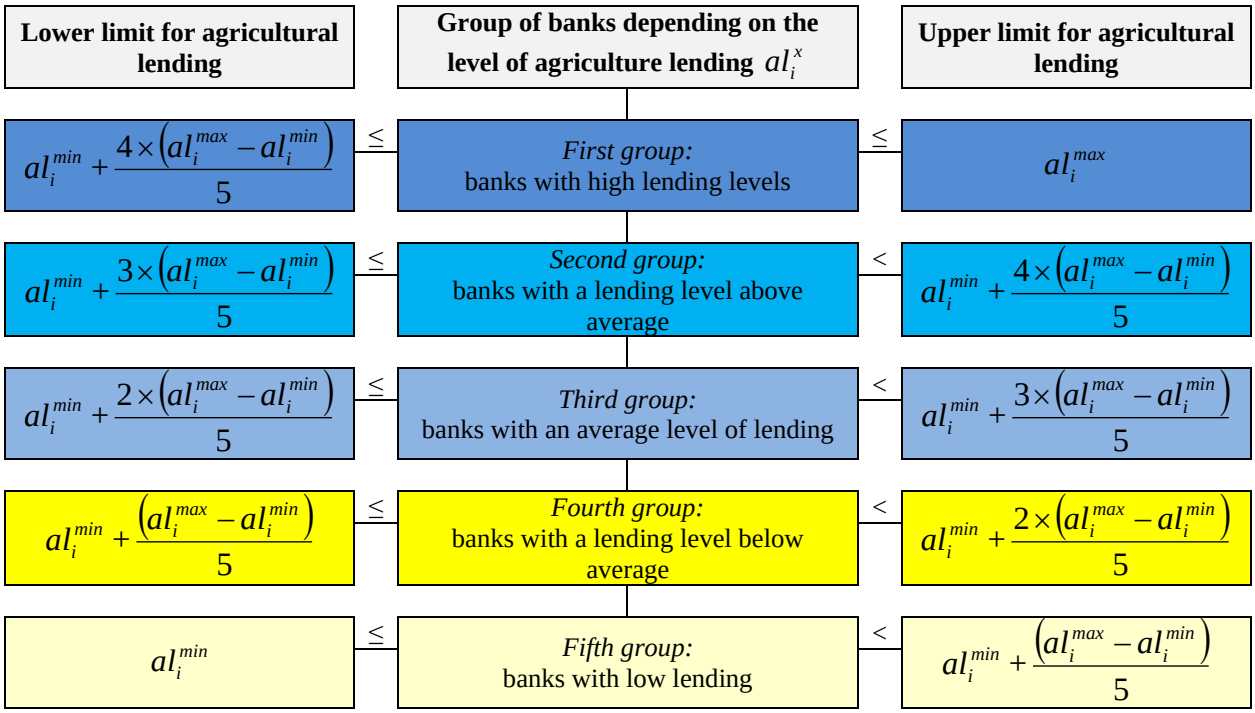


Fig. 1. Grouping of banks depending on the size of agricultural lending:

al_i^x – balances of funds in the bank x as of the i-thdate on loans granted to business entities by type of economic activity "Agriculture, hunting and provision of related services";

al_i^{min} – minimum balance of funds among all banks of Ukraine as of the i-th date on similarloans;

al_i^{max} – maximum balance of funds among all banks of Ukraine as of the i-thdate on similar loans.

Source: developed by the author based on [16].

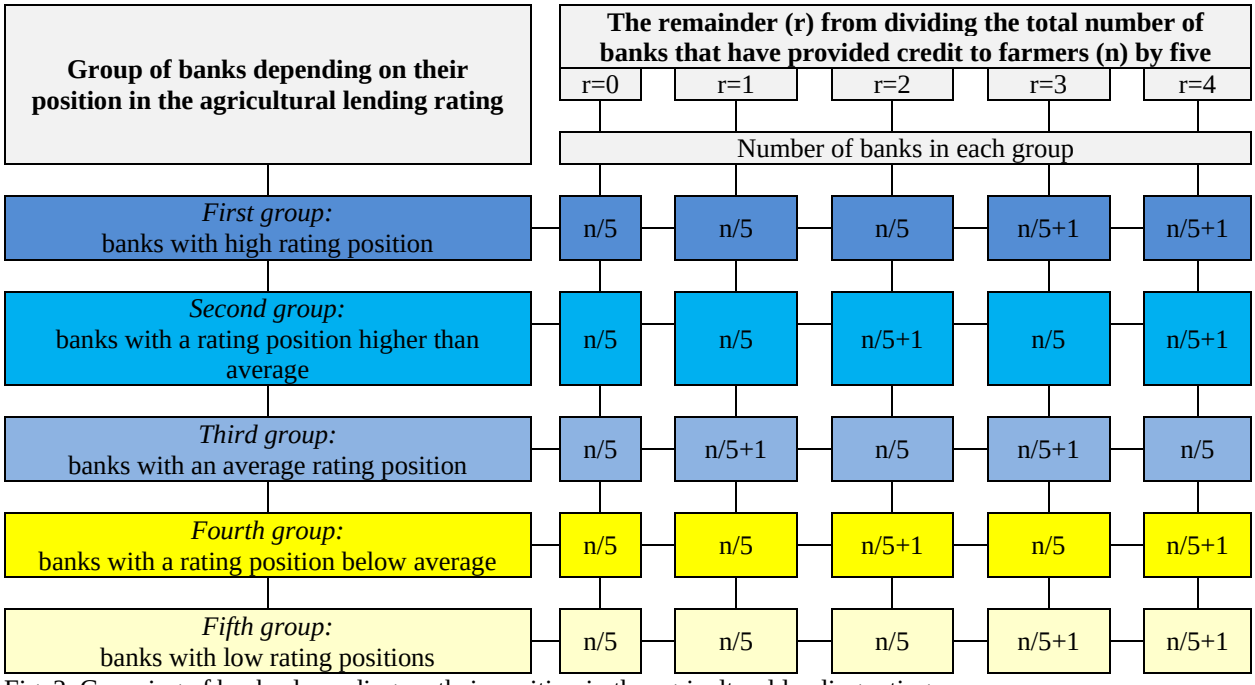


Fig. 2. Grouping of banks depending on their position in the agricultural lending rating
Source: developed by the author based on [16].

The second method will divide banks into five groups evenly depending on their position in the agricultural credit rating (high, above average, average, below average, low). The rating scheme according to this method is shown in Figure 2. Here, the specific number of banks that will be included in each group depends on the remainder after dividing their total number (n) by five:

a) if the remainder r=0, the number of banks in each group is the same;

b) if the remainder r=1, the third group will have one more member than all the others;

c) if the remainder r=2, the second and fourth groups will have one more member than all the others;

d) if the remainder r=3, the first, third and fifth groups will have one more member than all the others;

e) if the remainder r=4, the third group will have one less member than all the others.

Note that the ranges of internal dispersion of indicators within groups using this method will differ.

RESULTS AND DISCUSSIONS

To analyze the distribution of loans granted to business entities by type of economic activity "Agriculture, hunting and provision of related services", Table 1 was constructed. It lists banking institutions in descending order of total balances of funds under loans granted to business entities.

As we can see, as of October 1, 2025, 46 Ukrainian banks granted loans to farmers for a total amount of 139,485 millionUAH, including 110,164 million UAHin national currency, and 29,321 million UAHin foreign currency. That is, loans in national currency exceed loans in foreign currency by 3.8 times.

Applying the *first method* for grouping banks (depending on the size of agricultural lending), we obtain the following results:

1st group (two banks with the amount of loans within the range of 16,426≤ al_i^x ≤20,532 million UAH) – JSC "OSCHADBANK" (20,532 million UAH); JSC "RAIFFEISEN BANK" (20,209 million UAH);

2nd group (two banks with the amount of loans in the range of 12,319≤ al_i^x <16,426 million UAH) – JSC CB "PRIVATBANK" (14,712 million UAH); JSC "FUIB" (12,955 million UAH);

3rd group (one bank with a loan amount within the range of 8,213≤al_i^x <12,319 million UAH) – JSC "PROCREDIT BANK" (11,983 million UAH);

4th group (six banks with a loan amount in the range of 4,107≤ al_i^x <8,213 million UAH) – JSC "OTP BANK" (8,019 million UAH); JSB "UKRGASBANK" (8,015 millionUAH); JSC "Ukreximbank" (7,767 million UAH); JSC "CREDIT-AGRICOLE BANK" (7,417 million UAH); PJSC "Pivdenny Bank" (4,528 million UAH); JSC "SENSE BANK" (4,378 million UAH);

5th group (35 banks with the amount of loans within 1≤ al_i^x <4,107 million UAH) – from JSC "KREDOBANK" (3,420 million UAH) to JSC"KRISTALBANK" (1 million UAH).

As we can see, the ranges of internal dispersion of indicators in these groups are equal to 4,106 million UAH. Two banks fell into the 1st (with a high level of lending) and 2nd group (with a level of lending above average) each, and one into the 3rd (with an average level of lending). The 4th (with a level of lending below average) and 5th (with a low level of lending) groups are the most numerous – they contain six and 35 banks, respectively.

The correspondence of banks to groups is displayed in the second column of Table 1 using the corresponding colors.

To apply the *second method*, we will determine the number of banks for each group. In our case, n=46 (46/5=9, remainder=1), so the third group will have one more member (10) than all the others (9 each).

The grouping of 46 banks, depending on their rating position in 2025, will look like this:

Table 1. Distribution of loans granted to business entities by type of economic activity "Agriculture, hunting and provision of related services" as of October 1, 2025, millionUAH

Bank name	Total	National currency	Foreign currency	Rating position
JSC "OSCHADBANK"	20,532	18,390	2,142	1
JSC "RAIFFEISEN BANK"	20,209	15,142	5,067	2
JSC CB "PRIVATBANK"	14,712	14,156	556	3
JSC "FUIB"	12,955	10,528	2,427	4
JSC "PROCREDIT BANK"	11,983	9,887	2,095	5
JSC "OTP BANK"	8,019	5,283	2,736	6
JSB "UKRGASBANK"	8,015	6,786	1,228	7
JSC "Ukreximbank"	7,767	4,405	3,362	8
JSC "CREDIT-AGRICOLE BANK"	7,417	5,569	1,848	9
PJSC "PivdennyBank"	4,528	1,988	2,541	10
JSC "SENSE BANK"	4,378	1,987	2,392	11
JSC "KREDOBANK"	3,420	3,160	260	12
JSCB "LVIV"	3,038	2,825	212	13
JSC "BANK CREDIT DNIPRO"	2,966	2,917	50	14
JSC "TASCOMBANK"	2,192	1,347	845	15
JSC "AGROPROSPERIS BANK"	1,520	1,499	21	16
JSC "VST BANK"	820	820	0	17
JSC "UKRSIBBANK"	809	14	795	18
JSC "BANK ALLIANCE"	740	661	79	19
JSC "PIRAEUS BANK ICB"	538	388	150	20
JSC "METABANK"	351	351	0	21
JSC "POLTAVA-BANK"	303	303	0	22
JSB "RADABANK"	203	141	61	23
JSC "UNEX BANK"	194	194	0	24
JSC "SKY BANK"	183	183	0	25
JSC "A-BANK"	178	38	140	26
PJSC "MTB BANK"	173	173	0	27
JSC "PRAVEX BANK"	170	38	132	28
JSC "POLICOMBANK"	162	137	26	29
JSC "BANK "GRANT"	148	147	1	30
JSB "CLEARING HOUSE"	137	23	114	31
JSC "CREDITWEST BANK"	122	122	0	32
JSC "MIB"	109	109	0	33
JSC "BISBANK"	103	103	0	34
JSC "CB "GLOBUS"	86	86	0	35
JSC "ASVIO BANK"	55	55	0	36
JSC "OKCI BANK"	52	52	0	37
JSC "COMINBANK"	51	51	0	38
PJSC "CB "ACCORDBANK"	50	9	41	39
JSC "BANK "UKRAINIAN CAPITAL"	49	49	0	40
JSCB "INDUSTRIALBANK"	16	16	0	41
JSC "ALTBANK"	12	12	0	42
JSC "IDEA BANK"	8	8	0	43
JSC "MOTOR-BANK"	5	5	0	44
JSC "EIB"	3	3	0	45
JSC "CRYSTALBANK"	1	1	0	46
Разом	139,485	110,164	29,321	

Source: Compiled by the author based on data from the National Bank of Ukraine (2025) [9].

1st group (nine banks with the amount of loans from 7,417 to 201,532 million UAH) – from JSC "OSCHADBANK" to JSC "CREDIT-AGRICOLE BANK";

2nd group (nine banks with the amount of loans from 809 to 4,528 million UAH) – from PJSC "PivdennyBank" to JSC "UKRSIBBANK";

3rd group (ten banks with loans from 170 to 740 million UAH) – from JSC "BANK ALLIANCE" to JSC "PRAVEX BANK";

4th group (nine banks with loans from 52 to 162 million UAH) – from JSC "POLICOMBANK" to JSC "OKCI BANK";

5th group (nine banks with loans from 1 to 51 million UAH) – from JSC "COMINBANK" to JSC "CRYSTALBANK".

Despite the almost uniform number of banks in all five groups (9 or 10), the internal limits of lending indicators in each group differ greatly. Thus, the difference between the first and ninth positions in the 1st group is 13,115 million UAH, between the 10th and 18th positions in the 2nd group is 3,719 million UAH, between the 19th and 28th in the 3rd is 570 million UAH, between the 29th and 37th positions in the 4th group is 110 million UAH, between the 38th and 46th in the 5th is 50 million UAH. The most homogeneous according to this method is the 5th group.

The correspondence of banks to groups is reflected in the fifth column of Table 1 using the corresponding colors.

CONCLUSIONS

Ukrainian farmers can use the credit services of domestic banks to replenish financial resources: overdraft, replenishment of working capital, purchase of vehicles, equipment, land plots, for demining agricultural lands, unsecured credit, promissory note programs, etc. As of October 1, 2025, 46 Ukrainian banks provided loans to farmers for a total amount of 139,485 million UAH, with loans in the national currency exceeding loans in foreign currency by 3.8 times.

The largest creditors of agriculture in Ukraine are five banks: "OSCHADBANK", "RAIFFEISEN BANK", "PRIVATBANK", "FUIB", and "PROCREDIT BANK", which

issued loans in the amount of over 11 billion UAH each. According to the criterion of the level of agricultural lending, these banks were included in the first three groups (first author's methodology); depending on their position in the agricultural lending rating – in the first group (second author's methodology).

Deepening the study of the provision of financial resources to agricultural enterprises in Ukraine can be done by analyzing state programs to support farmers: subsidies, grants, and compensation.

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MECHANICALLY ASSISTED AEROBIC COMPOSTING UNDER RURAL CONDITIONS: A LOW-COST STRATEGY FOR SOIL RESILIENCE AND DECENTRALIZED ORGANIC WASTE MANAGEMENT

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Abstract

The sustainable management of agricultural and household organic waste continues to pose significant challenges for European small-scale farming systems, under the Green Deal strategy of the European Union. The need for a local strategy regarding organic waste composting would reduce the environmental pressures for waste recycling. The scope of this pilot study is to evaluate a mechanically assisted aerobic composting system under rural conditions. A 70-day experiment was designed by using three 80 L containers representing distinct strategies: mechanically shredded biomass without turning (CP1), stratified unshredded biomass (CP2), and unshredded biomass subjected to periodic mechanical aeration (CP3). The process performance was assessed through several indicators: temperature monitoring, physicochemical characterization, nutrient content, carbon-to-nitrogen ratio, and redox stability indicators. Based on our results, mechanical pre-treatment enhanced thermophilic development, with CP1 reaching 58°C, while mechanical aeration supported biochemical stabilization, reflected in the lowest final C/N ratio (14.8) observed in CP3. Electrical conductivity and oxidation–reduction potential confirmed progressive mineralization and the absence of unstable organic matter. All three variants produced stable compost suitable to be used as a fertilizer for agricultural purposes, indicating that low-intensity mechanical interventions improve composting efficiency without increasing technological complexity. Mechanically assisted decentralized composting represents a feasible strategy contributing to soil resilience and circular nutrient use in small-scale agro-ecosystems.

Key words: *aerobic composting, agriculture, decentralized organic waste management, mechanical pre-treatment, compost maturity, soil resilience*

INTRODUCTION

Soil degradation represents one of the most pressing environmental and agricultural challenges across the world [15, 26, 27]. At the regional level, the European Union has recently assessed that a substantial proportion of soils are affected by erosion, organic carbon depletion, compaction, and biodiversity loss [9]. These processes are frequently associated with intensive agricultural practices and inadequate management of organic residues, resulting in reduced organic matter inputs and impaired soil biological functioning [15, 26].

In response to these risks, after almost 16 years of negotiations, the European Union adopted in 2022 the Soil Strategy for 2030, which establishes that soil health is a strategic priority and promotes the restoration of soil organic matter through sustainable land management practices [9]. Within the Green Deal strategy and this regulatory framework, the recycling of biodegradable residues is increasingly recognized as a practical pathway for enhancing soil resilience while also synergistically supporting circular bioeconomy objectives [22, 23].

Globally, soil is acknowledged as a finite and non-renewable resource essential for food security, ecosystem stability, and climate regulation [10]. Today, different strategies are applied all over the world for soil fertility recovery [19]. There is a broad range of solutions, but the most friendly solutions are using organic amendments [3, 4], including composting [13]. This should be the best solution, as it supports nutrient recycling from all farms' waste materials [11, 27]. Therefore,

different methods are already in place to speed up the composting process [2, 8], and today we may have new technologies or innovative techniques operating from the industrial level to the local level and small-scale farms [7, 18]. The need to seriously take into consideration further composting solutions at the local level is also determined by different regulatory frameworks already in place and all acting for the reduction of carbon emissions. [21, 25]. Under these conditions, decentralized composting systems at a small scale emerge as a potential solution due to their adaptability, reduced operational costs, and potential to support on-farm and household nutrient recycling [12]. Beyond their environmental role, such systems may also contribute to farm-level sustainability by reducing dependence on external fertilizers and promoting the local reuse of organic resources [12]. This functional integration aligns with broader European objectives targeting the Green Deal strategy, including climate mitigation through soil carbon sequestration and improved land management [15].

Despite the recognized benefits of composting, empirical evidence derived from mechanically assisted processes operating under household-scale conditions remains limited [17]. Generating applied research in this area is essential for bridging the gap between regulatory ambitions and feasible implementation at the farm level [12].

Against this background, the present pilot study investigates the influence of mechanical biomass management on composting dynamics under decentralized rural conditions. By evaluating low-intensity interventions such as particle size reduction and periodic aeration, the research aims to determine whether small-scale systems can produce stable, nutrient-rich organic amendments while supporting soil resilience and sustainable agricultural practices.

MATERIALS AND METHODS

Study area and experimental context

The study was conducted in the commune of Rucăr, Brașov County, Romania (45.39° N, 25.17° E), a hilly–mountainous rural area characterized by mixed farming systems and decentralized management of organic residues. The experiment was implemented under household-level conditions to reflect operational constraints typically encountered by small-scale farms lacking access to centralized composting infrastructure. Locally available biodegradable materials originating from agricultural and household activities were used, while the mechanical tools employed in the experiment corresponded to equipment commonly accessible in rural settings. This applied context was intentionally selected to evaluate the feasibility of mechanically assisted composting as a practical residue management strategy rather than as a strictly controlled laboratory process.

Experimental design

The research followed a pilot exploratory design aimed at assessing the influence of mechanical biomass management on aerobic composting dynamics, designed according to [20]. Owing to the applied nature of the study, spatial replication was not implemented, as the objective was to evaluate operational feasibility under real-world rural conditions rather than to perform statistical inference. To enhance analytical reliability, physicochemical determinations were performed in triplicate for each collected sample, and mean values were reported.

Three identical rigid batch containers with a nominal capacity of 80 L were used, a volume representative of decentralized, household-scale organic waste generation. The containers were placed outdoors on a permeable surface to prevent leachate accumulation while allowing natural drainage. Each container corresponded to a specific composting strategy: (1) CP1 – mechanical pre-treatment: biomass mechanically shredded to an approximate particle size of 2–5 cm prior to loading, with no subsequent turning during the composting cycle; (2) CP2 – traditional layering: unshredded bulk materials arranged in alternating carbon-rich and nitrogen-rich layers, simulating conventional rural composting practices; (3) CP3 – mechanical aeration: unshredded bulk materials

periodically mixed through manual mechanical aeration to improve oxygen diffusion within the compost matrix (Photo 1).



Photo 1. Experimental composting batch containers used in the study.
Source: Original photo

Mechanically assisted protocol

Mechanical intervention was intentionally maintained at low intensity in order to reflect practices realistically accessible to small-scale farms. Mechanical pre-treatment in CP1 was carried out using a 1.5 kW electric shredder to increase substrate surface area and enhance microbial accessibility. Aeration in CP3 was performed weekly using a manual auger-type aerator to improve oxygen diffusion within the compost matrix while preserving structural porosity. CP2 served as a passive control without mechanical intervention [20].

Substrate composition

Table 1. Quantitative composition of the composting substrate (per container).

Organic residues	Mass (kg)	Dry Matter (%)	C/N Ratio
Fresh cattle manure	19.4	18.5	12.4
Wheat straw	14.5	88.2	80.2
Orchard pruning residues	9.7	65	120.5
Household vegetable waste	4.9	12	15.2
Total / Average	**48.5**	**42%**	**27.8:1**

Source: Original data.

The composting mixture was formulated to achieve an initial carbon-to-nitrogen ratio of approximately 28:1, consistent with recommended conditions for aerobic composting. Carbon-rich inputs included wheat straw, dried leaves, orchard pruning residues, and minor quantities of sawdust, whereas nitrogen-rich materials consisted of fresh bovine manure and household vegetable waste. Material proportions were adjusted empirically to ensure adequate moisture and aeration throughout the compost mass.

Process monitoring and sampling

The composting process was monitored over a period of 70 days, encompassing mesophilic, thermophilic, and maturation phases. Internal temperature was measured periodically using a probe thermometer inserted into the central zone of each container. Samples were collected at multiple stages of the composting cycle and air-dried to approximately 6% moisture to prevent microbial reactivation and to standardize chemical concentrations before laboratory analysis. All nutrient values are therefore expressed on a dry matter basis.

Physicochemical measurements

Physicochemical parameters, including (1) pH and (2) electrical conductivity, were measured using a multiparameter probe. Total dissolved solids and salinity were derived from electrical conductivity values using instrument-specific conversion factors. Oxidation–reduction potential was determined in aqueous compost extracts prepared at a 1:5 (w/v) compost-to-water ratio [6].

Chemical analysis

Total nitrogen (N) was determined using the modified Kjeldahl method in accordance with SR ISO 11261:2000, enabling the quantification of both inorganic and organically bound nitrogen fractions.

Available phosphorus (P) was measured spectrophotometrically (Analytik Jena) following extraction with ammonium lactate–acetate solution, while potassium (K) was determined by flame photometry (Analytik Jena) using the same extract [1].

Organic carbon was quantified through wet dichromate oxidation, with the residual oxidant determined by titration using 0.2 N Mohr's salt solution [16]. Humus content was estimated from organic carbon values using conventional

conversion factors widely applied in soil and compost evaluation [14].
All chemical analyses were performed in triplicate, and the reported values represent the mean of the determinations.

RESULTS AND DISCUSSIONS

Given the exploratory nature of this pilot study, each container represented a distinct operational variant rather than a replicated treatment. While this design limits statistical inference, the experiment was intentionally conducted under real rural conditions to evaluate operational feasibility rather than to optimize the controlled process.
Physicochemical analyses performed in triplicate enhanced data reliability, allowing the results to be interpreted as applied evidence supporting decentralized composting strategies. Similar pilot-scale approaches are widely recognized as essential preliminary steps for developing scalable waste management solutions [5,8].

Thermal behavior

Temperature is widely recognized as one of the primary indicators for evaluating microbial activity and process intensity during aerobic composting [3, 11]. Monitoring thermal evolution provides essential information regarding the transition between mesophilic and thermophilic phases, as well as the overall efficiency of organic matter degradation.
The temperature dynamics recorded throughout the 70-day composting cycle are presented in Figure 1, consistent with international standards [3, 11, 24].
The thermal profiles revealed distinct decomposition patterns among the experimental variants. A rapid temperature increase was observed during the initial stage, indicating intense microbial metabolism and the onset of active biodegradation.
After 21 days, the temperature rose to 58 °C in the first container, and there are different authors considering that such a temperature peak would act to reduce pathogens and even the germination ability of weed seeds [11].

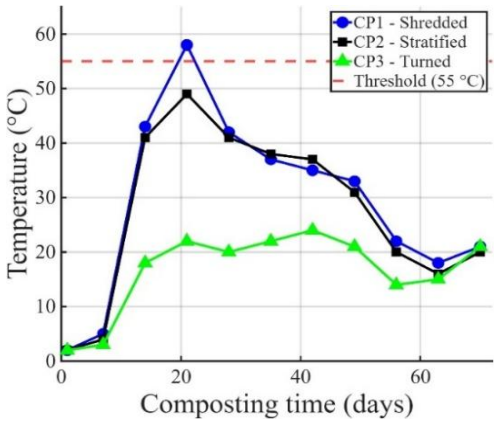


Fig. 1.Temperature dynamics recorded during the composting process. The red dashed line represents the 55 °C sanitization threshold.
Source: authors' own data.

Therefore, this mechanical reduction of organic material size should be very important in accelerating the compositing process, too. For the second container, the temperature reached 49°C, and for the third, it can be considered that it was only a moderate rose of temperature. Upon this phase, which can be considered as thermophilic, followed the maturation phase in composting, in agreement with other authors [3]. We may consider, based on the analysis of these results, that it is compulsory to implement a mechanical operation for organic waste size reduction before starting the composting process, and supplemented with a controlled aeration process during the maturation phase.

pH evolution during composting

The evolution of pH during the composting process represents a key indicator of biochemical transformations occurring within the organic matrix, particularly those associated with organic acid degradation and ammonification [13]. The temporal variation of pH values across the experimental containers is illustrated in Figure 3.
The recorded data revealed a progressive transition from near-neutral conditions at the onset of biodegradation toward slightly alkaline values during the maturation phase. This pattern is commonly reported in composting systems and reflects the decomposition of organic acids alongside the formation of ammoniacal compounds as microbial activity intensifies.

Despite minor fluctuations during intermediate stages, all variants remained within the regulatory limits for compost suitability, indicating a chemically stable transformation process. These limits, represented by the red dashed lines in Figure 2, ensure the absence of phytotoxic organic acids and prevent ammonia toxicity [3, 13, 24].

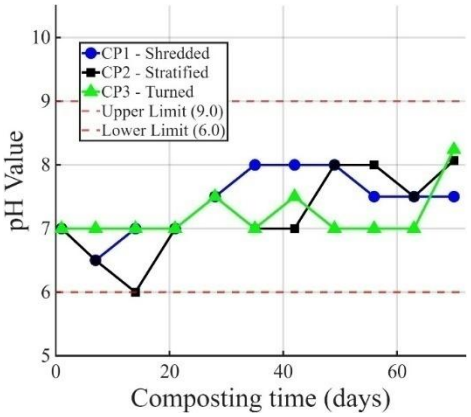


Fig. 2. Evolution of pH values during the composting period. These limits, represented by the red dashed lines in Figure 3, define the suitability window of pH ranging between 6.0 and 9.0
Source: authors' own data.

By the end of the composting cycle, pH values converged within the interval of approximately 8.0–8.5, a range widely recognized as indicative of biologically mature compost suitable for agricultural application [3].
Among the tested variants, CP1 displayed the most consistent progression toward stabilization, whereas CP2 exhibited greater early-stage variability, likely reflecting slower structural breakdown in the absence of mechanical pre-treatment.
By observing the pH curve, it can be considered that the piloting phase is reliable and reproducible considering the chemical composition presented in Table 2. By analyzing all data presented in Table 2 it can be better understood that the chemical transformation of organic compounds down to total nitrogen, phosphorous and potassium is similar for all three containers. The differences among the thermophilic phases for each of the containers also support the idea that mechanical treatment of the organic waste is essential to accelerate further nutrient release during the composting process. This is in line with the best obtained results in case of the first container, which proved to provide the highest concentrations of available nitrogen, phosphorous and potassium, being in line with other authors' results [1, 2].

Table 2. Final chemical characteristics and C/N ratios of the compost variants.

Variant	**Total N (%)**	**Total P (%)**	**Total K (%)**	**Organic Carbon (%)**	**Humus %**	**C/N ratio**
CP1	1.85	0.72	1.12	29.97	51.67	16.2
CP2	1.67	0.69	1.08	30.73	52.98	18.4
CP3	1.39	0.64	0.96	20.57	35.46	14.8

Source: Original data.

Importantly, all experimental variants exhibited C/N values within this maturity threshold, confirming the effectiveness of aerobic degradation under decentralized operational conditions.
The recorded nutrient ranges are consistent with values commonly reported for mature compost derived from mixed organic substrates, further supporting the stability of the final products [4].
Overall, these physicochemical indicators demonstrate that mechanically assisted composting can generate nutrient-rich organic amendments appropriate for agricultural use while maintaining process reliability at a small scale.

Redox stability and soluble salt balance

To further evaluate compost maturity, oxidation–reduction potential (ORP) and soluble salt indicators were analyzed at the end of the composting cycle. These parameters are increasingly used as complementary markers of biochemical stabilization and humification [13].The measured values are summarized in Table 3.
Final ORP values ranged from −76 mV to −103.2 mV, indicating the absence of active anaerobic fermentation processes and suggesting the establishment of a chemically stabilized organic matrix. Moderately negative redox conditions are typically associated with mature compost in which microbial activity has shifted from rapid biodegradation toward long-term stabilization [3].

Table 3. Final physicochemical stability indicators of the compost variants. Original data

Parameter	CP1	CP2	CP3
pH	7.98	8.47	8.32
ORP (mV)	-76	-103.2	-98.7
Electrical conductivity (µS/cm)	3590	2940	3070
TDS (ppm)	2370	1940	2020
Salinity (ppm)	1840	1460	1560

Source: Original data.

Electrical conductivity values varied between 2.94 and 3.59 mS/cm, reflecting the progressive mineralization of organic matter and the release of soluble nutrients. Despite this increase, salinity levels remained below thresholds commonly associated with phytotoxic effects, indicating that the compost is unlikely to induce osmotic stress when applied to soil [4].

The combined interpretation of ORP, electrical conductivity, and nutrient concentrations therefore provides multi-parameter evidence that mechanically assisted composting can produce chemically stable organic amendments under decentralized rural conditions.

It is important to note that ORP was measured in aqueous extracts (1:5 w/v), reflecting the chemical stability of the soluble fraction rather than in situ oxygen availability. No persistent anaerobic odors were detected during sampling, further supporting the interpretation that the recorded values indicate humification rather than anaerobic conditions.

Process performance under decentralized conditions

The experimental results demonstrate that effective compost stabilization can be achieved even in small-volume containers operated under real rural conditions. Unlike industrial systems that rely on automated aeration and controlled environments, the present setup functioned with minimal technological input while still reaching maturity indicators consistent with agronomic standards.

This finding carries practical significance for small-scale farming systems, where financial and infrastructural constraints often limit access to centralized waste treatment facilities. Low-cost mechanical interventions such as shredding and manual aeration can substantially improve process efficiency without requiring major capital investment.

By enabling on-site organic residue recycling, mechanically assisted composting supports circular nutrient management while reducing dependency on external inputs — an approach aligned with current European strategies for sustainable soil management [9].

Final compost characteristics

The visual appearance of the compost obtained after 70 days is illustrated in Photo 2.



Photo 2. Final appearance of the compost obtained in the three experimental containers after 70 days of aerobic composting under decentralized rural conditions.
Source: Photo taken by authors.

The final compost presented a dark brown coloration, a friable texture, and a homogeneous structure, all widely recognized indicators of advanced organic matter stabilization and compost maturity.

No visible undecomposed residues were detected, indicating effective organic matter degradation across all experimental variants.

Practical implications for small-scale farming

The findings of this pilot study have direct practical relevance for small-scale farming systems where access to industrial composting infrastructure is limited. The results demonstrate that effective organic waste stabilization does not necessarily require complex technological solutions.

Instead, low-cost mechanical tools can substantially improve process efficiency while remaining accessible to rural households. This operational simplicity increases the likelihood of adoption and supports the transition from

residue disposal to circular nutrient management practices.

Economic and operational relevance

Beyond the agronomic benefits, the experimental results highlight the economic feasibility of mechanically assisted composting for small-scale farming systems. Unlike industrial composting technologies that require substantial capital investment, automated aeration, and specialized infrastructure, the system evaluated in this study relied exclusively on low-cost mechanical tools commonly available in rural households.

The electric shredder and manual auger used in the experiment represent accessible equipment that does not impose significant financial barriers for farmers. This reduced technological dependency enhances the transferability of the method and supports its rapid adoption in regions where waste management alternatives remain limited.

From a management perspective, decentralized composting contributes directly to on-farm nutrient recycling, reducing the need for externally purchased fertilizers while simultaneously addressing regulatory restrictions on residue burning. Such integration aligns with European policy objectives promoting circular bioeconomy models and sustainable soil management [9].

Moreover, although the present study was conducted at the household scale, the operational principles remain scalable. Replication through modular container units could enable cooperative or community-level composting initiatives without requiring a full industrial transition. This scalability strengthens the strategic relevance of mechanically assisted composting as both an environmental and economic solution for rural territories.

Study limitations

This study presents several limitations that should be acknowledged when interpreting the results. The experimental design was exploratory and conducted at the pilot scale, with each container representing a distinct operational variant rather than a replicated treatment. While analytical determinations were performed in triplicate to enhance data reliability, the absence of spatial replication limits the statistical generalization of the findings.

Additionally, the relatively small container volume reflects household-scale conditions and may not fully capture the thermal inertia and process stability characteristic of larger composting systems. Environmental factors such as ambient temperature and natural moisture fluctuations also influenced process dynamics, as the experiment was intentionally implemented under real rural conditions rather than within a controlled laboratory environment.

Despite these constraints, the applied nature of the study provides valuable insight into the practical feasibility of mechanically assisted decentralized composting. The results should therefore be interpreted as operational evidence supporting scalable residue management strategies, while future research should prioritize replicated designs, larger processing volumes, and integrated economic assessments to strengthen external validity.

CONCLUSIONS

This pilot study evaluated the performance of mechanically assisted aerobic composting under decentralized rural conditions using low-intensity mechanical interventions accessible to small-scale farms.

The results demonstrate that mechanical pre-treatment of biomass significantly influences composting dynamics. Particle size reduction facilitated rapid microbial activation and generated the highest thermophilic peak (58 °C), supporting effective sanitation of the composting mass. Conversely, periodic mechanical aeration proved decisive for achieving advanced biochemical maturity, as reflected by the lowest final C/N ratio (14.8). Although moderate nitrogen reductions were observed in the aerated variant, all compost treatments produced stable organic amendments suitable for agricultural use.

The convergence of thermal behaviour, pH stabilization, redox balance, and nutrient profiles confirms that controlled aerobic

degradation can be successfully achieved even at the household scale. Importantly, all compost variants complied with agronomic safety thresholds defined by Regulation (EU) 2019/1009 [24], indicating their environmental compatibility and potential contribution to circular nutrient management.

Rather than identifying a single optimal strategy, the results support a sequential mechanical approach in which shredding ensures sanitation while aeration promotes biochemical stabilization.

From a rural development perspective, the findings suggest that effective organic residue stabilization does not necessarily require complex technological infrastructure. The use of affordable mechanical tools — such as electric shredders and manual augers — can support on-farm and household nutrient recycling, reduce dependence on external inputs, and provide a practical alternative to residue disposal practices restricted under current environmental regulations. Such compositing systems may be easily used in rural areas inside protected areas.

Although conducted at a pilot scale, the operational principles observed in this study demonstrate strong transferability and potential for modular scaling. Mechanically assisted decentralized composting may therefore represent a viable management strategy capable of simultaneously supporting soil health, improving resource efficiency, and strengthening the transition toward circular bioeconomy models in small-scale agroecosystems.

Future research should focus on replicated trials, extended process monitoring, and economic assessments to further validate system robustness and quantify its long-term benefits for sustainable rural waste management, organic fertilizer production, and the implementation of nature-based solutions for soil regeneration [19].

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EFFICIENCY OF COTTAGE CHEESE PRODUCTION FROM MILK OF DIFFERENT COW BREEDS

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Abstract

The effect of cattle breeds on the technological properties of milk in the production of cottage cheese is understudied to date. Modern domestic dairy breeds have hardly ever been studied in this regard. This issue is particularly relevant in the context of the peculiarities of creating domestic breeds by including the best global gene pool in the selective breeding process. The aim of the study was to determine the effect of cattle breed on the technological properties of milk when processed into cottage cheese. Interbreed differentiation in milk quality characteristics has been revealed. It has been established that the use of milk from Brown Swiss cows increases the yield of cottage cheese (by 6.2%), which is characterized by a higher content of protein and dry matter. There is no difference in the organoleptic characteristics of cottage cheese made from the milk of the studied breeds. In terms of quality characteristics, cottage cheese from Brown Swiss cows prevails. The efficiency of cottage cheese production is higher from cows of the Ukrainian Brown dairy breed.

Key words**:** *milk, breed, cattle, cottage cheese, cheese yield*

INTRODUCTION

Cottage cheese contains easily digestible and complete proteins; therefore, it has a high biological and nutritional value. This product is important in children's nutrition. The quality of cheese and, accordingly, the economic attractiveness of its production depends on the organoleptic, physicochemical and technological properties of milk [19]. It has been proven that cow genotypes for various milk proteins: alpha-casein [2], beta-casein [1] and kappa-casein [1], beta-lactoglobulin [1] and alpha-lactalbumin [1] have a significant impact on its technological properties.

The quality of raw milk is a key factor in the efficiency of dairy production. Protein is one of the important milk constituents, which explains the interest of researchers in studying its structure [23]. Cattle breeds differ significantly in the genetic structure of milk proteins [25]. Recently, scientists have been paying more attention to the composite genotypes of animals in terms of milk proteins [21]. Beta-casein gene is considered a new genetic marker of milk quality characteristics. This has led to an increase in the frequency of the A2 allele of this protein. At the same time, the effect of the beta-casein gene on the technological properties of milk remains poorly studied. This can lead to a decrease in profits due to a reduction in the amount of product obtained or a deterioration in its quality [8]. Separate research findings indicate that milk from animals with the A2A2 genotype is characterized by undesirable technological characteristics: in cheese production, the curdling time and the amount of raw materials required increase; in yogurt production, a weak curd forms [7]. The

genotype for the beta-casein gene influences the technological properties of milk [4]. This is explained by the difference in milk coagulation between cows with different genotypes for this gene [9]. The evaluation of animals for kappa-casein increases the efficiency of improving the technological properties of milk [4]. Such genes as beta-casein, kappa-casein, and beta-lactoglobulin considered constituent elements of milk, which are associated with its technological properties [6].

Kappa-casein protein is one of the main milk proteins [11, 16]. Researchers have revealed the influence of the kappa-casein gene on the technological properties of milk in cheese production [3]. When producing cheese from milk from cows with the BB genotype for the kappa-casein gene, the time required for curd formation is reduced. In addition, less raw material is required to produce cheese from such milk [5, 15]. Similar trends are characteristic of cottage cheese production [22]. The genotype of cows for beta-lactoglobulin gene affects their milk productivity traits [10, 24]. Animals with homozygous BB genotype have a higher content of fat and protein in milk [18, 24]. Scientists believe that one of the important technological properties of this protein is the interaction with casein, the result of which is the slowing down of rennet clotting [17].

Domestic dairy breeds, created using the best global gene pool, differ significantly in the genetic structure of milk proteins. Holstein, Swiss, Ayrshire, and Montbéliarde breeds were involved in their creation. They are characterised by the specific genetic structures of milk protein genes and productive features. This has undoubtedly contributed to the formation of productive traits in domestic cattle breeds [12, 13]. Therefore, it can be assumed that there are differences between them in terms of the technological properties of milk.

MATERIALS AND METHODS

The experimental groups were formed from cows of two domestic dairy breeds (9 heads in each): Ukrainian Brown Dairy breed (experimental group I) and Sumy intrabreed type of Ukrainian Black-and-White Dairy breed (experimental group II).

Experimental samples of cottage cheese were produced by the acid method according to the classical technology. Main technological processes: cooling of milk to a temperature of 4±2°C, filtration, pasteurization at 76±2°C with a holding time of 20 seconds, cooling to the fermentation temperature (32±2°C), introduction of 3-5% of starter from the amount of the mixture, fermentation 6-8 hours, cutting the curd into 2x2 cm cubes, increasing acidity and separating the whey, slowly heating the curd for one hour at a temperature of 40–48°C, separating the curd from the whey, self-pressing (2-4 hours), cooling (4±2°C), packing, storage (4±2°C).

Samples studied in accordance with the requirements of DSTU 4554:2006 "Lactic cheese. Technical conditions". The selection of the average sample of the studied products carried out in accordance with DSTU 4834:2007 "Milk and dairy products. Rules for acceptance, selection and preparation of samples for control". To determine the quality of lactic cheese, the following indicators were selected: organoleptic (colour, consistency and appearance, smell and taste), physicochemical (acidity, content of the main constituents). Moisture content was determined according to DSTU 8552:2015 "Milk and dairy products. Methods for determining moisture and dry matter", fat content (DSTU ISO 11870:2007), protein content according to DSTU ISO 8968-1:2005). The efficiency of cottage cheese production was calculated by the ratio of theoretical and experimental cheese yield using the appropriate methodology [14]. Statistical processing of research results was carried out according to generally accepted methods [20].

RESULTS AND DISCUSSIONS

There is a difference in milk composition between the animals of the experimental groups. The animals of the first group have a higher average fat content in milk ($P<0.05$). No difference is found in the average protein and dry solids content (Fig. 1).

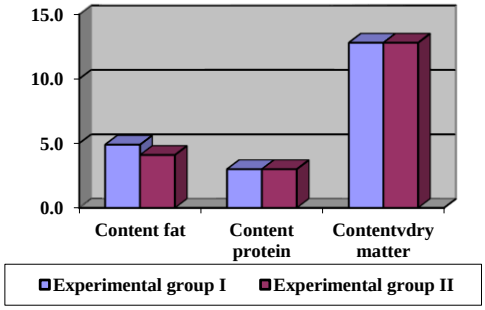


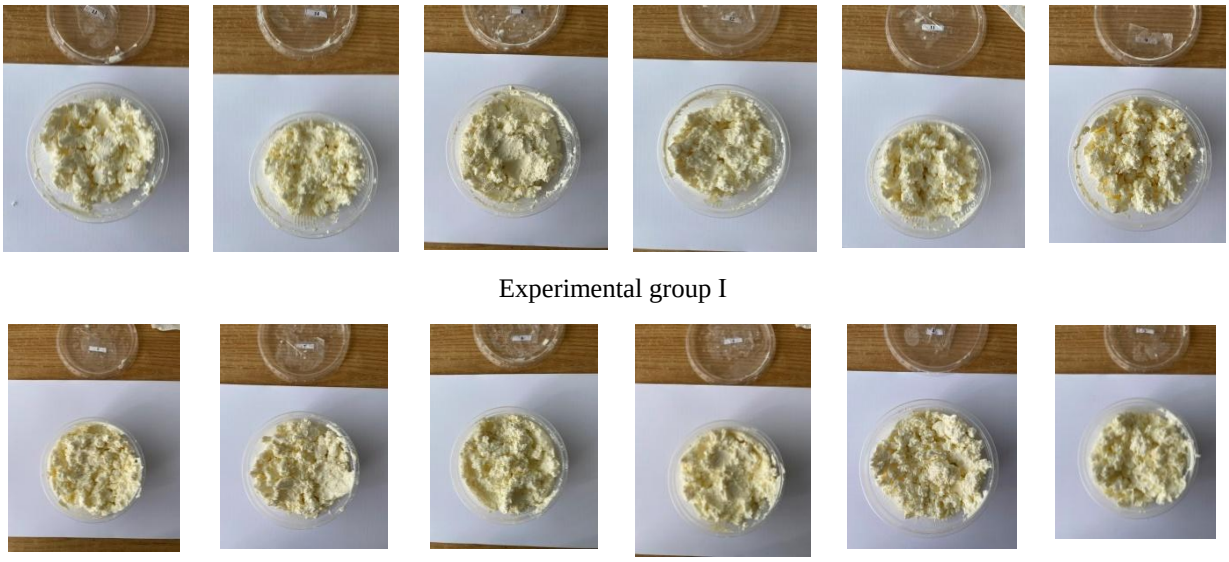
Fig. 1. Milk constituents, %
Source: Own research.

No differences are found in terms of average density (pH = 6.7) and milk acidity (1,026.0). The results of studies of the technological characteristics of milk indicate that the highest average yield of cottage cheese is observed in milk from cows in the first experimental group. ($P<0.01$). As a result, milk consumption per unit of production in the first group was lower. ($P<0.01$) (Table 1). No differences between the experimental groups were found as for most organoleptic indicators of sour milk cheese. They only differed in appearance and consistency. All experimental cheese samples were white in colour.

Table 1. Study of the technological and economic characteristics of milk in terms of milk and cheese yield

Experimental groups	Amount of product obtained from 1 kg of milk, g	Cheese yield, %	Milk consumption for the production of 1 kg of product
I	293.0±11.97	29.3±1.20	3.44±0.14
II	231.1±10.02	23.1±1.00	4.37±0.19

Source: Own research.



Experimental group I

Experimental group II

Fig. 2. Appearance of sour milk cheese samples
Source: Authors' own research.

The cheese samples from experimental group I had a coarse texture, in contrast to the samples from experimental group II. All samples had a characteristic sour milk and creamy taste and aroma. No differences in taste and smell were found between the experimental groups. The quality characteristics of manufactured products are of fundamental importance in terms of their appeal to consumers. We have established that there is a certain difference between the experimental groups in terms of the qualitative composition of cottage cheese. The latter were characterized by a smooth consistency with some graininess (Fig. 2). Samples from the first group prevail in terms of average protein and dry matter content. Meanwhile, samples from the second group prevail in terms of fat and moisture content. (Table 2).

Table 2. Characteristics of cottage cheese

Experimental groups	Indicators				
	Protein content,%	Fat content, %	Dry matter content, %	Humidity, %	pH
I	14.8±1.27	15.4±0.95	32.7±1.22	67.3±1.22	4.3±0.01
II	12.9±2.10	16.5±1.27	31.9±1.94	68.1±1.94	4.3±0.01

Source: Authors' own research.

It has been found that the production of cottage cheese is more efficient when using milk from cows in the first experimental group, where it exceeded the indicator for the second group by 17% (Fig. 3).

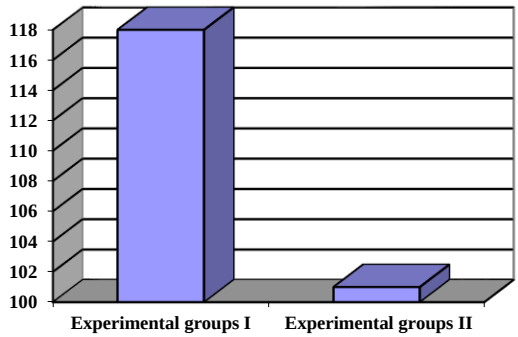


Fig. 3. Efficiency of cottage cheese production, %
Source: Own research.

CONCLUSIONS

Milk raw materials from cows of two domestic dairy breeds were studied. A difference in milk fat content was found in favour of animals of the Ukrainian brown dairy breed.

The main technological properties of milk differed between the experimental groups. In the production of cottage cheese, milk from Brown Swiss cows has a higher yield (by 6.2%). As a result, a larger amount of milk from Black-and-White cows is required to produce 1 kg of cottage cheese. There is no significant difference between the studied groups in terms of the organoleptic characteristics of fermented milk cheese.

According to quality characteristics, cottage cheese from Brown Swiss cows prevails (in terms of protein and solids content).

The evaluation of the efficiency of cottage cheese production indicates that there is an inter-breed difference in the technological characteristics of milk raw materials from cows of the studied breeds in favour of Brown Swiss cattle.

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TILLAGE TECHNOLOGIES AS A FACTOR IN OPTIMIZING SOIL FERTILITY AND STABILIZING WINTER WHEAT YIELDS

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Abstract

The article presents data on the impact of traditional and zero technology of winter wheat cultivation on the agrophysical properties of the soil, such as the content of productive moisture and water resistance, as well as crop yields. It has been revealed that the cultivation of winter wheat using zero technology contributes to the formation of more moisture and water-resistant aggregates due to the plant residues present on the surface. During landfill treatment, moisture evaporates from the soil and the amount of moisture decreases. The conducted studies allow us to recommend a zero technology of winter wheat cultivation, which is especially important for arid areas with the manifestation of erosion processes.

Key words**:** *winter wheat, zero technology, plowing, water resistance. productivity*

INTRODUCTION

The State Program for the Development of Agriculture in the Russian Federation and regulation of agricultural products, raw materials and Food markets for 2013-2020 provides for an increase in crop and livestock production. To implement the planned plans, it is necessary to carry out a number of measures, including the implementation of technical and technological modernization of agriculture, optimization of the cost of material and technical resources.

International agricultural experience demonstrates that regular deep plowing not only fails to provide benefits but also inflicts irrevocable damage by exacerbating erosion. Soil cultivation adversely affects its health, eliminating beneficial microbes, predatory insects, and earthworms. Moreover, the swift depletion of moisture from the seedbed compels premature commencement of fieldwork, frequently under unfavorable conditions with cold and overly wet soil [6].

Research findings indicate that using No-till technology leads to an accumulation of dry biomass from plant residues on the soil's surface nearly twice as much compared to traditional methods. This prevents excessive soil compaction, enhances structure and granular composition, increases soil aggregate size, and boosts organic matter content. Residues on the soil surface safeguard against erosion, lower surface temperatures, thereby enhancing soil fertility and crop productivity [12].

Southern carbonate chernozem soils have a genetic predisposition to wind erosion, necessitating protection through a cover of plant residue. The No-till farming technique offers advantages because it enables leaving all stubble on the field’s surface, particularly when crops are harvested using the combing method [13].

The authors suggest improving the precision of seed placement depth during direct drilling and implementing comprehensive weed management both prior to and within the initial weeks following sowing. To successfully implement the no-till technology, appropriate machinery such as specialized seed drills capable of operating amidst vegetative remains, along with tools for weed elimination and soil maintenance, must be utilized.

As noted by the authors, no-tillage techniques could potentially reduce greenhouse gas

emissions by approximately 21.2%, contributing significantly towards environmental cleanliness [10].

Studies demonstrate that the use of potassium fertilizers on sandy loam soils under zero-tillage conditions is crucial for attaining economically feasible crop yields. [8].

Plant residues on the soil surface during direct sowing lead to a substantial buildup of available phosphorus in comparison to ploughed fields across all studied areas, sustaining the trend of phosphorus accumulation in chernozem soils within a 10-20 cm layer [1].

According to scientists, at the present stage such land resource management systems are needed, which include the principles of soil conservation agriculture and may eventually lead to the accumulation of carbon in the soil in organic resource-saving agriculture (SOC) [3]. According to their data, it was proved that the absence of cultivation of winter wheat using no-till technology contributed to an increase in the biomass of soil microorganisms in the upper 0-30cm soil layer.

Similar observations are presented in the study conducted by these authors, who established that adopting the No-till technology leads to a reduction in the activity of agriculturally valuable microbial groups [5].

Conversely, it has been demonstrated that traditionally plowed soils exhibit greater diversity of micromycetes compared to those managed under no-till systems. High numbers of cellulolytic fungi were observed specifically in conventionally processed soils planted with soybeans and winter wheat, as well as in maize fields subjected to no-till practices [7, 11].

Under zero-treatment conditions, the amount of water-stable aggregates larger than 0.25 mm in pea-growing soil was considerably higher—by 68.61%—compared to moldboard plowing [2].

The No-Till technology makes it possible to restore eroded soil and expand the area of cultivated land, preserving soil fertility as a practice of sustainable soil management [9]. Zero technology, compared with conventional tillage, contributes to a significant increase in organic carbon in the 0-5 cm thick soil layer and a slightly smaller increase in the 5-10 cm thick layer [11].

Through their research, the authors have proven the probability of reaching the 90th percentile of yield with zero tillage.

Drepa et al. (2022) experimented no till system using 8 winter wheat varieties after sunflower and peas in the arid zone of the Stavropol Territory and evaluated the economic results in terms of yield, production cost, and profit. They noticed different economic results depending on wheat variety and predecessor plant [8].

If we consider agriculture as a soil improvement strategy, then no-till technology has more prospects. However, it is important not to forget about agronomic rules – it is necessary to properly manage plant residues, carry out optimal crop rotation and use suitable equipment. Only if these conditions are met, the soil properties can be improved.

In this context, the purpose of the research is a comparative assessment of no-till (direct seeding) technology and the recommended cultivation technology for winter wheat in the arid zone of the Central Ciscaucasia.

MATERIALS AND METHODS

The object of the study is winter wheat cultivated after peas as a predecessor. The wheat variety is 'Alekseich', with a seeding rate of 4.5 million seeds per hectare.

The research was conducted from 2021 to 2024 in the arid zone of the Central Ciscaucasia, with an average annual precipitation of 350-400 mm on dark chestnut soils.

The experiment was conducted under production conditions. The total field area was 100 hectares, with a plot sampling area of 55 m². The experimental design was a systematic layout with three replications.

The research objectives included:

-Determining soil moisture reserves and soil structure water stability depending on the cultivation technology.

-Determining winter wheat yield for each cultivation technology variant.

The recommended (conventional) tillage technology involves the following operations:

-Stubblediscing (Büller 370 + BDM-6).

-Ploughing (Büller 370 + PLN-5-35).
-Pre-sowing cultivation (Büller 370 + KPS-12 with packing rollers).
-Sowing winter wheat (СЗ-3,6 seeder).
-Post-sowing rolling (МТЗ 12-21 + СГ-21+3ККШ-6А).
-Mineral fertilizer application (МТЗ 12-21 + Amazone - Zg-B 5500/8200).
-Spraying (МТЗ-80 + ОП-2000).
-Harvesting (JohnDeere 9660 STS).
The machinery system used has several drawbacks: a high number of field passes, low efficiency of the employed technical means (low productivity, increased fuel consumption). Given the rising prices for machinery and fuels and lubricants, this does not contribute to saving energy and financial resources and leads to increased production costs and reduced profitability. From an agronomic standpoint, the main disadvantages of this technology include: soil compaction, drying of the topsoil, and uneven seed placement, leading to plant stand thinning and loss of part of the seed material.
Therefore, a no-till technology for winter wheat cultivation has been introduced on the farm, represented by the following operations:
-Sowing winter wheat with a Büller + Great Plains seeder.
-Spraying with a John Deere sprayer.
-Harvesting with a John Deere 9660 STS.
During the scientific research, the following soil analyses, observations, and recordings were carried out throughout the plant growing season:
-Determination of soil moisture reserves was performed according to the method by Dospekhov B.A., Vasiliev I.P., Tulikov A.M. (1987) and GOST 28268-89.
-Yield assessment was conducted using the mechanized harvesting method according to the state variety testing methodology for agricultural crops (1983), with subsequent conversion to standard moisture (GOST 10856-96) and purity (GOST 10854-88) levels.
Statistical processing of the research results was performed using analysis of variance and correlation-regression methods according to B.A. Dospekhov (1985), utilizing the Polyfactor and Statistica 17.0 software packages.

RESULTS AND DISCUSSIONS

Water is an integral part of plant life, providing them with vital nutrients. Soil moisture also acts as a thermo-regulator, affecting the thermal balance and soil regime. The soil moisture level directly affects its agrophysical properties, such as density, stickiness, water resistance, crumbling ability and formation of agronomically valuable aggregates. One of the key factors determining the water-physical properties of the soil is its basic processing and technology of cultivation of crops.In the arid regions of our region, when growing winter wheat, special attention is paid to the use of moisture-saving techniques.
Observations of the dynamics of productive moisture in the arable and meter-deep soil layer have shown that these indicators differ significantly depending on the technology of cultivation used (Fig. 1).

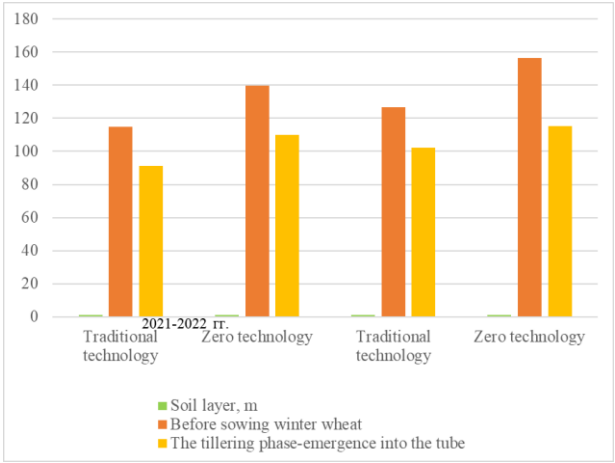


Fig. 1. Productive moisture reserve in winter wheat crops, mm
Source: Own results.

Our data show that the recommended tillage technology for winter wheat yields inferior moisture reserves to the no-till technology, especially when comparing the dry conditions of the 2021-2022 growing year with the wetter 2022-2023 growing year.
Before sowing winter wheat in 2022-2023, the plow layer in the no-till system contained 29.9 mm of moisture, while the one-meter layer contained 156.6 mm. In the recommended

technology, which utilized plowing as the primary tillage, the moisture content was 17.9 mm and 126.6 mm, respectively, in the 0-30 cm and 0-100 cm layers. While the moisture content was sufficient to ensure uniform and timely emergence, the no-till technology still has an advantage over the recommended technology in terms of moisture accumulation and retention. Conditions were somewhat different in the dry 2021-2022 growing year. While the no-till variant had good moisture reserves at the time of winter wheat sowing—21.4 mm of moisture in the topsoil and 139.8 mm in the topsoil—the conventional method yielded significantly lower levels: 10.6 mm and 114.7 mm, respectively. This level of moisture in the topsoil is not optimal for achieving uniform and timely winter wheat emergence.

As a rule, after harvesting the preceding crop, the soil is sufficiently dry, and only the possibility of precipitation provides the necessary moisture for normal emergence. Tillage aimed at moisture conservation plays a significant role. For example, with the recommended tillage method, which involves double stubble cultivation after harvesting the preceding crop, followed by plowing as the primary tillage, as well as cultivation to destroy weeds, partial evaporation of soil moisture occurs, which subsequently affects soil moisture content. The period from tillering to booting is a period of critical water consumption.

During this phase of crop development, ear rudiments form, plant rooting occurs, and stems develop. Insufficient soil moisture during this period can lead to a reduction in future yield potential. According to our scientists, during this period, productive moisture reserves in the arable layer should be at least 10-15 mm, and in the meter-deep layer, approximately 120 mm.

This research shows that the productive moisture content for the two technologies studied was optimal for crop growth.

With the recommended technology, the arable layer contained 21.5 mm, and the meter-deep layer contained 91.3 mm, while with no-till, these figures were 30.4 mm and 109.8 mm.

Consequently, no-till cultivation of winter wheat promotes greater soil moisture accumulation compared to traditional methods, which is especially important in the arid regions of the region.

An important property of aggregates is their strength, or resistance to the eroding action of water. The water resistance of the structure determines the stability and longevity of soil regimes.

Loose clods are broken down by precipitation or irrigation water, and the soil assumes a fragmented state with all its negative properties.

Soils with a high organic matter content have aggregates that resist the eroding action of water.

Conversely, soils with a low organic matter content are easily eroded by water, leading to the intensive leaching of fine soil particles, i.e., erosion.

In 1886, P.A. Kostychev was the first to develop a classification of soil structure according to its resistance to water: water-resistant, agronomically valuable, and non-water-resistant.

The water resistance of the soil structure determines the stability and longevity of various soil regimes.

Loose clods are broken down by precipitation or irrigation water, and the soil assumes a fragmented state with all its unfavorable properties for cultivated plants.

The structural condition of the soil depends on the number of water-stable aggregates.

The water-stable nature of soil aggregates is crucial for resisting soil erosion. Mechanical stress on the soil affects the water-stable nature of aggregates.

Based on the content of water-stable aggregates, soil structure is classified as follows: excellent (more than 70% water-stable aggregates); good (70-55%); satisfactory (55-40%); unsatisfactory (40-20%); and poor (less than 20%).

Soil texture is a key indicator of soil fertility, characterizing the structural composition and content of water-stable aggregates.

Favorable texture provides resistance to erosion and compaction, improves soil

conditions, and increases crop productivity. The optimal content of water-stable aggregates (0.25-10 mm in size) for sod-podzolic and gray forest soils is 30-45%; for chestnut soils – 35-50%; for chernozem soils – 45-60%.

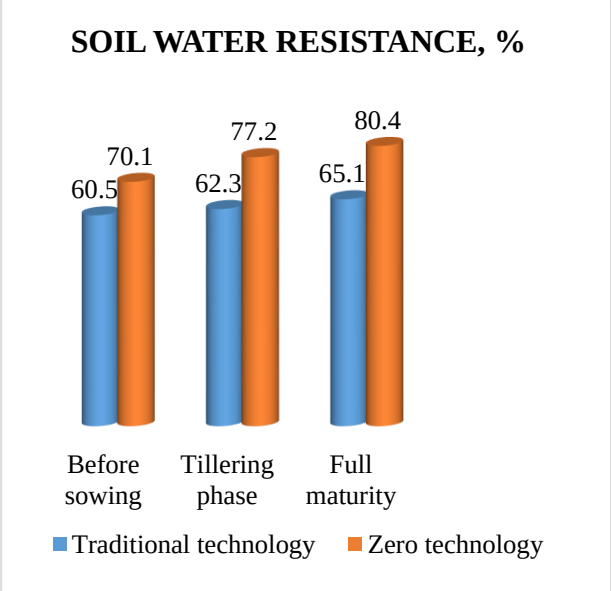


Fig. 2. Water resistance depending on primary soil cultivation methods (2021-2023)
Source: Own results.

The quantity of water-stable aggregates was also determined in all growth and development phases of winter wheat. As the research showed, the content of aggregates in the plow layer of soil at the time of winter wheat sowing varies depending on the methods of primary tillage.

Prior to the sowing of winter wheat, the greatest quantity of water-stable aggregates was noted in the no-till treatment and amounted to 70.1%, which is 9.6% higher than with plowing. One of the drawbacks of plowing is that turning the furrow slice brings the biologically active, more loosened layer to the surface, which is more susceptible to water erosion. A reduced content of water-stable aggregates leads to soil slaking, that is, crust formation.

The preservation of plant residues in the upper soil layers with surface tillage contributes to soil protection from solar overheating, improves precipitation accumulation, and reduces evaporation. All this activates the work of microorganisms and promotes the formation of a water-stable structure.

The same dependence is observed in the spring tillering phase. The greatest quantity of water-stable aggregates is noted under no-till treatment and corresponds to 77.2%. Under plowing, the quantity of water-stable aggregates is lower and amounts to 62.5% (Figure 2).

By the phase of full maturity, the quantity of water-stable aggregates increases across all tillage treatments, but the advantage remains with no-till technology. This treatment also shows the greatest quantity of water-stable aggregates at 80.4%, corresponding to excellent water stability of the structure. Somewhat lower water stability was observed in the treatment where plowing was used as the primary tillage — 65.1%, which corresponds to good water stability of the soil structure.

Consequently, in optimizing the agrophysical indicators of soil fertility, a significant role belongs to soil tillage within crop cultivation technologies.

The cultivation of winter wheat using no-till technology promotes the formation of an excellent soil aggregate structure.

The main indicator of the entire experiment is grain yield. Data on winter wheat grain yield depending on the primary soil tillage method are presented in Table 1.

Table 1 presents the results of statistical analysis, which demonstrated that the yield of winter wheat increases in the recommended tillage treatment, and compared to the no-till technology, it was not statistically significant.

Table 1. Grain yield of winter wheat depending on soil tillage technologies, t/ha

Treatment	2022	2023	Average
Recommended Technology	3.00	4.31	3.65
No-Till Technology	2.41	3.22	2.82
Sx, %	0.47	0.89	
HCP_{05},t/ha	2.33	1.85	

Source: Own results.

The highest grain yield was in the recommended tillage treatment, averaging 3.65 t/ha over the years of research. In the treatment using no-till technology, it was 0.58 t/ha lower.

Economic Efficiency

Economic efficiency reflects the ultimate beneficial effect from the application of means of production, in other words, the return on aggregate investments. In agriculture, the criterion of efficiency is the increase in net output (gross income) with minimal costs of living and materialized labor. This is achieved through the rational use of land, material, and labor resources.

The calculation of economic efficiency (Table 2) showed that the maximum profit from winter wheat grain production was obtained in the no-till technology variant – 10,206.4 rubles per ton of product, which exceeded the recommended technology variant by 6,073.9 rubles.

Table 2. Economic indicators by type of applied technology and year: production cost per ton, income per ton, profit per ton.

Type of technology	Prod. cost (Rubles/ton)	Income (Rubles/ ton))	Profit (Rubles/ ton)
Recommended Technology	8,226.3	12,358	4,132.5
No-Till Technology	7,956.6	18,163	10,206.4
Differences	269.7	5,805	6,073.9

Source: Own results.

This is related to the fact that production costs per hectare are lower in the no-till variant, and consequently, the production cost per ton of product is also lower by 269.7 rubles.

As a result, the income from cultivating winter wheat using no-till technology amounted to 18,163 rubles per ton, exceeding this indicator in the recommended technology variant by 5,805 rubles.

Consequently, in the arid zone of the Central Ciscaucasia, high production profitability is ensured by cultivating winter wheat using no-till technology, which plays not only a soil-protective role but also contributes to high profitability of agricultural crop production.

CONCLUSIONS

Therefore, the no-till technology for winter wheat cultivation ensures uniform seedling emergence, good overwintering, and further plant development.

Compared to the classic technology, the higher economic profitability of the no-till technology under the conditions of a lower yield is explained by the lower costs associated with soil tillage using machinery and implements, which in the recommended tillage system account for approximately 40% of all production costs.

The deterioration of the phytosanitary situation in the no-till (reduced tillage) treatment is primarily attributed to the accumulation of plant residues, which serve as a substrate harboring disease inoculum and larvae of winter wheat pests.

Under this cultivation system, continuous monitoring of harmful organisms and the timely application of plant protection products, predominantly biological agents, is essential.

However, the deterioration of the phytosanitary condition leads to a reduction in yield compared to the recommended tillage.

Aa a final conclusion, No-till technology is applied on an area of 320 thousand hectares in the Central Ciscaucasia.

More than half of this area is located in the arid zones of the region, as under these conditions, no-till promotes moisture accumulation and conservation by preventing soil moisture evaporation during periods of high temperatures and protecting the soil from erosion processes.

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ECONOMIC EFFICIENCY OF HETEROSIS BREEDING OF PIGS IN UKRAINE

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Abstract

The aim of this article is to economically demonstrate the impact of the heterosis effect using animals of different breeding lines and methods of their breeding on the efficiency of rearing and fattening of hybrid pigs of different genetic origin in comparison with purebred pigs of maternal breeds and their crosses and with animals of the synthetic terminal parental line PIC-337 of the Pig Improvement Company selection. The study has shown that the profitability of piglet rearing and fattening depends largely on the breeding method. Purebred rearing of landrace pigs resulted in a 3.1 increase in the sales value of the nest, a 21.2%, increase in profit, a 3.9%, increase in profitability and a 21.2 increase in the sow's annual income compared to the large white breed. The use of the parent line PIC-337 in the purebred version made it possible to increase the gain by 69.3 %, the profitability by 21.2 %, and the annual income by 69.3 %. The use of the parental line PIC-337 in purebred form resulted in an increase in weight gain by 69.3%, profitability by 21.2%, and annual income by 69.3%. Implementing double crossbreeding of the maternal genotypes (♀LW×♂L and ♀L×♂LW) led to higher sales value (7.97–11.4%), profit (34.5–45.7%), profitability (5.6–7.1%), and annual income (34.5–45.6%) compared with purebred breeding of Large White pigs, which can be attributed to the heterosis effect. These findings suggest that purebred breeding ensures only a baseline level of economic efficiency. At the same time, interbreed crossing increases it by 30–45%, and intrabreed hybridization by 50–70%, which makes the latter method the most economically feasible for modern industrial pig farming.

Key words**:** *pig breeding method, heterosis, cost, income, profit, profitability*

INTRODUCTION

In animal husbandry, it is a well-known fact that crossbreeding usually yields better results than breeding within the same breed. It is known that [3, 34, 48], the main factor in the effectiveness of crossbreeding is heterosis - a phenomenon when the productivity of hybrid offspring exceeds the average indicators of parental forms. Recent studies [8, 10, 16] emphasize that the extensive application of crossbreeding in modern pig production is primarily driven by the benefits of hybrid vigor and the complementary traits of different breeds. Meanwhile, as highlighted by other researchers [30, 39], these beneficial effects tend to diminish in later generations, creating the need to maintain and selectively enhance purebred animals for continued use in crossbreeding programs. In addition, differences in the heritability of productive and reproductive traits do not always allow the full realization of the potential of heterosis. In this regard, the strategy of intrabreed hybridization is becoming increasingly widespread in modern pig farms [27]. In this approach, maternal lines (in particular, Yorkshire and Landrace) are bred separately from paternal lines, represented mainly by Duroc, Pietren or their combinations, which contributes to improving meat and fattening characteristics. Each line undergoes separate selection and systematic testing for compatibility for crossing [3, 9, 17]. As reported in earlier studies [7], over the past decades, industrial pig farming has been experiencing a steady increase in the proportion of hybrid pigs, which are widely used in fattening. According to [33], in countries with a developed pig industry, the share of such animals among the commercial livestock exceeds 80–85%. As shown by studies [35, 42, 47], hybridization allows young animals to be obtained with improved growth rates and higher carcass quality. This is

especially noticeable if terminal boars are involved in the final stage of crossbreeding schemes. As noted [15, 26, 36], carefully selecting breeds for creating maternal and paternal lines is crucial in this context. Large White and Landrace, which are characterized by a high level of reproductive ability, are usually used as maternal lines [33, 41]. Both purebred and crossbred boars are used for paternal lines. According to [1, 40], terminal boars are a key component of hybrid breeding systems. Among the breeds that most often perform this role, Pietre and Duroc dominate, as also reported by scientists [25, 35]. At the same time, as noted [1, 40], in practice, along with purebred boars, crossbred animals or representatives of synthetic lines created based on Duroc, Pietre and Hampshire breeds, but with different genetic proportions, are often used.

As it was reported [22, 24], Pietrain is often used as a parent breed in Europe, especially in Germany, Spain, France, Belgium and the Netherlands, as the animals of this breed have a higher meat content. According to research [45], an evaluation of the efficiency of heterosis when using domestic and foreign boars in industrial crossbreeding showed that the use of Pietrain and Red White Belt breeds in the final stage increases the profitability of pork production by 5.64–29.70%. The optimal option is the combination of Pietrain boars with crossbred sows of the Large White Ukrainian×Landrace selection, which brings an additional profit of 12.03 EUR compared to purebred carcasses and significantly improves the profitability of production. As stated by scientists [32, 44], in Denmark Duroc boars are traditionally used in combination with Landrace×Yorkshire (DLY) crossbred sows, resulting in high growth rates and good meat quality. According to reports [11, 12, 22], Duroc animals are characterised by high weight gain and intramuscular fat, while Pietrain have a higher meat content in the carcass. Comparative studies [28] showed that DLY outperforms PLY (Pietrain×LY) in growth rate by about 15.5 % and has a better conversion of 0.14 FEsv/kg. In Denmark [38], they were also used in parallel with Duroc boars as the last form of hybridisation of Hampshire boars. According to their data, the cross between Duroc and Hampshire reached slaughter weight 4 days earlier than the cross between Large White and Landrace. In another study conducted [29] in the United States of America and Canada, an economic evaluation of different crossbreeding schemes of four pig breeds was carried out. The results showed that the most productive combinations reduced production costs by 6.7–10.5 % compared to the most efficient purebred breed – Duroc. The rotational terminal crossbreeding system proved most effective under the Duroc×(Yorkshire, Landrace, Spotted) scheme, followed by the Duroc×(Yorkshire×Landrace) combination. The static variants Duroc×(Spotted×Landrace) and Duroc×(Spotted×Yorkshire) ranked third and fourth, respectively. The static variants Duroc×(Spotted×Landrace) and Duroc×(Spotted×Yorkshire) came third and fourth respectively. The authors emphasised that using three- and four-breed rotational terminal or static systems makes it possible to maximise the benefits of heterosis and breed compatibility in pig breeding.

In the conditions of industrial complexes of Ukraine [19], the average daily gain of animals of the Danish Duroc breed is 991–1,025 g with a feed conversion ratio of 2.75, and in the nucleus herd of LLC "Genetic-Invest" hybrids reached 1,100 g of gain per day, while purebred Durocs - 1,350 g. It was noted [37] that in the conditions of industrial pork production in Ukraine, the offspring of specialised parent breeds of Duroc and Pietren have higher growth rates than pigs of Large White and Landrace breeds.

According to the data in the publication [31], hybrid animals of Danish origin based on crossbred sows of the Landrace×Large White breed reached a live weight of 120 kg in 150–170 days with an average daily gain of about 1,000 g and feed consumption of 2.7–2.8 kg per 1 kg of gain. According to the results of the studies [46], pigs of Danish origin had a 9.6 % higher gross gain during fattening, which gave them a 7.6 % higher weight at the end of the fattening period, a 7.6 % higher market value

and a 10.1 % higher fattening income compared to animals of Canadian origin. The fattening profitability of these pigs was 0.77% better. Studies under industrial conditions in Ukraine of three combinations of commercial lines of sows (LW×L) with boars of the breeds Duroc (Genesus), Pietren (Axiom) and the terminal line Maxter (Hendrix Genetics) showed that at a weight of 80–100 kg, the best results were demonstrated by pigs of the Maxter breed [20]. They reached 100 kg in 152.73 days, faster than the others ($p<0.001$), with an average daily gain of 941 g and a feed conversion ratio of 2.64 kg. At a carcass weight of 120–140 kg, the pigs were better when combined with Duroc as finishing form, with an average daily gain of 900–901 g. According to study [6], in an industrial complex with Danish pig breeding in Ukraine, the best master results were achieved with the combination ¼Y ¼L ½D, which outperformed the variant ½Y ½L in growth rate by 5.4 % and in feed conversion ratio by 5.2 % and reached a weight of 100 kg 2.9 % earlier, resulting in an increase in profit by 24.4 % and an increase in profitability by 6.6%.

According to work [49], the second largest pig herd in Ukraine is represented by the English company Pig Improvement Company, which, according to report [7], in industrial farms of countries with developed pig farming, achieves average daily gains during fattening of 1,150 g and for the entire life period – 850 g with a feed consumption of 1.91 kg per 1 kg of gain. It was published [14] that, in Brazil, the combination of PIC 337 boars with Camborough sows of English origin achieved a gain during fattening of 1,002–1,008 g and from birth to slaughter of 751–774 g with a feed conversion ratio of 2.61–2.67. In the Philippines, hybrid pigs of this genetics achieved average daily gains of 861 g during fattening and 755 g during the entire life cycle with a feed conversion ratio of 2.70 kg according to the results of studies [18]. In the conditions of Ukraine, depending on the feeding system, the average daily gains in hybrids of the English PIC selection were 915–1,028 g with feed consumption of 2.77–2.91 kg [32] and 899–988 g with feed efficiency of 2.76–2.84 kg [43].

Other research [21] demonstrated that these hybrids surpassed purebred Landrace and Large White pigs, as well as their two-breed crosses, by 8.0–15.7% in growth rate, 0.6–2.8% in feed conversion efficiency, and 0.7–1.3% in survival rate when evaluating average daily and overall weight gains. According to a study [2], piglets from a combination of sows (½ ULW-1 ½ L) with Pietren boars achieved the highest fattening rates when using domestic and foreign pig breeds. They reached 100 kg live weight 7.6 days faster and consumed 3.33 feed units/kg gain. The most economical was the breeding of triple hybrids (¼ ULW-1 + ¼ L + ½ P) with a profitability of 22.3 % for fattening up to 100 kg and 12.5 % for up to 120 kg and being overweight over 100 kg reduced profitability. They believe the optimum method for producing pork fat is using Pietren and Red White-Belt boars and lard – Duroc boars from the Ukrainian selection. At the same time, note [5] that in the structure of industrial pig farming in Ukraine, the proportion of animals obtained by domestic selection is only 6.6%, while the majority consists of sows bred by genetics companies from abroad. The largest share is accounted for by animals of Danish origin, around 40%, while pigs from French breeding account for 21.8% and English 21.2%. International genetic companies regularly conduct compatibility tests on their lines to determine the most effective combinations. This article is dedicated to testing the economic efficiency of different combinations of English-bred pigs under industrial production conditions.

MATERIALS AND METHODS

In a study examining how breed and breeding methods affect the profitability of rearing and fattening hybrid pigs of various genetic origins, seven groups totaling 1,300 animals were established. These groups included purebred maternal breeds, their crosses, and pigs from the synthetic terminal parent line PIC-337 developed by the Pig Improvement Company. The experiment was conducted using different breeding methods – inbreeding, crossbreeding, and hybridisation – as well as different genotypes of the animals.

The control group (Group I) consisted of 200 pigs of the Large White (LW) breed, which were bred as purebreds. The second test group also consisted of 200 animals, but of the Landrace (L) breed, which was obtained by pure breeding. The third experimental group consisted of 100 animals and was obtained by in-line breeding of sows of the L-65 terminal line, which were inseminated with boars PIC-337 of the same genotype. In this way, the efficiency of fattening parent animals of the GGP level was compared.

In experimental groups IV and V (200 animals each), a simple crossbreeding was carried out. In group IV, Large White sows were mated with Landrace boars (♀LW×♂L), producing offspring with the ½LW×½L genotype. Conversely, in group V, Landrace sows were bred with Large White boars (♀L×♂LW), yielding progeny of the ½L×½LW genotype.

The experimental groups VI and VII (also 200 animals each) were formed by complex crossbreeding. In group VI, sows from the cross (♀LW×♂L) were inseminated with the semen of the boar PIC-337, which produced offspring with the genotype (¼LW×¼L)½PIC-337. In group VII – in the reverse combination: ♀L×♂LW) with boars PIC-337, which produced offspring with a hybrid genotype (¼L×¼LW)½PIC-337).

For all groups, the duration of the suckling period was 28 days, the rearing period 49 days and the fattening period 100 days. This study set out to determine how various breed combinations and breeding approaches impact key production outcomes – specifically growth rates, feed utilization efficiency, and overall economic returns – when raising and fattening purebred, crossbred, and hybrid pigs, together with their litters, under intensive farming conditions.

The experimental materials were processed using variational statistics methods [23].

During the study, all manipulations of pigs were performed in accordance with the rules and principles of humane treatment of animals [13].

All procedures were performed with minimal stress to the animals, ensuring adequate housing conditions, access to food and water, and veterinary supervision throughout the experiment.

Biometric analysis of the research findings was conducted using Microsoft Office Excel 2016. The levels for statistical significance were established at $p<0.05$, $p<0.01$, and $p<0.001$.

RESULTS AND DISCUSSIONS

The study analysed the effects of different breeding strategies on piglet survival and weight gain patterns. Analysis of the data presented in Table 1 revealed differences between the experimental groups, which were primarily related to the genotypes of the animals and the breeding methods used.

In the case of purebred breeding, the maternal breeds – Large White (Group I, control) and Landrace (Group II) – produced generally similar results, although Landrace exhibited a slight advantage.

Pigs in Group III, which were produced through linebreeding (terminal line PIC-337), displayed significantly higher productivity at all stages. Notably, their birth weight was 1.43 kg, an increase of 13.5% compared to the average of the purebred maternal breeds ($p<0.01–0.001$).

The live weight at weaning for this group reached 8.04 kg, marking a 19.5% increase, and the final live weight at the end of fattening was 145.0 kg, surpassing the control group by 26.70% ($p<0.001$).

Application of two-breed industrial crossbreeding of maternal lines (Group IV: ♀LW×♂L and Group V: ♀L×♂LW) led to an improvement in productivity indicators, primarily due to the heterosis effect.

As a result, the final live weight of pigs in these groups reached 123.5 kg and 125.2 kg, exceeding the control group values by 4.5% and 5.9%, respectively ($p<0.01–0.001$).

In purebred breeding, the animals of two maternal breeds – the Large White (first, or control group) and the Landrace (second group) – showed comparable performance metrics.

However, the Landrace breed exhibited a slight advantage in its indicators: the weight of newborn piglets was 1.29 kg (+2.38%

compared to the control), the number of piglets at weaning was 13.30 animals (+2.31%) and the live weight at weaning was 6.75 kg (+0.45%).

Table 1. Survival and dynamics of live weight of pigs from birth to slaughter

Indicator	Groups						
	I	II	III	IV	V	VI	VII
Individual piglet birth weight, kg	1.26±0.005	1.29± 0.010	1.43± 0.006 *bb ggg lll mmm nnn ooo*	1.34± 0.010 *cc hhh*	1.36±0.006 *iii*	1.35 ±0.005 *jjj*	1.39±0.005 *f kkk rrr vvv*
Litter size at weaning, head	13.00±0.13 *ввв*	13.30±0.16 *ccc*	10.90±0.07	13.36±0.10 *d*	13.41±0.12 *e*	13.29±0.16 *mmm*	13.45±0.11 *ii nnn*
Individual piglet weaning weight, kg	6.72±0.029	6.75±0.05	8.04±0.03 *bbb ggg*	6.98±0.05 *ccc hhh*	7.04±0.02 *ddd iii*	7.12±0.02 *eee jjj qq*	7.24±0.*025 fff kkk rrr uuu vv*
Litter size at the beginning of the finishing phase, head	12.65	13.03	9.28	13.09	13.23	13.11	13.27
Post-nursery piglet weight, kg	26.60±0.11	26.81±0.20	32.60±0.13 *bbb ggg lll mmm nnn ooo*	27.53±0.22 *ccc h*	27.83±0.11 *ddd iii*	29.35±0.10 *eee jjj qqq ttt*	31.54±0.10 *fff kkk rrr uuu vvv*
Litter size at weaning, head	12.57	12.86	9.15	13.00	13.23	13.02	13.27
Final fattening weight, kg	118.30±0.46	119.25±1.00	145.00±0.57 *bbb ggg lll mmm nnn ooo*	123.45±1.11 *ccc hh*	125.16±0.52 *ddd iii*	132.45±0.47 *eee jjj qqq ttt*	136.54±0.44 *fff kkk rrr uuu vvv*

Note: a –1 and 2; b - 1 and 3; c - 1 and 4; d - 1 and 5; e- 1 and 6; f- 1 and 7; g- 2 and 3; h – 2 and 4 i - 2 and 5, j - 2 and 6; k - 2 and 7;l - 3 and 4; m -3 and 5; n - 3 and 6;o - 3 and 7;p - 4 and 5; q - 4 and 6; r - 4 and 7; t - 5 and 6;u - 5 and 7;v - 6 and 7
Source: own calculations.

The animals in the third group (endline – PIC-337), which were obtained by linear breeding, showed significantly higher productivity indicators. Here, a significant increase in live weight was observed at all stages: The birth weight was 1.43 kg (+13.5% to the average indicator of the purebred groups of maternal breeds), the weight at weaning was 8.04 kg (+19.5%), and the final live weight at the end of fattening reached 145.0 kg, which was 26.70% higher than the indicator of the control group. The use of two-breed industrial crossing of maternal forms (group IV: ♀LW×♂L and group V: ♀L×♂LW) contributed to the improvement of productive indicators due to the manifestation of the heterosis effect, as a result of which the final live weight of animals was 123.5 kg and 125.2 kg, which was 4.5% and 5.9% higher than the control, respectively. Intra-breed hybridisation, in which crossbred sows (F_1) were combined with boars of the parent line PIC-337, showed the highest efficiency. The highest live weight indicators were recorded in groups VI (♀(LW×L)×♂PIC-337) and VII (L×LW)×♂PIC-337): Weight at weaning was 7.12 kg and 7.24 kg (5.95–7.74% higher than the control group) ($p<0,001$), and final live weight after fattening reached 132.5 kg (+12.0%) and 136.5 kg (+15.4%) ($p<0,001$), respectively, while piglet survival remained high and was not inferior to the control indicators.

The findings of the study confirm the economic justification for intrabreed hybridisation of crossbred sows from maternal breeds with boars of the terminal PIC-337 line.

This approach enables the realisation of the heterosis effect, which is expressed in a notable improvement in animal productivity compared to purebreeding and crossbreeding of maternal lines.

The economic outcomes of piglet rearing were influenced by both genotype and breeding strategy. As shown in Table 2, the breed and breeding method applied had a considerable effect on production costs, revenue, and overall profitability of raising piglets of various genetic types.

Table 2. Economic efficiency of rearing one purebred, crossbred and hybrid piglet

Indicator	Groups						
	I	II	III	IV	V	VI	VII
Cost of a weaned piglet, EUR	1,061.8	1,066.5	1,270.3	1,102.8	1,112.3	1,125.0	1,143.9
Avg. compound feed price for rearing, kg	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Feed cost per reared piglet, EUR	17.8	17.4	19.1	17.5	17.4	18.4	19.9
Rearing operational cost per piglet, EUR	22.8	22.3	24.4	22.4	22.2	23.6	25.5
Total rearing cost per piglet at completion, EUR	44.7	44.2	50.6	45.1	45.2	46.8	49.0
Sale value per piglet at completion, EUR	53.2	53.6	65.2	55.0	55.6	58.7	63.1
Profit per head, EUR	8.5	9.4	14.6	9.9	10.5	11.9	14.0
Profit per kg of live weight, EUR	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Profit per kg of weight gain, EUR	0.4	0.5	0.6	0.5	0.5	0.5	0.6
Profitability of rearing a piglet, %	37.31	42.02	59.56	44.35	47.06	50.40	55.03

Source: own calculations.

When comparing the Large White (Group I) and Landrace (Group II) maternal breeds, the Landrace piglets had slightly higher weaning costs, a result of their faster growth and heavier weight at weaning. However, they proved more cost-effective during rearing, with 2.3% lower feed and operating costs. This efficiency meant that while their sale cost was marginally higher, the Landrace piglets generated 10.03% more income than the Large Whites, with a 9.06% greater income per kilogram of gain. Overall, the Landrace group's profitability was 4.71% higher.

A comparison of the efficiency of rearing crossbred pigs obtained through direct (♀LW×♂L, group IV) and reverse (♀L×♂LW, group V) crossbreeding showed that most economic indicators improved relative to the average values for purebred animals (groups I and II). Specifically, the higher live weight of piglets at weaning led to an increase in piglet production costs by 3.64% in the direct cross and 4.53% in the reverse cross. During the rearing phase, feed expenses for crossbred piglets were reduced by up to 1.26%. Meanwhile, their sales value increased by 2.7–4.6% due to faster growth rates and higher body weight at the end of rearing. As a result, the profitability of rearing improved by 6.1–23.1%, with a corresponding increase in return on investment by 5.5–11.04%. This outcome can be attributed to the heterosis effect, which enhances productivity while lowering production costs per unit of output.

The most effective system was the intrabreed hybridisation system, in which the maternal forms (♀LW×♂L or ♀L×♂LW) were combined with the paternal component of the PIC-337 endline (groups VI or VII). The piglets in these groups had 5.95% higher production costs (in group VI and 7.74% in group VII compared to the control group due to their greater mass at weaning. They had 3.6–11.7% higher operating costs for rearing compared to purebred animals of the dam breeds. In Group III, consisting of PIC-337 parent line animals, this indicator was 13.85% higher than the average for the purebred animals of the dam breeds.

However, the situation is reversed regarding the sales value of the products. The average sales value of a piglet in the purebred groups was 53.39 EUR, while in the hybrids it was higher: by 9.92% in group VI and by 18.08% in group VII. The highest sales value for a piglet was recorded in animals of the terminal line (PIC-337) – 65.17 EUR, 22.09% more than the similar indicator for purebred breeding options of maternal breeds. Hybrid piglets from Group VI and Group VII had sales values that were 10.35% and 18.57% higher, respectively, than the control group. This allowed them to generate a higher profit per animal, even though the maternal genotypes had lower rearing costs. Thus, the average profit per piglet in groups VI and VII was 11.89 EUR and 14.01 EUR, respectively, which is 39.90 EUR higher in group VI than in the

control group and 27.14% higher than in purebred Landrace animals.

In Group VII hybrids, this indicator exceeded the control by 64.79% and the landraces by 49.76%. Breeding profitability increased by 13.09% and 17.22% in groups VI and VII, compared to purebred large white animals, and outperformed purebred landraces by 8.38% and 13.01%, respectively. Breeding profitability was higher for hybrids and the parental line. The highest profit was achieved in Group III – 14.55 EUR, which is 63.0% more than the average profit of purebreds (8.92 EUR).

Overall, the findings indicate that hybridisation of maternal lines (Large White and Landrace) with the paternal line (PIC-337) ensures the highest economic results in pig production. At the same time, crossbreeding of maternal forms also demonstrates better efficiency than traditional pure breeding, confirming the relevance of wider use of heterosis-based selection in industrial pig farming.

The analysis of fattening costs for purebred, crossbred, and hybrid pigs showed that the lowest expenses are associated with fattening animals of purebred maternal breeds. According to Table 3, the average cost of fattening one pig in groups I and II was 119.53 EUR, which is 0.2–3.2% lower than in crossbreds, 6.2–9.7% lower than in hybrids, and 8.2–10.9% lower than in pigs of the same age from the parental line.

At the same time, variations in growth rates during fattening, and consequently differences in final live weight, resulted in the lowest selling price per animal in these groups – 3.5–5.8% lower than in crossbreds, 11.1–15.4% lower than in hybrids, and 21.6–22.6% lower than in pigs of the parental terminal line. This negatively affected both profit per animal and overall fattening profitability.

A moderate increase in costs was recorded for direct and reverse crossbreeding of maternal breeds (groups IV and V), where the total operating cost per animal rose by 1.6% compared to purebred forms, reaching 124.48 EUR.

However, the selling price also increased to 146.03 EUR, which provided an average profit of 24.54 EUR per head – 22.8% higher than in purebred forms.

As a result, profitability reached 32.15%, which exceeded the fattening profitability of purebred maternal breed animals by 2.01–8.98% (Table 3).

Even greater profitability was achieved in Groups VI and VII, which were the result of a cross between crossbred maternal forms (♀LW×♂L and ♀L×♂LW) and boars from the PIC parental line.

At an average cost of 128.95 EUR – 7.9% higher than the average for purebred maternal breeds – a 13.2% increase in profitability was achieved for fattening.

The highest efficiency for fattening was observed in Group III, which consisted of purebred animals from the PIC-337 parental line.

Although the operating cost of one animal in this group was the highest at 132.89 EUR, and exceeded the average cost of purebred animals by 11.2%, their sales value was 170.34 EUR, which is 22.1% more than in purebred maternal breeds, which contributed to an increase in profit per fattened animal by 87.3 compared to purebred maternal breeds.

The profitability in Group III reached 45.5%, which was 21.46% and 16.30% higher than in the primary parental breeds.

When compared with hybrid pigs from groups VI and VII, animals of the parental line demonstrated a 28.9% greater profit and a 9.68% higher profitability, despite only a 1.5% increase in fattening costs and a 3.0% higher total cost per fattened animal. The comparative results show that purebred breeding causes the lowest costs, but does not enable high economic results. Crossbreeding of parent breeds only moderately increases the financial indicators, while hybridisation with the parent line or its pure breeding shows a clear profitability advantage. From an economic perspective, implementing hybridisation in industrial pig production appears to be the most rational strategy, as the increased market value and overall production output can more than compensate for the associated higher production costs.

Table 3. Economic efficiency of fattening one purebred, crossbred and hybrid animal

Indicator	Groups						
	I	II	III	IV	V	VI	VII
Operating cost of 1 piglet upon completion of rearing, EUR	44.7	44.2	50.6	45.1	45.2	46.8	49.0
Cost of 1 piglet when placed for fattening, EUR	53.2	53.6	65.2	55.0	55.6	58.7	63.0
Operating cost of fattening 1 head of pigs, EUR	76.0	74.2	82.3	76.1	76.6	80.7	81.4
Operating cost of 1 animal upon completion of fattening, EUR	120.7	118.4	132.9	121.2	121.7	127.5	130.4
Realization cost of 1 animal upon completion of fattening, EUR	139.0	140.1	170.3	145.0	147.0	155.6	160.4
Profit from fattening 1 pig, EUR	18.3	21.7	37.4	23.8	25.3	28.1	30.0
Profit per 1 kg of live weight, EUR	0.2	0.2	0.3	0.2	0.2	0.2	0.2
Profit per 1 kg of gain, EUR	0.2	0.2	0.3	0.2	0.3	0.3	0.3
Profitability of fattening one animal, %	24.1	29.2	45.5	31.2	33.1	34.8	36.9

Source: own calculations.

To consider the reproductive and fattening indicators of pig productivity in purebred, crossbred, and hybridised pigs, we compared the economic efficiency of rearing a nest of sows from each combination and the economic efficiency of fattening piglets obtained from the sow per year. As shown in Table 4, the purebred dams (Groups I and II) had an average reproductive productivity: Their nests contained 13.0–13.3 piglets at weaning, of which an average of 12.65–13.03 were retained until the end of rearing. The total operating costs for rearing a nest were 565.29 EUR in Group I and 576.71 EUR in Group II. After selling a nest with piglets for 672.87–698.66 EUR, the profit was 107.60–121.94 EUR, and the profitability was 37.31% and 42.02%, respectively. Thus, the purebred options offered minimal costs, but also a moderate level of income. For the cross of the dam breeds (Groups IV and V), reproductive performance didn't change much, with about 13 piglets at weaning and end of rearing. However, the economic results got better. The total cost of the nest increased by 2.4–5.7% compared to the purebred counterparts (up to 590.64–597.67 EUR), but the selling price increased by 3.1–10.4% to 720.61–736.19 EUR. This resulted in an increase in profit to 129.96–138.52 EUR and profitability to 44.35–47.06%. Thus, when crossing maternal breeds, the economic yield increased due to the heterosis effect compared to purebred breeding of these animals (Table 4).

In the highest breeding form of commercial pigs of hybridisation (groups VI and VII), as a result of the combination of inbred maternal lines with the parental form PIC-337, the average number of piglets at weaning was 13.29–13.45 animals, of which 13.11–13.27 were kept until the end of rearing.

The operating costs for one nest in these groups amounted to 613.52–650.78 EUR, which is 6.4–12.8% higher than in purebred piglet nests of the mother breeds.

However, due to the 10.1–24.4% higher sales value (769.51–836.74 EUR), the profit increased by 27.96–72.8% and amounted to 155.97–185.75 EUR, and the profitability increased by 13.9–31.0%. Thus, hybridisation brought 45–72% more income and 13.9–31.0% higher profitability than the purebred variant.

In Group III, representing the purebred parental line PIC-337, the number of piglets at weaning (9.60) and after rearing (9.28) was the lowest; however, animals of this genotype demonstrated a clear advantage in terms of nest sales value, which reached 604.80 EUR, while maintaining relatively low operating costs of 469.72 EUR. This combination resulted in the highest profit among all groups – 135.07 EUR – and a profitability rate of 59.56%. Compared to the average values of purebred Groups I and II, this corresponds to an increase in profit by 10.8–16.9% and profitability by 17.55–22.26%. When compared with the hybrids in Groups VI and VII, the profit remained competitive, and the profitability level was the

highest overall, despite the lower piglet survival rate.

Table 4. Economic efficiency of rearing and nesting purebred, crossbred and hybrid piglets

Indicator	Groups						
	I	II	III	IV	V	VI	VII
Number of piglets in the nest at weaning, pigs	13.00± 0.13 *ввв*	13.30± 0.16 *ccc*	10.90±0. 07	13.36± 0.10 *d*	13.41± 0.12 *e*	13.29± 0.16 *mmm*	13.45± 0.11 *ii* *nnn*
Weaned litter size, head	13	13.3	9.6	13.36	13.41	13.29	13.45
Number of piglets in the nest at removal from rearing, pigs	12.65	13.03	9.28	13.09	13.23	13.11	13.27
Cost of a nest of piglets at weaning, EUR	672.9	698.7	604.8	720.6	736.2	769.5	836.7
Operating cost of rearing a nest of piglets, EUR	288.4	290.2	226.8	293.1	294.3	309.5	337.9
Realization cost of a nest of piglets after rearing is completed, EUR	672.9	698.7	604.8	720.6	736.2	769.5	836.7
Operating cost of a nest of piglets after rearing is completed, EUR	565.3	576.7	469.7	590.6	597.7	613.5	650.8
Profit from rearing a nest of piglets, EUR	107.6	121.9	135.1	130.0	138.5	156.0	185.9
Profitability of rearing a nest of piglets, %	37.31	42.02	59.56	44.35	47.06	50.40	55.03

Note: a –1 and 2; b - 1 and 3; c - 1 and 4; d - 1 and 5; e- 1 and 6; f- 1 and 7; g- 2 and 3; h – 2 and 4 i - 2 and 5, j - 2 and 6; k - 2 and 7;l - 3 and 4; m -3 and 5; n - 3 and 6;o - 3 and 7;p - 4 and 5; q - 4 and 6; r - 4 and 7; t - 5 and 6;u - 5 and 7;v - 6 and 7
Source: own calculations.

The findings from piglet rearing indicate that breeding systems involving hybridisation, along with pure breeding of parental lines, offer the greatest economic advantage. These approaches ensure the highest profit per litter while requiring only a moderate increase in costs, with profitability surpassing that of purebred animals by 17.55–22.26%. In contrast, although purebred breeding entails lower expenses, it proves considerably less effective in terms of both total revenue and profitability. When analysing the profitability of piglet nests, significant differences were found in the quantity and cost indicators depending on the breeding method. The selling price of a piglet nest in the control group was 1,746.45 EUR with an average number of piglets of 12.57 animals. Operating costs totaled 1,516.50 EUR, resulting in an income of 229.96 EUR and a profitability of 24.1%.

An evaluation of piglet nest profitability revealed notable variations in quantitative and cost parameters depending on the breeding strategy applied. In the control group, the average selling price per nest was 1,746.45 EUR, with an average litter size of 12.57 piglets. Production expenses amounted to 1,516.50, yielding 229.96 EUR in profit and a profitability rate of 24.1% (Table 5).

Purebred Landrace breeding (Group II) demonstrated improved economic outcomes. The nest selling price reached 1,801.05 EUR, representing a 3.1% increase over the control, while the production cost remained almost the same at 1,522.36 EUR. Consequently, profit rose by 21.2% to 278.70 EUR, and profitability climbed by 5.15 percentage points to 29.2%.

In contrast, although Group III recorded a smaller litter size (9.15 piglets), it achieved the highest profit among purebred groups. This was due to reduced fattening expenses (1,216.15 EUR) and a selling price of 1,558.96 EUR, which was 49.1% above the control. As a result, profitability reached 45.5%, exceeding the control by 21.46 percentage points, indicating strong genetic potential for efficient feed conversion.

Crossbreeding of maternal genotypes (Groups IV and V) led to increased production efficiency, likely due to heterosis effects. In Group IV (♀LW×♂L), the nest value was 1,885.86 EUR (+7.97% vs. control), with higher production costs of 1,576.58 EUR (+34.5%) and profitability of 31.2% (+7.1

p.p.). Group V (♀L×♂LW) showed even stronger results: profit of 334.85 EUR (+45.6%), profitability of 33.05% (+8.95 p.p.), and nest value of 1,945.50 EUR (+11.4%).

Table 5. Economic efficiency of fattening a nest of purebred, crossbred and hybrid animals

Indicator	Groups						
	I	II	III	IV	V	VI	VII
Weaned litter size, head	12.57	12.86	9.15	13.00	13.23	13.02	13.27
Cost of a nest of piglets at weaning, EUR	1,746.5	1,801.1	1,559.0	1,885.9	1,945.5	2,026.6	2,128.6
Operating cost of fattening a nest of piglets, EUR	955.1	953.5	752.9	990.0	1,013.0	1,051.0	1,079.9
Realization cost of a nest of piglets after finishing fattening, EUR	1,746.5	1,801.1	1,559.0	1,885.9	1,945.5	2,026.6	2,128.6
Operating cost of a nest of piglets after finishing fattening, EUR	1,516.5	1,522.4	1,216.2	1,576.6	1,610.7	1,660.4	1,730.7
Profit from fattening a nest of piglets, EUR	230.0	278.7	342.8	309.3	334.9	366.2	398.0
Profitability of fattening a nest of piglets, %	24.1	29.2	45.5	31.2	33.05	34.8	36.9

Source: own calculations.

The best economic indicators were recorded in Groups VI and VII, where intra-breed hybridisation was performed using crossbred sows (♀LW×♂L or ♀L×♂LW) and boars from the PIC-337 sire line. In Group VI, the nest value reached 2,026.60 EUR (+16.0%), operating costs were 1,660.40 EUR, profit was 366.19 EUR (+59.2%), and profitability reached 34.8% (+10.7 p.p.). Group VII achieved the highest overall performance, with profit rising to 397.98 EUR (+73.1%), a selling price of 2,128.64 EUR (+21.9%), and profitability of 36.9%, exceeding the control by 12.78 percentage points.

The results of the study, therefore, convincingly show that the breeding method has a direct influence on the profitability of pig fattening. Purebred breeding of the Large White and Landrace breeds ensures a basic level of profitability of fattening, while the use of boars from a specialised terminal line, PIC-337, allows you to significantly reduce production costs and increase profitability. The highest level of comprehensive economic efficiency is achieved with hybridisation within one breed, which combines the advantages of several breeds in terms of reproduction and fattening.

Such a strategy provides maximum income from the nest and the highest profitability, which justifies it as a priority direction for modern industrial pig breeding.

The results of the study on the economic efficiency of piglet rearing – from weaning to the end of fattening – show a significant influence of the breeding method on the level of production indicators, costs, profit and profitability.

In the control group, which comprised pigs of the large white breed, the number of piglets at weaning was 13.0 animals and 12.57 animals at weaning from fattening.

The operating cost of rearing and fattening the nest was 1,243.43 EUR, while the cost of the nest of pigs at the time of sale was 1,516.50 EUR, while the sale value reached 1746.45 EUR, giving a profit of 229.96 EUR and a profitability of 18.5%. The annual profit of the sow with 2.42 piglets was 556.49 EUR (Table 6).

Purebred breeding of the Landrace breed (Group II) gave slightly better indicators. With a slight increase in costs (1,243.71 EUR), the sales value of the nest totalled 1,801.05 EUR (+3.1% compared to the control), which resulted in an income of 278.70 EUR (+21.2%) and a profitability of 22.4% (+3.9%). The annual income per sow was 674.46 EUR.

A significant improvement in profitability was observed in group III – animals of the parent line PIC-337. Despite the lower number of piglets in the nest (9.6 at weaning and 9.28 at weaning), the costs were significantly lower (979.67 EUR), and the sales value of the nest

was 1,770.07 EUR. This resulted in an increase in profit by 69.3% (389.24 EUR), profitability by 21.2% (39.7%), and annual profit by 69.3% (941.96 EUR) compared to the control.

Table 6. Economic efficiency of rearing and fattening a nest of purebred, crossbred and hybrid animals

Indicator	Groups						
	I	II	III	IV	V	VI	VII
Weaned litter size, head	13	13.3	9.6	13.36	13.41	13.29	13.45
Number of piglets in the nest at weaning, pigs	12.57	12.86	9.28	13.00	13.23	13.02	13.27
Operating cost of rearing and fattening a nest of piglets, EUR	1,243.5	1,243.7	979.7	1,283.0	1,307.3	1,360.5	1,417.8
Operating cost of a nest of piglets after completion of fattening, EUR	1,516.5	1,522.4	1,380.8	1,576.6	1,610.7	1,660.4	1,730.7
Realizable value of a nest of piglets after completion of fattening, EUR	1,746.5	1,801.1	1,770.1	1,885.9	1,945.5	2,026.6	2,128.6
Income from rearing and fattening a nest of piglets, EUR	230.0	278.7	389.2	309.3	334.9	366.2	398.0
Profitability of rearing and fattening a nest of piglets, %	18.5	22.4	39.7	24.1	25.6	26.9	28.1
Number of farrowings per sow per year, times	2.42	2.42	2.42	2.42	2.42	2.42	2.42
Annual income from rearing and fattening all piglets from a sow per year, EUR	556.5	674.5	942.0	748.4	810.3	886.2	963.1
Profitability of obtaining, rearing and fattening a nest of piglets, %	18.5	22.4	39.7	24.1	25.6	26.9	28.1

Source: own calculations.

The use of bi-breed crosses (groups IV and V) made it possible to significantly improve the results due to heterosis. In group IV (♀LW×♂L), the number of piglets in the nest at the time of weaning reached 13.0 pigs, cost price – 1,283.01 EUR, selling price – 1,885.92 EUR, profit – 309.27 EUR (+34.5%), profitability – 24.1%, and annual profit from fattening the offspring of one sow – 748.43 EUR. In Group V (♀L×♂LW), the number of piglets was even slightly higher (13.23 pigs), with a cost price of 1,307.33 EUR and a sales value of 1,945.50 EUR. This provided a profit of 334.85 EUR (+45.7%), a profitability of 25.6% (+7.1%), and an annual profit per sow of 810.32 EUR.

The highest indicators of overall economic efficiency were achieved in hybrid groups VI and VII, in which crossbred sows (♀LW×♂L or ♀L×♂LW) were combined with a boar of the PIC-337 line. In group VI (♀LW×♂L)×♂PIC), the number of piglets in the nest was 13.02, the cost price – 1,360.53 EUR, the selling price – 2,026.60 EUR, the profit – 366.19 EUR (+59.3%), the profitability – 26.9%, the annual profit – 886.19 EUR. In Group VII (♀(L×LW)×♂PIC-337), these indicators were even higher: the number of piglets was 13.27, the cost price was 1,417.78 EUR, the selling price was 2,128.64 EUR (+21.9%), the income was 397.98 EUR (+73.1%), the profitability was 28.1% (+9.6%), and the annual income was 963.12 EUR.

The results of the study thus convincingly show that the genetic origin and the breeding method directly influence the economic efficiency of pig breeding. Purebred breeding offers a basic efficiency level, which is further improved by using a high-performance boar line – PIC-337. Crossbreeding enables higher profitability due to heterosis, and hybridisation within the breed shows the best results in all indicators - from the number of piglets in the litter to the maximum annual income of a sow. Considering the results obtained, the most economically viable strategy is the implementation of intra-breed hybridisation, which allows the highest level of profitability through the combination of high fertility, efficient feed conversion and high marketable quality of piglets.

Our results confirm the well-known statements about the advantages of crossbreeding and

hybridisation in pig breeding, which have been described in numerous publications [4, 8, 48]. As in the studies [35, 42, 46], the inclusion of specialised terminal boars in the last link of the breeding scheme was found to allow a significant improvement in the fattening performance of hybrids compared to purebred animals.

Our conclusions that the double crossing of maternal genotypes allows an increase in sales value by 7.97–11.4%, profit by 34.5–45.7%, profitability by 5.6–7.1%, and annual income by 34.5–45.6% compared to purebred breeding, which is due to the manifestation of the heterosis effect, are consistent with the data [2, 37, 45], although they differ in the values of specific parameters.

Under our production conditions, the combination of sows from the commercial Large White×Landrace lines with the PIC-337 terminal sire resulted in an increase in piglet weight at weaning of 5.95–7.74%, an increase in income from rearing and fattening of 16.0–21.9%, profit – 59.3–73.1%, profitability – 8.4–10.7%, and annual sow income – 59.2–73.1% compared to purebred rearing of dams with high welfare indicators, which is consistent with the data [21], where the level of profitability of rearing one piglet and nest by 18.0%, and profit from one piglet – by 20.5% compared to rearing of boars of Large White and Landrace breeds and in the works [31, 43] for similar genotypes. However, they turned out to be significantly higher than the results in the works [14, 18] and worse than the results published in the work [7]. Our results are consistent with or better than those found in reference [6]. That study showed that triple-bred hybrids had 5.4% higher live weight, 5.2% better feed efficiency, and reached 100 kg 2.9% faster than Landrace × Large White crosses. This led to a 24.4% increase in profit and a 6.6% rise in profitability, which also aligns with data from other breeding companies as cited in references [20, 32, 44, 46].

Thus, the results obtained not only confirm the data in the literature on the advantages of hybridisation (heterosis, complementarity of breeds, increased productivity), but also show that under the conditions of appropriate selection of paternal and maternal lines in domestic industrial complexes, it is possible to achieve a level of productivity that meets or exceeds the indicators of the world's leading farms. This underlines the prospects for implementing customised crossing plans that are tested for compatibility under specific production conditions.

CONCLUSIONS

The breeding method has a decisive influence on the profitability of rearing and fattening pigs, and determines the level of sales value, profit and profitability.

Purebred breeding provides a basic level of productivity, the increase of which, when using Landrace pigs compared to Large White, is 3.1–21.2%, and when using the PIC-337 line, up to 69.3%.

Bibreed crossbreeding allows you to increase economic indicators by 7.97–45.7% due to the heterosis effect, which ensures a stable increase in profitability.

Using boars from the PIC-337 terminal line for intrabreed hybridization yielded the best results. This method boosted profit by 59.3–73.1% and profitability by 8.4–10.7% compared to purebred Large White pigs.

In industrial pig production, intra-breed hybridisation proves to be the most cost-effective approach, as it merges the strong reproductive traits of maternal breeds with the efficient feed utilisation and rapid growth rates of parental line animals. This synergy, enhanced by the heterosis effect, can boost profitability by as much as 70%.

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ELEMENTS OF THE TECHNOLOGY OF WINTER BARLEY GROWING IN THE WESTERN FOREST-STEPPE ZONE OF UKRAINE AND THEIR INFLUENCE ON THE EFFICIENCY OF GRAIN PRODUCTION

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Abstract

The article systematizes and identifies the main factors influencing the formation of winter barley yields. The optimal sowing dates in the context of climate change were experimentally determined. The dependence of the protein content in winter barley grains on the sowing date was established. Sowing winter barley at the most optimal dates, namely September 15–25, ensured the formation of higher yields (5.75 and 5.81 t/ha), compared to October ones (5.24 and 4.92 t/ha). It was found that the highest yield of all varieties was obtained in favourable weather conditions - in 2024 (6.43 t/ha), the lowest - in the dry year 2020 (3.73 t/ha). The protein content increased from the earliest to the latest sowing date: from 12.3 to 12.6%. In years with different weather conditions, regardless of sowing dates, the highest quality indicators were formed in 2019 (14.0%), the lowest in 2024 (10.4%).
Thus, shifting the sowing dates by 10 days later than the optimal ones leads to a decrease in yield by 0.57–0.82 t/ha (11.6%–16.7%). The decrease in productivity occurs mainly due to a lower density of the productive stem and grain size. The work used a wide range of statistical analysis methods, as well as field and laboratory research methods. The results obtained are expected to be used to improve the technological elements of growing winter barley, which will be aimed at increasing its yield and improving the quality characteristics of the products obtained.

Key words**:** *weather factors, growing technology, sowing time, winter barley, grain yield, protein content, production efficiency*

INTRODUCTION

Winter barley (*Hordeum vulgare* L.) is the one of the earliest-maturing grain crops, characterized by high yields and valuable forage properties. The ripening of this crop occurs 12–16 days earlier than spring barley and 9–14 days earlier than winter wheat, which reduces the amount of work during the harvest period of grain crops and makes it possible to successfully grow many post-harvest crops [13].

Winter barley in Ukraine is recommended for cultivation in 14 regions. However, most of its sowing areas are located in the southern region. The main reason for this is the low winter and frost resistance of the varieties [15].

Numerous observations of scientists have shown that the thinning of crops of this type of culture most often occurs due to freezing. According to Academician A. A. Linchevsky, yield losses of winter barley of the new selection from freezing are more significant than from diseases, pests and weeds combined [12].

Many years of research have established that the critical temperature at the depth of the tillering node for most varieties of winter barley is -10 - - 15°C, which is mostly 4-5°C higher than the critical temperature for winter wheat. In recent years, according to the agrometeorological station located at the territory of the TSAES of IA of Carpathian region of the NAAS, this indicator has not dropped below -7- -8 °C. Thus, climate change contributes to the successful wintering of winter barley and the expansion of its sowing areas.

Many domestic and foreign scientists were engaged in the study of the influence of climatic factors on the efficiency of barley cultivation. So, in particular, studies of the influence of climatic factors such as heat, high rainfall or drought on sensitive stages of barley

plant development were conducted by such scientists as: Hakala K., Jauhiainen L., Rajala A. A., Jalli M., Kujala M., Laine A., Hossain A., da Silva J. A. T., Lozovskaya M. V., Zvolinsky V. P. [7, 9].

It was established that climate change affects the nutritional value of grain by worsening its quality and content of nutritional elements [6, 27].

Important is the statement that the protein content in grain increases as a result of abiotic stress, in particular the effects of heat and drought [18, 19], and its decrease occurs in response to increasing CO_2 levels.

In general, many studies are devoted to studying an impact of climate change on barley physiology and productivity [3, 5, 17, 23, 24, 25]. Based on the results obtained, a number of conclusions were drawn from experimental field studies, while others were made using crop modelling approaches. In addition, multifactorial climate change conditions may also affect barley crop quality. [27].

In general, the shift in barley sowing dates can contribute to minimizing the dependence of crop formation on weather factors in the context of climate change.

The study also showed [30] that annual weather patterns are causing shifts in the timing and duration of critical phenological phases responsible for crop formation, leading to yield losses for spring barley.

Although global warming is negatively affecting spring crops, studies have also been published that predict a positive effect for winter crops such as barley due to increased temperatures during overwintering and vegetation recovery [8, 20, 21]. The positive influence of climate on the yield of grain crops is studied in the work [14].

Thus, in conditions of significant climate change, due to the value of winter barley, its sown areas began to grow rapidly. A number of Western European countries have almost completely switched to autumn sowing. The main reason for the spread of winter barley areas was its high yield. In Ukraine, back in 2000, the crop occupied 300 thousand hectares. By 2021, the areas of winter barley had increased significantly, the volume of crops reached 1.3 million hectares, however, after 2022, due to the occupation of part of Ukrainian territories by Russia, the sown areas began to decrease again, and in 2023 the sown area was 760 thousand hectares, and in 2024 – 506 thousand hectares [31].

According to the Ministry of Agrarian Policy, Ukrainian farmers sowed in 2024 49.6% below the pre-war 2021 [16] (Fig. 1).

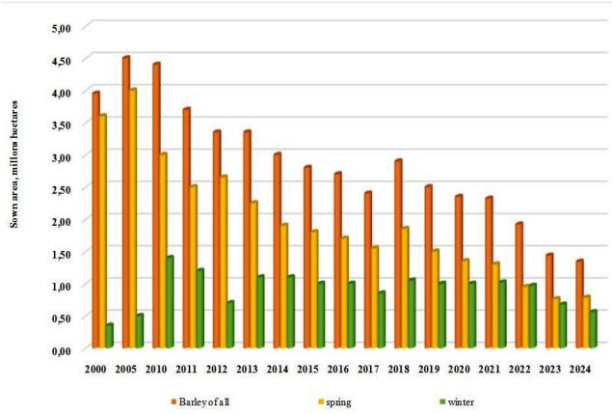


Fig. 1. Dynamics of barley sowing area in Ukraine, millions hectares, 2000–2024

Source: compiled by the authors based on data from [16].

Starting from 2022, under the influence of the challenges of wartime and their consequences in Ukraine, a significant reduction in cultivated areas is observed, primarily due to the limitations of expert logistics. After all, the barley market is quite narrow, and Europe is not a target buyer of this crop. Our state usually exported barley to China, and without a grain corridor, it will be impossible to sell it through the previous sales channels in today's conditions. Therefore, barley is focused on domestic consumption and, in limited quantities, to the near abroad.

If we analyse the yield, then on average during this period it varied from 1.91 to 3.53 t/ha for spring barley, and from 2.05 to 4.37 t/ha for winter barley, which indicates a positive dynamics of productivity growth. Undoubtedly, the productivity of the crop is primarily influenced by weather conditions and growing technology, as evidenced, for example, by 2024, where the yield of winter barley on average in Ukraine was 4.34 t/ha, in agricultural enterprises it was 4.70 t/ha. Due to more favourable weather conditions, a

particularly high indicator of 6.0–6.5 t/ha was in the western regions [22, 26], (Fig. 2).

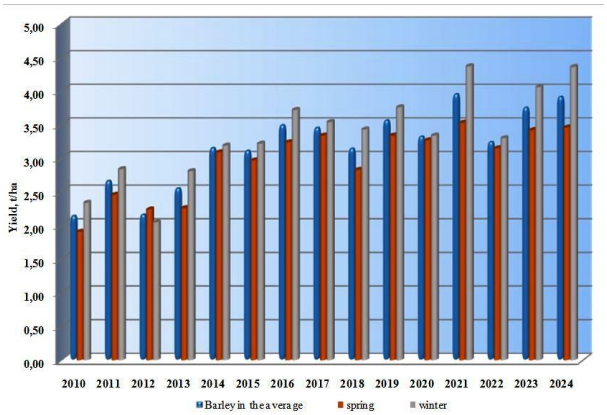


Fig. 2. Dynamics of barley yield in Ukraine, t/ha, 2010-2024
Source: compiled by the authors based on data from [22].

We should not forget about weather conditions, which are often unfavourable, and therefore, in addition to the ability to form high productivity, plants must demonstrate high resistance to the influence of adverse factors [1].

Therefore, there is a need for targeted selection of agro technical techniques that would increase or, at least, not reduce the natural adaptive properties of plants of modern varieties of winter barley.

In any cultivation technology, great attention is paid to sowing dates, which directly affect not only the quantity and quality of the crop, but also the formation of plant resistance to many adverse factors [4, 11, 28].

So, on the one hand, at early sowing dates, plants are more damaged by pathogens and pests, and their most productive shoots are more often affected, and on the other hand, late crops are mostly underdeveloped, poorly bushy, more susceptible to mechanical damage during wintering, and suffer more from dry winds in spring and summer [10].

Sowing at the optimal time should ensure that winter barley plants pass through the stages of organogenesis in the autumn period, on which the level of vital activity of the agrobiocenosis and its productivity subsequently depend.

MATERIALS AND METHODS

The research was conducted during 2016–2024. Six varieties of winter barley zoned for the Western Forest-Steppe zone were studied.: Valkyrie, Bureviy, Dev'yatyi val (Originator – Breeding and Genetic Institute – National Center for Seed Science and Variety Research); MIP Status, Paladin Myronivskyi, Tutankhamun (Originator – Myronivsky Institute of Wheat named after V.M. Remesla), which were sown in four periods, in steps of 10 days from September 15 to October 15 (Table 1).

Table 1. Varietal composition of winter barley by years of research

Years of research	Sort
2016–2020	Tutankhamun
	Dev'yatyi val
2020–2023	Bureviy
	Paladin Myronivskyi
2024	Valkyrie
	MIP Status

Source: compiled by the authors based on their own research.

The soil of the experimental plots is deep low-humus black soil, of medium loamy mechanical composition. Humus content is 3.55%, saline pH is 5.6. Hydrolytic acidity is 2.21 mg-eq/100 g of dry soil; low soil supply of alkaline hydrolyzed nitrogen is 126.0 mg/kg of soil (according to the Kornfield method); sulphur is 2.3%, very low; increased phosphorus supply is 123.0 mg/100 g of air-dry soil and increased potassium supply is 92.0 mg/100 g of air-dry soil (according to the Chirikov methods).

Repetition – three times. Sowing area of the plot – 28.05 m^2 (17 m × 1.65 m), accounting – 25.0 m^2 (15.15 m × 1.65 m). The order of placement of plots and repetitions – single-tier, sequential. For pre-sowing cultivation, a complete mineral fertilizer was applied at a dose of $N_{30}P_{30}K_{30}$ kg/ha a. s. (nitroammophoska). Winter barley plants were fed with nitrogen fertilizer in the form of ammonium nitrate (N – 34.4%): early spring – on frozen soil at a dose of N_{30} kg/ha a. s., local – at the end of the tillering phase at a dose of N_{30}.

The seeds were treated with preparations Avicenna (0.5 l/t) + Komandor Extra (0.6 l/t). Sowing was carried out with a CH-16 seeder, the seeding rate was 5 million pieces of similar seeds per hectare.

The technology of growing winter barley is generally accepted for the Western Forest-Steppe zone.

The predecessor is annual grasses. Research and accompanying analyses of soil and plant material were carried out according to the recommended methods: easily hydrolysed nitrogen according to Tyurin-Kononova, mobile forms of phosphorus and potassium – according to Chirykov, humus content – according to Tyurin, pH – according to the TsINAO method; field germination, plant density in the autumn period, plant survival during the wintering process, plant density before harvesting were determined on fixed plots, with an area of 0.25 m^2 in four places along the diagonal of the plot, which in total amounted to 1 m^2; selection of sheaf material was carried out one or two days before the start of harvesting from an area of 0.25 m^2 in four places of the plot.

Structural analysis of the harvest was carried out according to the "Methodology of State Variety Testing of Agricultural Crops"; determination of the mass of 1000 seeds was carried out according to DSTU 4138-2002; the content of total nitrogen/protein in the grain was determined according to the Kjeldahl method; the harvest was recorded using the method of split threshing of winter barley with a Sampo 500 combine harvester with subsequent grain cleaning and conversion to 100% purity and 14% moisture; mathematical analysis of the results of field experiments was carried out on a personal computer using the program of dispersion and correlation-regression analysis according to the method of Yeshchenko V.O. "Fundamentals of Scientific Research in Agronomy" [29] and using the computer program "Statistica 5.0".

The economic assessment was carried out based on the application of generally accepted methods for assessing technology by yield level, cost of production per unit of product, profitability per hectare of sown area and level of profitableness [2].

Agrometeorological conditions were characterized by only some deviations from the average long-term indicators, both in terms of precipitation, temperature regime, and their distribution during the growing season with an upward trend. Extreme conditions that would significantly affect the reduction in the yield of winter barley were not observed.

RESULTS AND DISCUSSIONS

To increase and stabilize grain production in Ukraine, considerable attention is paid to increasing the yield of winter barley, since this crop, together with spring barley, is strategically important, and in terms of sown areas it ranks second after winter wheat.

It is well known that climate change towards warming requires the adaptation of agricultural production and the improvement of agro technical methods of growing crops.

It is under such conditions that such an important agro technical measure as the sowing date should be clarified.

This method does not require any additional costs, and the correct choice of the timing of the sowing campaign lays the foundation for successful overwintering and high crop productivity.

According to the results of research conducted in 2016–2024, it was found that the yield of winter barley largely depended on the sowing dates (Table 2).

The highest yields were recorded in plots sown in September This trend was independent of the year of research.

The maximum yield – 5.75–5.81 t/ha, on average for all varieties, was recorded for sowing on September 15; September 25, slightly lower – for sowing on October 5 – 5.24 t/ha, and the lowest – 4.92 t/ha for the latest (October 15) sowing. As the data show, shifting sowing later than September 25 contributes to a decrease in yield by 0.57–0.89 t/ha, respectively.

Table 2. Yield of winter barley depending on the sowing dates, t/ha*

Year	The term of sowing			
	September 15	September 25 вересня	October 5	October 15
2016	4.96	5.42	3.69	3.14
2017	5.47	5.54	5.19	4.66
2018	6.56	6.82	5.63	5.50
2019	6.02	5.91	5.76	5.55
2020	4.02	3.81	3.37	3.73
2021	6.10	6.40	6.14	5.60
2022	6.27	5.66	5.13	4.55
2023	6.10	6.05	5.52	5.29
2024	6.29	6.72	6.73	6.26
Average over the years	5.75	5.81	5.24	4.92

Source: compiled by the authors based on their own research.

If we analyze the yield by year, the highest data indicators from all winter barley varieties were obtained in 2024 (6.50 t/ha), due to the formation of the main elements of plant productivity and yield structure. A warm winter, a very early (February 1) resumption of vegetation, a long period with average daily air temperatures between 5 and 10ºC, which lasted more than two months, contributed to intensive tillering of plants of late sowing dates. This had a positive effect on such a structural indicator of yield as the density of the productive stem, which almost did not decrease during late sowing dates. The formation and filling of grain also took place mainly in favorable agrometeorological conditions, which ultimately had a direct impact on the formation of winter barley grain yield.

The lowest yield was obtained in the dry year of 2020 (3.73 t/ha). The complicating factors were again weather conditions: a long rainless autumn period, which did not allow for the accumulation of sufficient moisture in the soil, a snowless and abnormally warm winter, a rainless and warm spring.

According to the results of the research, the yield potential of varieties (7–10.5 t/ha) was used on average by 30–50%, decreasing in individual years and periods to 24–26%, which indicates the need to improve barley growing technology. Therefore, the adaptability of the variety to adverse influences becomes one of its most important characteristics under climate change.

Today, it is important to increase not only the yield of winter barley grain, but also to improve its quality – a complex of biological, physical, chemical and technological characteristics of the grain, which is influenced by the selected technology. Among a number of factors that play a decisive role in shaping the quality of barley grain, there are soil and climatic conditions, variety, elements of agricultural technology. The last two factors are most regulated by man.

The protein content in winter barley grain, according to average indicators for nine years, depended little on the sowing date, but there is a tendency for its growth with a shift to later ones: from 12.0% – when sowing on September 25 to 12.6% – when sowing on October 15 (Table 3).

In general, if the trend of protein content changes over nine years can be explained by varietal characteristics, the selection of new, more adaptive varieties to local conditions, then individual decreases (for example, compare quality indicators in 2016, 2020, 2024) are only due to the weather factor and the reaction of plants to agroclimatic factors. After all, the varieties of winter barley used in the study are declared by the originators as a grain direction of use, with a potential yield of 7-10.5 t/ha, and a protein content of 12–14.5%. However, it is important to note that the decrease in protein in winter barley grain in some years has interested brewing industry producers in its use in production.

The very high protein content (over 13%) in the grain makes it unsuitable for brewing due to the deterioration of the taste of beer and a decrease in its yield. Good brewing barley contains 9–10% protein.

Table 3. Protein content in winter barley grain depending on sowing dates, %

Year	The term of sowing			
	September 15	September 25	October 5	October 15
2016	10.9	9.9	11.8	12.9
2017	13.4	12.3	12.2	12.3
2018	13.9	13.1	12.5	13.0
2019	14.2	14.1	14.0	13.7
2020	10.2	10.4	10.8	10.9
2021	12.1	11.5	12.0	12.3
2022	13.6	13.3	14.1	14.4
2023	12.5	12.7	12.9	13.0
2024	9.9	10.3	10.6	10.7
Average over the years	12.3	12.0	12.3	12.6

Source: compiled by the authors based on their own research.

It is known that the yield and quality of grain products are strongly negatively correlated. In particular, the formation of the protein complex is significantly influenced by unregulated factors, namely weather conditions during the period of grain filling and ripening, the amount of precipitation, air temperature and humidity, and the intensity of solar radiation.

The results of our research have shown a noticeable impact of climatically different years on the quality of grain of winter barley varieties.

For example, the lowest protein content over nine years of research was observed in 2016 and 2024 (this is most noticeable during the September sowing period) and in 2020, when a reduced temperature regime was observed during the period of grain formation and filling in combination with cloudy weather.

According to the correlation analysis between the average yield indicators and the protein content in the grain for the studied period, depending on the sowing dates, it was established that with a decrease in winter barley productivity, the content of the protein indicator in the grain increases.

The indicator of the correlation coefficient ($r = -0.854$) confirms the inversely proportional relationship between the yield per unit area and the level of protein in the grain.

According to the results of the experimental data obtained on the cultivation of winter barley, an economic analysis was conducted, which was determined by comparing the results of production depending on the sowing dates based on a system of such indicators as the cost of 1 ton of products, profit from 1 hectare, and the level of profitability (Table 4).

The sowing dates of winter barley, according to the results of the research, largely determined the economic indicators of its cultivation. The lowest cost of 1 ton of grain – 2,449–2,480 UAH was obtained when sowing on September 15 and 25, while on October 5 it was 2,721 UAH, and when sowing on October 15 – 2,873 UAH. The September sowing dates also provided the highest conditional net profit from 1 ha, which amounted to 12,120–12,395 UAH/ha, with a profitability level of 91.7–93.0%. With the October sowing dates, the conditional net profit was significantly lower and ranged from 8,794 to 10,112 UAH/ha, with a profitability level of 65.4–73.6%.

Table 4. Economic efficiency of growing winter barley depending on sowing dates, 2016–2024

The term of sowing	Average yield, t/ha	Production costs, UAH/ha	Cost price, UAH/t	Revenue from sales, UAH/ha	Conditional net profit, UAH/ha	Profitability, %
September 15	5.75	13,975	2,449	25,984	12,120	91.7
September 25	5.81	13,975	2,480	26,302	12,395	93.0
October 5	5.24	13,909	2,721	23,845	10,112	73.6
October 15	4.92	13,858	2,873	22,541	8,794	64.5

Source: calculated by the authors.

As the data show, later (October) sowing dates were less economically profitable, as they were accompanied by a decrease in yield levels, which in turn affected the level of efficiency indicators.

CONCLUSIONS

According to the results of the research, it was found that the highest yield at the level of 5.75, 5.81 t/ha was formed by winter barley varieties sown in the optimal terms for the growing zone – September 15 and 25, respectively. The crop reacts to the shift of sowing later than September 25 by reducing the yield by 0.57, 0.89 t/ha.

It was found that the maximum implementation (12.6%) of the varietal indicators of protein content in the grain of winter barley of the studied varieties is ensured by sowing it on October 15. The value of the correlation coefficient (r =- 0.854) confirms the inversely proportional relationship between yield per unit area and the protein content in the grain.

Analysing the economic indicators of the efficiency of winter barley growing on average for 2016–2024, it was determined that sowing on September 25 is the most economically feasible. Sowing in October terms leads to a significant decrease in the economic indicator of net profit and the level of profitability compared to September terms.

Promising in terms of increasing grain production of winter barley in the Western Forest-Steppe zone is the improvement of its cultivation technologies taking into account the varietal composition, sowing dates, and elements of agricultural technology. In order to increase the profitability and payback of grain production, it is important to standardize production costs for their optimization in changing soil-climatic and organizational-economic conditions of management.

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STRATEGIC POSITIONING OF ROMANIA'S AGRICULTURAL SUSTAINABILITY PERFORMANCE IN THE EU AND TÜRKİYE COMPARATIVE LANDSCAPE

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Abstract

This paper investigates Romania's sustainability performance in agriculture by examining key agriculture-related Sustainable Development Goals (SDGs). Employing atwo-phase analytical approach, the study utilizes nine SDGs indicators sourced from the EUROSTAT database to assess Romania's standing relative to 28 EU countriesand Türkiye.In the first phase, standardized indicator scores are calculated to systematically visualize Romania's comparative position and deviations from EU averages. In the second phase, Partial Least Squares (PLS) regression is employed to identify the indicators that significantly affect overall agriculture-related SDGsperformance. The results reveal Romania's strengths in areas such as pesticide use reduction and ammonia emissions, while challenges remain in agricultural income and soil erosion control. The regression analysis highlights organic farming, phosphate pollution, and erosion risk as the most impactful indicators. The comparative analysis also sheds light on Türkiye's performance, indicating relative strengths in agricultural profitability but ongoing challenges in organic farming compared to the EU average.These findings emphasize Romania's increasing alignment with the 2030 Agenda and demonstrate the utility of data-driven tools for informing targeted policy interventions in sustainable agriculture.

Key words**:** *Sustainable Development Goals, agricultural sustainability, comparative analysis, Romania, Türkiye*

INTRODUCTION

With growing global policy alignment, it has become crucial for countries to strategically align their agricultural systems and policies with the Sustainable Development Goals (SDGs), particularly within the European Union, where long-term sustainability, competitiveness, and agile systems are considered among core strategic priorities. Characterized by a promising agricultural structure and a policy environment increasingly shaped by European integration and sustainability agendas, Romania offers a valuable context to examine how national-level agricultural policies align with selected SDGs priorities, which in turn could contribute to broader SDGs objectives in the longer term. Recently, Romania has increasingly treated the SDGs framework as a constructive pathway to modernize its agricultural practices and enhance environmental outcomes, vowing to support the Sustainable Development Goals [18]. The country adopted its national development strategy in 2018 to reflect *the 2030Agenda* objectives and has expressed interest in implementing the principles of sustainable development at the national level to reduce development gaps, to increase citizens' well-being, and to preserve a clean environment [13]. Given that agriculture is not only vital for Romania's economic expansion but also for rural development and environmental sustainability [18], Romania's approach to the SDGs framework is of strategic importance in achieving these objectives. Recent studies have revealed that Romania has made progress in specific areas of sustainable agriculture, which can be interpreted as a reflection of the country's growing commitment to the Sustainable Development Goals and its efforts to integrate these principles into national agricultural and environmental strategies. One example is the substantial reduction in pesticide sales, with Romania decreasing its sales from 1.1 to 0.6 kilograms per hectare between 2016 and 2021 [19], which indicates a reduction in pesticide use based on growing awareness of more sustainable practices. This decline also signals

a shift toward more environmentally conscious farming practices and greater alignment with the European Union's sustainability agenda. Moreover, research shows that Romanian agriculture is increasingly integrating sustainability metrics into national strategies. A local case study [1]demonstrates that specific rural development interventions led to significant progress in agricultural productivity and led to a 30% reduction in food insecurity, coupled with strengthened community cohesion and empowerment, thereby evidencing the positive influence of rural development on well-being. This exemplifies the interdependent relationship between rural development policies and the Sustainable Development Goals and how such strategies can contribute to national sustainability objectives. Such examples highlight the potential of rural-level initiatives to align with the broader aims of the 2030 Agenda and emphasize the importance of community-anchored approaches in promoting the implementation of the SDGs. Such developments demonstrate Romania's commitment to the 2030 Agenda as part of a larger transformation toward environmentally responsible and economically viable agriculture. At the same time, a comprehensive understanding of agriculture-related SDGs performance requires both dynamic and strong tools for measuring progress. Building upon this necessity, the present study utilizes nine agriculture-related SDGs indicator performances sourced from the EUROSTAT database. These indicators were selected based on their direct relevance to both environmental sustainability and agricultural-rural development goals. To support comparative and analytical insight, this study applies a two-phase methodology. In the first phase, Romania's relative performance is analysed and assessed across 28 countries, including Türkiye, by standardizing indicator values on a Likert scale and visualizing deviations from the European average. The analysis also included visualization processes. In the second phase, Partial Least Squares (PLS)regression is used to evaluate the weight of each indicator in shaping overall agriculture-related SDGs performance, identifying the specific areas with the most substantial contribution. This approach offers a comprehensive and data-informed basis for identifying not only strengths but also areas where development can be further enhanced. Ultimately, this study contributes to the literature by emphasizing the need for context-sensitive and data-driven sustainable development assessments in rural and agricultural domains. As shown in the case of Valea Lupului [1], rural development efforts closely aligned with the SDGs have yielded tangible results such as a 30% drop in food insecurity alongside stronger community empowerment and cohesion, evidencing the effect of rural development on well-being. These examples reflect Romania's capacity to connect national strategies with localized solutions that advance both agricultural competitiveness and sustainable development. In this context, the current study aims to deepen our understanding of Romania and Türkiye's SDGs performance in agriculture by offering an elaborate, data-driven insight.

The findings aim to support both national stakeholders and international researchers aiming to design more targeted and adaptive strategies for advancing agricultural goals under the *2030 Agenda*.

MATERIALS AND METHODS

Data Sources

The dataset employed in this research was sourced from the EUROSTAT database, which serves as a comprehensive and publicly accessible data repository maintained by the European Union as one of the EU's official platforms. The data used in this study were downloaded from the source in April 2025. The dataset used in this study is derived from Sustainable Development Goals (SDGs) indicators that are specifically related to agriculture and rural development. Among the 17 SDGs identified by the United Nations, only a subset includes indicators that are explicitly related to agricultural practices, food security, natural resource management, and rural livelihoods. Accordingly, 9 SDGswere selected for analysis as they are among the key agriculture-related metrics in the EUROSTAT

framework that offer a holistic representation of economic, environmental, and management aspects of sustainable agriculture. Their inclusion was also informed by expert opinion to ensure thematic relevance and alignment with the study's analytical objectives.

Table 1. SDGs for agriculture and their definitions

SDG	Description
Sdg2.20	Agricultural real factor income measures the income generated by farming, which is used to remunerate borrowed or rented factors of production (capital, wages and land rents) as well as own production factors (own labour, capital and land) [5].
Sdg2.30	The indicator refers to government budget allocations for research and development (GBARD) for agriculture. GBARD data measure government support for research and development (R&D) activities [9].
Sdg2.40	This indicator is defined as the share of total utilised agricultural area (UAA) occupied by organic farming (existing organically farmed areas and areas undergoing conversion) [7].
Sdg2.53	The indicator monitors the trends in the use and risk of chemical pesticides in the EU and its Member States [12].
Sdg.2.60	This indicator measures ammonia (NH_3) emissions as a result of agricultural production.
Sdg.6.40	This indicator shows concentrations of nitrate (NO_3) in groundwater bodies measured as milligrams per litre (mg NO_3/L) [10].
Sdg.6.50	This indicator measures the concentration of phosphate (PO_4) per litre in the dissolved phase from water samples from river stations and aggregated to annual average values [11].
Sdg.15.42	This indicator shows the area impacted by drought in (km^2) and (% of the total area of the country) [8].
Sdg.15.50	This indicator estimates the area at risk of severe erosion by water such as rain splash, sheet-wash and rills (soil loss greater than 10 tonnes per hectare and year) [6].

Source: Author's compilation.

The countries included in the analysis were selected based on their membership in the EU so as to align with EU agricultural and sustainability policies. In particular, all existing member countries of the EU available in the EUROSTAT dataset were included to ensure comparability and alignment with the EU-level SDGs monitoring framework. In addition, Türkiye was incorporated into the dataset due to its geopolitical relevance, candidacy status for EU membership, and, particularly, significant role in regional agricultural production. This selection allowed for a consistent comparison among EU member states, while also enabling the inclusion of Türkiye as a relevant non-EU country with strong agricultural ties to the region.

Data Processing and Analysis

For each of the 9 indicators, data were initially downloaded from the EUROSTAT database in Excel format and merged into a single dataset. Each of the downloaded indicator datasets contains annual scores for the countries. However, these 9 indicators do not exhibit a homogeneous structure in terms of annual data coverage. While some indicators provide data for every year, others include values for only three specific years. Similarly, the time span of the data varies: some indicators offer data going back to 1990, whereas others begin only from 2000 or 2004.To conduct the analysis in this study, the most recent available data, whether from 2022, 2023, or 2024, were used as the primary basis.

In line with the April 2025 data retrieval, the analyses were initiated using the latest available reference year for each indicator. This approach was driven by two key reasons. First, the objective of the research is to suggest an up-to-date evaluation utilising the latest data. Second, since the indicators vary in terms of the years they cover, calculating multi-year averages could weaken the accuracy and comparability of results across different indicators. Also, during the data screening process, it was observed that some countries lacked values for the selected reference years. Rather than omitting these countries entirely, the data from the most recent year was used. If data for that year were also unavailable, the process continued by moving further back in the data set until a valid data point was identified. In cases where no data could be

retrieved despite these efforts, the median value of the respective indicator calculated across all countries included in the dataset was used. This approach made it possible to keep all relevant country cases in the dataset, even in the presence of partial data gaps, without compromising the consistency, reliability, or interpretability of the overall analytical results. It ensured that no country was excluded due to missing data in specific years, thereby preserving the comparative nature and scope of the study. The nine indicators combined in the dataset originate from different SDGs and, therefore, exhibit substantial variation in their units of measurement. This diversity poses a key challenge to ensure comparability across indicators, as each one is expressed using a distinct measurement scale or format. In order to address this issue and ensure comparability across indicators with differing units and scales, all nine indicators were standardized individually within each column onto a unified Likert scale ranging from 1 (lowest performance) to 10 (highest performance).The standardization procedure was carried out using MATLAB (Matrix Laboratory), and for each indicator, the values were rescaled to a 1–10 Likert-type scale by determining the minimum and maximum values within each column and dividing the resulting range into equal-sized intervals. This unique method [23] ensured that the transformation was tailored to the distribution of each individual indicator. Next, reverse coding was applied to the standardized indicator Likert scores to ensure directional consistency across the dataset. Because certain indicators interpret higher values as unfavourable outcomes, while others denote higher values as positive performance, reverse coding was not merely a technical adjustment, but a necessary procedure to ensure the validity and reliability of the results. In the first phase, standardized Likert-scale scores were computed for each SDGs indicator across 28 countries, enabling a comparative assessment of Romania's agricultural performance relative to the EU average and Türkiye, and supporting a visualization-based interpretation of indicator-level deviations utilizing MATLAB and Python. In the second phase of the analysis, Partial Least Squares (PLS) regression was applied to assess the relative impact of each indicator on the overall SDGs performance in agriculture, which allowed the determination of the indicators that contribute most significantly to particular SDGs.

RESULTS AND DISCUSSIONS

Phase 1

Figure 1illustrates Romania's relative performance across nine indicators in comparison to the performance of the countries in the EU and Türkiye.

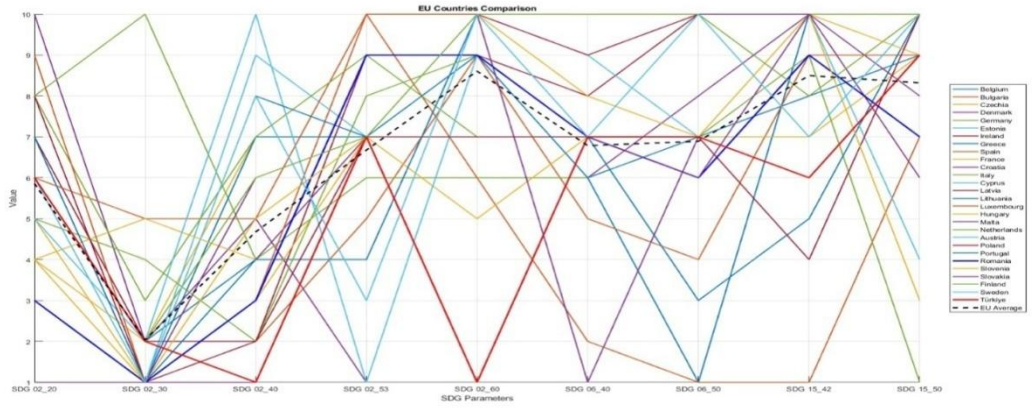


Fig. 1. Romania's relative performance across the EU
Source: Author's own visualization.

Figure 2 illustrates the indicator-based rankings of Romania and Türkiye across nine SDG measures, and the gap between the two. In Figure 2, however, country ranks are derived

directly from the original Eurostat series rather than from the Likert rescaling employed in the primary analyses. This specification preserves each country's exact ordinal position for each indicator and avoids transformation-induced distortions; ties are retained. The figure shows that Türkiye ranks higher on SDG 02_20, SDG 02_30, SDG 06_50, and SDG 15_50, while Romania achieves a comparatively higher position on SDG 02_40, SDG 02_53, SDG 02_60, and SDG 15_42. The two countries tie on SDG 06_40. Türkiye's profile is more dispersed, while Romania's is more concentrated around the lower mid-table. The largest gaps favor Türkiye on SDG 06_50 (+15 positions), SDG 02_20 (+12), and SDG 02_30 (+10), while Romania's largest advantage appears on SDG 15_42 (+8).However, the ranking snapshot, which places Romania in the lower mid-table, provides very little insight and may obscure how it actually sits. The study's methodologically richer Likert-scaled model sharpens Romania's relative standing by measuring its distance from the EU average and its indicator-level strengths and shortfalls. In this sense, Figures 1 and 3 reveal that Romania performs quite strongly in certain SDGs, while in some others, its performance is relatively weak, which indicates areas requiring further progress.

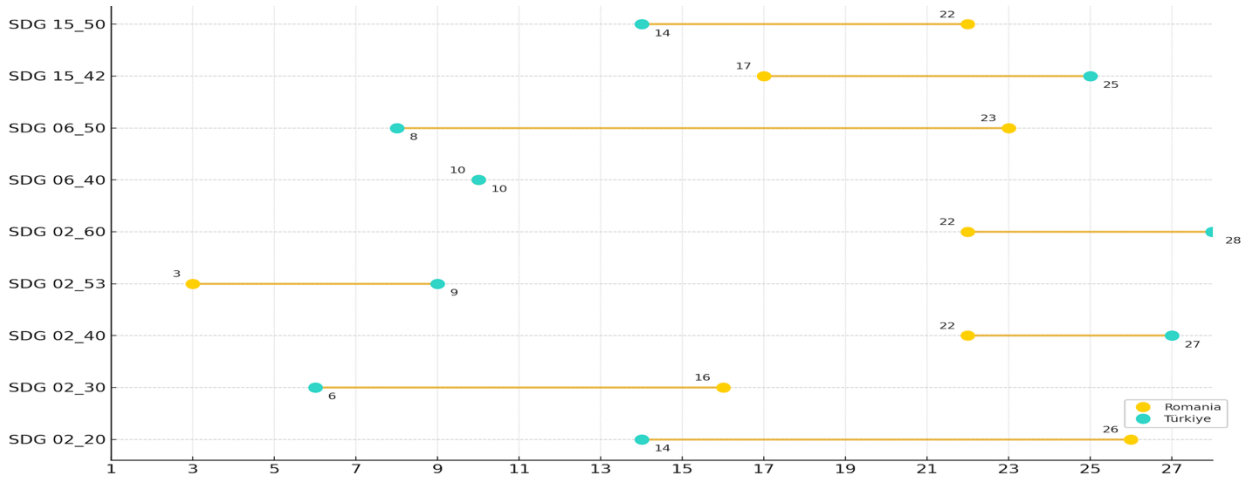


Fig. 2. Indicator-based rank comparison: Romania versus Türkiye
Source: Author's own calculations and visualization.

These general patterns become more evident when examined through concrete examples of these nine individual indicators, which reveal both high-performing and underperforming areas. For instance, Figures 1 and 3reveal that Romania's performance on SDG 02_53, SDG 02_60, SDG 06_40, and SDG 15_42 is above the European average. Here, Romania demonstrates its strongest results in SDG 2_53,where it ranks third among 28 countries after Luxembourg and Spain, and exceeds the EU average, which indicates its competitive edge and long-term developmental alignment within this SDG. This finding of the study is also further supported by [19] and empirical data from Eurostat [4], which indicate that between 2011 and 2021, while pesticide sales declined across the EU overall, Romania distinguished itself as one of the five countries with the most pronounced reductions, recording a 27% decrease in 2021 compared to the average of the preceding decade. Notably, Romania's strong performance in this area may point to effective regulatory frameworks or more sustainable agricultural practices relative to many of its European counterparts. Such outcomes could also suggest a growing awareness of environmental and health risks associated with pesticide use. This may also reflect successful national efforts to align agricultural inputs with EU sustainability targets. The strongest result in SDG 2_53 is followed by SDG15_42 and SDG 02_60, in which Romania shares top positions (9 out of 10 points) in the list of 28 countries and performs above the EU average. Since this particular indicator reflects ammonia emissions from agricultural sources,

Romania's above-average performance may indicate relatively effective emission control measures or more efficient management practices within its agricultural sector. Also, this finding aligns with the previous findings [16], which reported a consistent decline in Romania's ammonia emissions from Romania's agriculture, anticipated to drop from 12.2 kg/ha in 2015 to 9.1 kg/ha by 2030 in a comprehensive assessment of sustainable agriculture across EU Member States. These amounts are notably lower than those recorded in numerous EU states and the EU mean, which indicates a downward trend that aligns closely with the present study's results. Such consistency suggests that Romania's relatively high position in this particular indicator is not incidental, but rather reflects broader improvements in agricultural practices and emission management, as also anticipated in prior EU-level forecasts.

Conversely, one of the weakest performances of Romania was observed in SDG 02_20, where Romania ranks 26thamong 28 countries and falls below the EU average. Given that this particular indicator captures the real factor income from agriculture, reflecting the economic returns to both external and internal production inputs, Romania's low score may signal structural challenges in farm profitability and the limited economic viability of agricultural activities relative to many of its European counterparts. This finding is further supported by the findings of [20], who highlighted that Romania continues to face structural challenges, including low capitalization, high volatility in financial liquidity, and heavy reliance on public subsidies, which are the factors that directly limit farm profitability and investment capacity. These constraints show similarity with the low ranking observed in SDG 02_20 in this study. As such, the present study's results align closely with broader patterns identified in the literature regarding the limited economic viability of Romanian agricultural activities. In this context, focused investments and supportive policies could help strengthen Romania's agricultural sector and bring long-term benefits. Lastly, another prominent weak performance was observed in SDG 15_50, where the country ranks 22ndamong 28 countries, falling below the EU average. Given that this indicator reflects the extent of land at risk of severe erosion, Romania's below-average performance may indicate underlying geographic vulnerabilities or highlight the need for better land management practices. This finding is also very important, because according to EU statistics [3], Romania is one of the several countries in the southern and south-eastern parts of Europe that had significantly higher mean erosion rates than the mean value for the EU on all-erosion-prone land.

Figure 3illustrates the distribution of SDG scores across 28 countries, with Romania's position highlighted by red dots, offering an alternative perspective on the country's relative strengths and weaknesses. The figure reveals Romania's relative performance across given indicators, and Romania's performance heterogeneity across them, which points to both strategic strengths and critical development gaps. The varying widths of the boxes across these indicators also suggest differing levels of disparity among countries, with broader distributions indicating inconsistent progress and narrower ones reflecting convergence. Accordingly, Romania consistently appears in the upper quartile of the distribution, which exhibits competitive performance above the majority of countries, particularly in SDG 02_53, SDG 02_60, and SDG 15_42.In these areas, Romania has positioned itself not only above the average but also ahead of many other countries in the data set. Furthermore, Romania demonstrates moderate performance in SDG 06_40, SDG 06_50, and SDG 02_30, with scores that are close to the median, suggesting alignment with average EU standards.

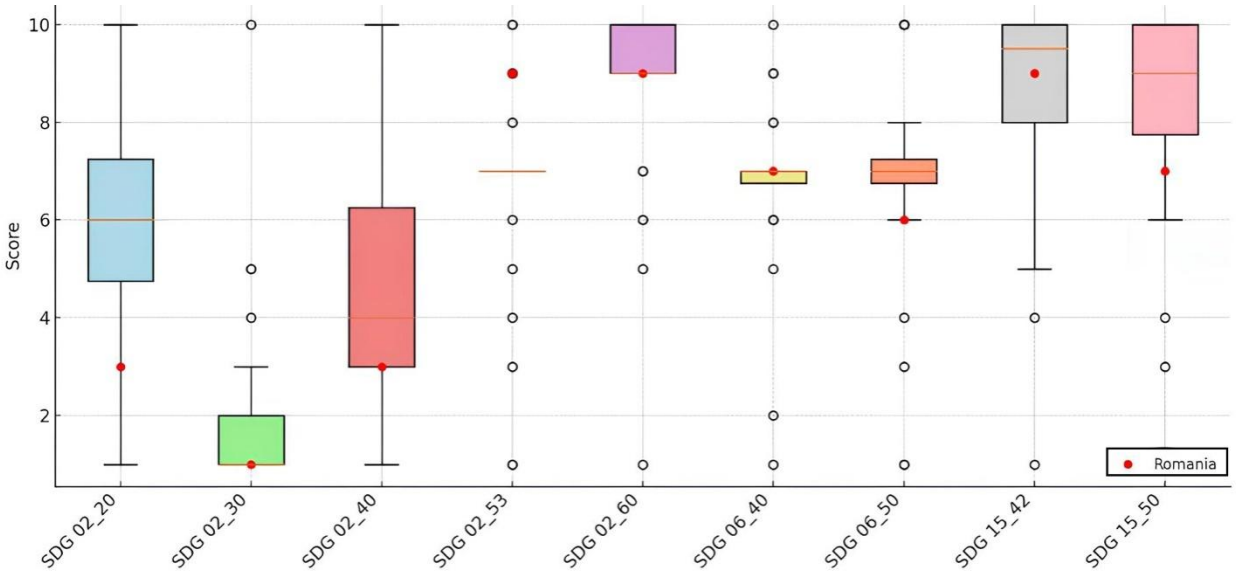


Fig. 3. Score distribution of each SDG indicator
Source: Author's own calculations and visualization.

However, Romania shows relatively weaker outcomes in SDG 02_20, SDG 02_40, and SDG 15_50, with scores falling into or near the lower quartile, indicating a need for improvement in these areas.

Romania versus Türkiye

Based on Türkiye's EU candidacy status and its strong role in regional agricultural production, a direct comparison between Romania and Türkiye across the selected nine SDG indicators (Fig. 4) provides further insights into their relative strengths and weaknesses in agricultural sustainability.

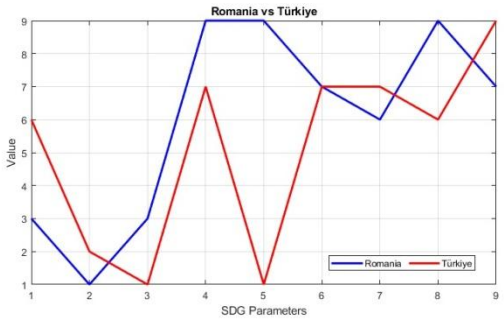


Fig. 4. Romania and Türkiye comparison
Source: Author's own calculations and visualization.

When comparing Romania and Türkiye across the nine SDG indicators, Romania shows a slightly stronger overall performance with an average score of 6.0 compared to Türkiye's 5.1. In this regard, Figure 4 reveals that Romania's main advantages appear in SDG 02_60 (ammonia emissions as a result of agricultural production), SDG 15_42 (the area impacted by drought), SDG 02_53(use and risk of chemical pesticides), and SDG 02_40 (organic farming), where it scores higher than Türkiye, with the order reflecting the size of the score differences between the two countries from the largest to the smallest.

Türkiye, on the other hand, shows stronger results in SDG 02_20 (Agricultural real factor income), SDG 15_50 (the area at risk of severe erosion), SDG 02_30(GBARD), and SDG 06_50 (measures the concentration of phosphate),particularly suggesting relative strengths in agricultural profitability and government support for research and development. Regarding SDG 06_40, both countries are observed to perform equally. However, one of the most salient findings of the comparison is the low performance of both Romania and Türkiye in areas that are essential in long-term agricultural transformation. In particular, both countries exhibit relatively weak results in agricultural R&D (SDG 02_30), indicating limited investments in innovation and research capacity, and in organic farming (SDG 02_40), where their scores remain at the lower end of the scale. Although Romania records a slight advantage over Türkiye in terms of the share of total agricultural land under organic farming, the low scores of both countries in this area point to significant room for improvement and

highlight an important opportunity to strengthen their alignment with sustainability objectives and EU standards.

The causes and factors influencing Romania's performance

The causes and factors that have influenced Romania's sustainability performance in agriculture are multiple and, more importantly, interrelated, which reflect structural, economic, environmental, and demographic challenges. First of all, Romania has low resource productivity, around 70% below the EU average, and the circular material use rate was observed to decrease from 2.6% in 2012 to 1.8% in 2017, which points to crucial structural inefficiencies in the use of resources and a weak circular economy [14]. These trends show that resource productivity outcomes are still poor and that there is a larger scope of reform and progress required. Although these trends refer to the broader economy, they are also relevant for agriculture since low resource productivity and a weak circular economy could also lead to inefficiencies in agricultural inputs and outputs in a way that will also affect Romania's agricultural sustainability performance. Moreover, Romanian agriculture seems to retain certain characteristic factors, namely excessive farm fragmentation, heightened reliance on family labor, and a relatively limited degree of capitalization in comparison with the EU average.

On this basis, differences in efficiency, profitability, and dependence on subsidies become evident [20]. Accordingly, the evidence points to fast economic expansion among Romanian farms; however, this growth remains tied to structural vulnerabilities, such as low capitalization, high liquidity volatility, and heavy reliance on public support, while farms in the EU are financially resilient, with a steady investment capacity. These aspects underline the economic sustainability challenges of Romanian agriculture, which include structural vulnerabilities, issues regarding profitability, low capitalization, and also higher dependence on subsidies.

In addition, Romanian agriculture also faces important environmental challenges. While the results of our analysis show that Romania currently performs relatively well in pesticide use reduction, even exceeding the EU average, the long-term outlook is less favorable according to the latest forecast model in the research [16]. This implies that, notwithstanding the EU's Farm-to-Fork Strategy target of a 50% cut in chemical and hazardous pesticide use by 2030, several countries, such as Latvia, Bulgaria, Slovakia, Slovenia, Hungary, and Romania, are projected to experience an increase in the hazardous pesticides index. Therefore, urgent action at the EU level is essential to speed up the reduction of hazardous pesticide use, given their especially detrimental effects on people and the environment. Notably, the EU average remains well below the proposed target, both in 2020 (9.08%) and in the 2030 projection (14.98%) [16].Secondly, although the present achievements of Romania are notable, measures are still required to prevent a potential reversal, as such an increase would have particularly negative consequences for both public health and the environment. Moreover, a very recent study reveals that Romania is not only facing structural and environmental challenges, but also a demographic dilemma. Because younger generations are moving to bigger cities or countries with improved economic prospects, and rural areas are left with an old population that naturally shows limited willingness to embrace modern agricultural technology [18].

According to this study, with agriculture remaining the chief source of income for Romania's rural majority, implementing sustainable practices is fundamental to ensuring the country's long-term development. Since Romania's rural population relies strongly on agriculture for jobs, food security, and rural livelihoods, the country is facing challenges of fragmented landholdings, outdated infrastructure, and limited access to technology. Also, Romanian agriculture is highly vulnerable to climate change, as recurrent floods and droughts disproportionately affect rural populations, while the adoption of adaptive practices remains slow due to several reasons. These are all continuing to obstruct rural areas in their

attempts to align with the Sustainable Development Goals [18].

The Causes and factors influencing Türkiye's performance

As highlighted earlier, Türkiye demonstrates strong results compared to Romania in SDG 02_20 (agricultural real factor income generated by farming), SDG 15_50 (the area at risk of severe erosion by water such as rain splash, sheet-wash and rills), SDG 02_30 (government budget allocations for research and development), and SDG 06_50 (the concentration of phosphate per liter in the dissolved phase from water samples from river stations). However, when Türkiye's nine indicators analyzed in this research are compared with the EU average, additional noteworthy results become evident. While Türkiye slightly surpasses the EU average in several areas, SDG 2.20 proves especially significant, showing Türkiye's relative strength in agricultural real factor income and aligning with recent findings in the literature. The relevance of SDG 2.20 can be better understood by examining recent developments in Türkiye's agricultural production and support policies. Türkiye's agricultural real factor income being above the EU average can be explained by strong state support and notable improvements in productivity. According to recent evidence [17] between 2002 and 2020 the value of agricultural production increased by 94 percent, while agricultural production per capita rose from 3,285 USD to 9,281 USD. Accordingly, agricultural support payments increased by approximately 135 percent, and in the period 2002–2022 producers received nearly 70 billion USD in public support, which directly influenced the sector's growth. Beyond these overall figures, production increases were recorded in several key categories, including vegetables (from 25.82 to 31.20 million tons, +20.83%), grains (from 30.83 to 37.20 million tons, +20.66%), fodder crops (from 0.758 to 2.458 million tons, +224.27%), and seeds (from 0.145 to 1.241 million tons, +755.86%). Moreover, agricultural exports grew from 4.57 to 24.34 billion USD, an increase of more than 430 percent, highlighting the sector's growing competitiveness in international markets. These results reveal a significant reinforcement of the agricultural sector's income-generating capacity.

By contrast, this study reveals that Türkiye's score on SDG 2.40, measuring the share of farmland under organic farming, remains substantially beneath the EU average, and aligns with the evidence presented by Çakırlı Akyüz and Theuvsen [2] based on Turkish Ministry of Agriculture and Forestry statistics [22]. As emphasized here,one of the most striking aspects of Türkiye's agricultural performance is its low share of land under organic farming, measured by SDG 2.40.Accordingly, although Türkiye exports various organic products, the data indicate that organic farming accounts for only about 1.4% of agricultural land, which is well below the EU average, and this limited share can be explained by several interrelated factors. Firstly, because of weak consumer awareness regarding the specific characteristics of organic products as well as high retail prices in Türkiye, the domestic market for organic products remains a small niche, with only about 5% of total production consumed domestically, while nearly 95% is exported [2]. Secondly, due to the high costs of individual certification, most farmers obtain certification through processors or exporters. In such cases, the certificate belongs to the applicant company, and individual farmers can only sell their products to the certificate holder under contractual terms [2]. This system would normally increase farmers' dependency on external actors and limits their ability to operate independently. Finally, although policy instruments to promote organic farming exist in Türkiye, governmental subsidies and institutional support have been more substantial for conventional schemes such as Good Agricultural Practices (GAP). This imbalance seems to have affected the effectiveness of organic farming policies in Türkiye [2].

Phase 2: PLS- Regression Results

In the second phase of the study, a PLS regression analysis was conducted (Figure4) via Smart PLS [21]. Partial Least Squares is a

regression-based approach that explores the linear relationships between multiple independent variables and a single or multiple dependent variables. Unlike regular regression, PLS constructs latent components from the set of independent variables using principal component analysis to estimate the regression model [15].

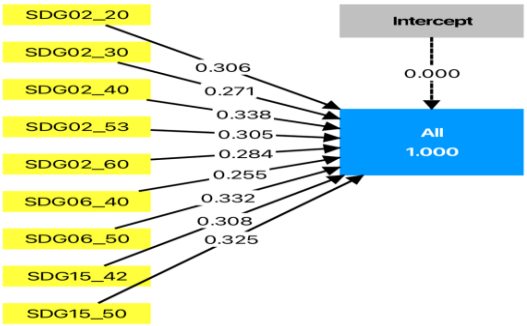


Fig. 4. Regression Model
Source: Author's own calculations.

The nine indicators given above were treated as different independent variable factors. The arithmetic mean of these indicators was calculated to create the dependent variable factor that reflects overall agriculture-related SDGs performance. The main objective at this stage is to determine which of these SDGs indicators has the greatest impact on the overall agriculture-related SDGs performance and to assess the contribution of each indicator to this overall performance.
The regression results for each individual indicator revealed significant findings (Table 2).

Table 2. Regression Results

Indicator	Standardized coefficients	P value	T- value	VIF
2_20	0.306	0.000	4637157292623.071	1.078
2_30	0.271	0.000	3382873753917.322	1.586
2_40	0.338	0.000	4030778097009.720	1.738
2_53	0.305	0.000	4218706100123.647	1.289
2_60	0.284	0.000	3081708220895.945	2.092
6_40	0.255	0.000	3041800987943.090	1.729
6_50	0.332	0.000	4214589304570.398	1.535
15_42	0.308	0.000	3720429699330.346	1.694
15_50	0.325	0.000	4321974768462.514	1.389

Note: Durbin-Watson test 1.511 / Breusch-Pagan Test P value 0.395
Source: Author's own calculations.

First, the findings facilitated the determination of which particular indicator(s) contribute most to the overall performance. Accordingly, SDG 2_40, SDG 6_50, and SDG 15_50 were observed as the top contributors to the overall performance. In contrast, SDG 6_40 and SDG 2_30 were found to have the lowest contributions.
However, it is necessary to state that when these two lowest-contributing indicators are excluded, the remaining seven indicators do not show substantial differences in their contribution levels, which shows that each indicator plays a highly important role in shaping overall performance.
This demonstrates the model's capacity to capture the relationship between the constructs within the model.

CONCLUSIONS

This study examined Romania and Türkiye's agriculture-related SDGs performance by employing a two-phase approach. In the first phase, the country's position was assessed compared to 28 other countries, which revealed that Romania has shown both competitive strengths (e.g., pesticide reduction and ammonia emissions) and weaknesses (e.g., agricultural income and soil erosion). In the second phase, a PLS regression model identified SDG 2_40 (organic farming), SDG 6_50 (phosphate pollution), and SDG 15_50 (soil erosion) as the strongest contributors to overall agricultural sustainability performance. These findings demonstrate that Romania is engaging with the *2030 Agenda* by integrating environmental and rural development objectives into its agricultural policies. The study contributes to the growing body of literature encouraging the use of data-driven tools to guide more targeted and effective policy interventions in sustainable agriculture.
With respect to Türkiye, the findings reveal differentiated outcomes across the agricultural indicators. However, SDG 2.20 points to the country's relative advantage in agricultural profitability, supported by subsidies and productivity gains. On the other hand, SDG 2.40 highlights structural weaknesses in organic farming, reflecting limited domestic demand, certification barriers, and relatively weak policy incentives. Taken together, these

results suggest that while Türkiye possesses considerable potential in certain areas of the SDGs, sustained reforms and stronger policy coherence are needed to address persistent shortcomings and achieve closer alignment with the EU.

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THE TRANSITION TO DIGITAL AGRICULTURE: CHALLENGES AND OPPORTUNITIES

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Abstract

The use of technologies and innovations in agriculture plays a crucial role in shaping the future of the global agricultural sector. Advances in artificial intelligence, the Internet of Things (IoT), precision agriculture, and biotechnology enhance productivity, reduce environmental impact and strengthen farmers' resilience. This study undertakes a comprehensive examination of existing literature on the key factors influencing digital agriculture adoption, providing relevant data to inform public policies and emphasizing strategic measures to accelerate digital integration. The results of this study highlight the essential role of socio-economic determinants in shaping farmers' capacity and willingness to adopt digital technologies, underscoring the need for targeted policy interventions and support mechanisms that address inequalities in access, education, and infrastructure.

Key words*: digital agriculture, emerging technologies, labor market, sustainability*

INTRODUCTION

No single technology can fully address future challenges. The most effective solutions arise from integrating multiple technologies and innovations, tailored to regional contexts and to the specific needs of the stakeholders involved. In this regard, a strategic approach is essential—one grounded in tools for selecting and supporting new technologies, a monitoring and evaluation framework for the responsible adoption of innovations and participatory governance mechanisms to ensure an equitable, system-wide transformation [2, 24, 25, 66].

The agricultural sector is undergoing rapid digitalization, in which "emerging technologies, such as artificial intelligence (AI), automation, 3D printing, nanotechnology, sensors, unmanned aerial vehicles (UAVs), blockchain, controlled-environment agriculture (CEA), big-data analytics and the Internet of Things (IoT)" [61], play a decisive role in optimizing productivity and promoting sustainability [26, 58]. According to Bertoglio et al. (2021) [8], the current wave of digital transformation in agriculture constitutes a digital agricultural revolution, characterized by exponential growth in research output, strong interdisciplinary collaboration and the convergence of technologies that enhance efficiency and sustainability. These innovations enable more efficient resource management, reduce losses and contribute to solutions adapted to current climatic and economic challenges [16, 39].

In parallel, technological change is restructuring labor markets, reducing the need for manual labor while increasing demand for specialized skills. This dynamic calls for the continuous adaptation of education systems and sustained investment in professional training [7, 35].

Emerging technologies are defined by Rotolo et al. (2016) [55] as relatively new technologies that exhibit rapid growth and are characterized by a degree of coherence that persists over time. Their most significant impact lies in the future, and during their emergent phase they remain uncertain and ambiguous.

This definition underscores several fundamental characteristics of emerging technologies.

First, they introduce radical innovation, representing a significant advance over preexisting technologies. Second, they are marked by an accelerated pace of development and adoption. They also maintain internal coherence, consolidating into distinct fields of research and application. Another essential feature is their capacity to generate substantial societal and economic impact.

The FAO and CIRAD report, "Shaping Sustainable Agrifood Futures Pre-Emerging and Emerging Technologies and Innovations for Impact – An Extended Global Foresight Report with Regional and Stakeholders' Insights, provides a detailed analysis of 32 promising technologies and innovations and explores how they can help address the challenges" [2] confronting global agrifood systems.

Among these, artificial intelligence (AI) stands out as especially promising, with the capacity to optimize agrifood processes through advanced data analysis and the identification of effective solutions [28,37]. Nevertheless, implementation requires appropriate regulation and inclusion mechanisms so that human resources in the agricultural sector, and less developed regions, are not excluded from this technological transition. In parallel, policy and organizational innovations play a key role in facilitating structural change, with the potential to balance access to technology and to stimulate the sustainable development of the agrifood sector [2, 24, 25, 44].

This paper aims to identify the determinants of new-technology adoption in order to support human resources in the agricultural sector during the digitalization process.

The study is organized into two essential parts, each addressing research questions relevant to the variables that influence the decision of agricultural-sector human resources to adopt digital technologies.

Part I: Theoretical Foundation and Systematic Review.

This section establishes the conceptual framework required to comprehend how new technologies are adopted. It explores key theoretical perspectives, models of adoption, and the main determinants of digital transformation, with particular attention to:

• the core concepts and theoretical models that explain the adoption of new technologies;

• the factors driving digitalization and the integration of new technologies across various sectors.

The systematic review of research in the agricultural domain synthesizes existing literature on the adoption of new technologies in agriculture, highlighting the models applied and the key factors that shape this adoption process. It examines the opportunities and risks of digital transformation, together with the challenges encountered when implementing it. Accordingly, it addresses the following research questions:

• What are the main trends in the adoption of new technologies identified in the agricultural literature?

• To what extent do the factors highlighted in previous studies influence farmers' adoption of technology?

Part II: Perspectives, future directions, and conclusions.

This section synthesizes the main findings and formulates recommendations for future research in this field. It analyzes emerging trends and proposes strategies to improve the digitalization process in agriculture, addressing:

• Which core findings concerning agricultural tech adoption arise from the reviewed research?

• What should future studies focus on to help people in agriculture adopt technology more effectively?

MATERIALS ȘI METHODS

The research was structured in several stages, including the explicit formulation of research questions, the rigorous identification and selection of relevant sources and a critical appraisal of the available evidence, thereby ensuring a coherent and methodologically grounded approach. The opening phase involved a precise definition of the research

question: to identify the determinants of adopting emerging technologies in agriculture and to underline their significance. The research questions were formulated to guide the analysis toward theoretical models, determining factors and the impact on human resources in the agricultural sector. To ensure comprehensive identification of pertinent studies, a systematic research was conducted in the Web of Science and ScienceDirect databases, both recognized for providing a broad perspective on progress and trajectories across diverse research fields. The selection process employed the following keywords: "adoption of digital innovations", "emerging technologies", "agriculture", "digital adoption" as well as combinations of specific terms such as "digitalization", "precision farming", "smart agriculture", "technology adoption" and "sustainability".

Throughout the research process, the search string and keywords were iteratively refined to secure more specific and relevant results. This continuous refinement enabled the selection of studies offering a detailed perspective on the adoption of emerging technologies in agriculture, including determinants, benefits and the challenges associated with this process. To ensure the relevance, quality and coherence of the materials analyzed within the systematic literature review, rigorous inclusion and exclusion criteria were defined and applied, aligned with the study's objective: investigating the factors that influence the adoption of digital technologies in agriculture, based on established theoretical frameworks. These criteria served to filter out non-relevant publications and to select only those studies that make a significant contribution to the field (Figure 1). In the first stage of the selection process, 1,433 studies were identified by querying the Web of Science and ScienceDirect databases. Their metadata—including title, abstract, publication type, language and keywords—were examined to perform an initial screening and to exclude duplicate records.

At the screening stage, 1,416 studies published in the last five years (2019–2024) matched the queried keywords.

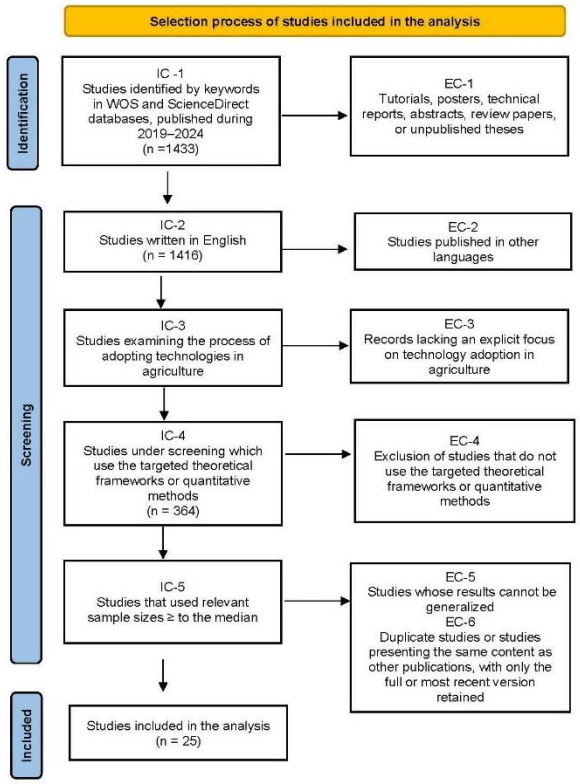


Fig. 1. PRISMA 2020 flow diagram adapted for the selection of relevant studies.
Source: Author's own processing using the PRISMA 2020 template [47].

These were then triaged by analyzing each article's title and abstract against the predefined inclusion criteria—publication period (IC-1), language of publication (IC-2) and thematic relevance (IC-3)—and by excluding records that met the exclusion criteria EC-1, EC-2 and EC-3, namely tutorials, posters, technical reports, doctoral theses or other sources; articles written in languages other than English; and studies that do not explicitly address the technology-adoption process. Subsequently, studies that were not directly relevant to the research questions were removed. Applying exclusion criterion EC-3 substantially reduced the corpus, yielding a set of 364 articles. For these, we examined the method and target group/number of publications according to the following inclusion criteria: the use of established theoretical frameworks or quantitative research methods (EC-4), studies with insufficient samples (<30) (EC-5) and redundant publications, retaining only the full or most recent version of each study (EC-6).

Table 1. Summary of the studies included in the systematic literature review.

No.	Authors/Paper	Datacollectionmethods	Research methodology	Region
1	Abdulai, et al., 2024, Will agricultural digitalization deliver relative advantages in quality of work, productivity, profitability, return on investments, and reliability? Perceptions of Canadian producers. [1]	Online-administered questionnaire. Statistical analysis	Diffusion of Innovations theory (Rogers), quantitative analysis with five dimensions of relative advantage	Canada
2	Ammann J. et al., 2022, The adoption of precision agriculture enabling technologies in Swiss outdoor vegetable production: a Delphi study. [3]	Delphi study (2020) Descriptive analysis with Excel & SPSS	Delphi study	Switzerland
3	Balafoutis, A.T.,et al., 2020, Smart farming technology trends: economic and environmental effects, labor impact, and adoption readiness.[4]	Questionnaires Systematic literature review Qualitative and quantitative analysis	Survey, secondary analysis, systematic review	Europe
4	Barrett, H., & Rose, D. C., 2020, Perceptions of the fourth agricultural revolution: What's in, what's out and what consequences are anticipated? [6]	Content analysis and interviews Thematic coding and discourse analysis	Multi-method qualitative study (triangulation of media, policy, practitioners)	United Kingdom (Norfolk, East of England)
5	Caffaro, F. et al., 2020, Drivers of farmers intention to adopt technological innovations in Italy: The role of information sources, perceived usefulness, and perceived ease of use [10]	Agricultural technology questionnaire. Structural equation modeling (SEM); validation using CFI, RMSEA, IFI	TAM – structurally mediated model; SEM tested for two types of smart technologies	Italy (Piedmont region)
6	Franco da Silveira et al., 2023, Farmers' perception of the barriers that hinder the implementation of agriculture 4.0 [15]	Validated online questionnaire (Google Forms). Statistical analysis	Confirmatory Factor Analysis (CFA) with five dimensions: technological, economic, political, social, environmental	Brazil
7	Das U. et al., 2022, Effectiveness and upscaling potential of climate smart agriculture interventions [20]	Questionnaires, focus groups, statistical analysis	Quantitative and participatory study.	India
8	Dawson Jr. et al., 2024, Creating a digital platform for the agricultural cooperative system through interorganizational collaboration [21]	Action research in 4 cycles. Qualitative inductive analysis (open coding, process mapping, participant validation)	Action research: collaborative development in four stages—strategy, MVPs, build, dissemination	Brazil
9	Degieter et al. 2023, Farmers' acceptance of robotics and unmanned aerial vehicles [22]	Systematic literature review. Narrative analysis, factor synthesis, meta-inferences	Systematic review (PRISMA), extraction of significant factors for adoption of UAVs and robots	EU, USA, Australia, China, Brazil, India, Malaysia
10	Dibbern et al., 2024, Main drivers and barriers to the adoption of Digital Agriculture technologies [23]	Bibliometrics, case studies	Review plus content analysis (VOSviewer)	Global
11	Gaspar P. D. et al. 2021, Development of Technological Capabilities through the Internet of Things (IoT): Survey of Opportunities and Barriers for IoT Implementation in Portugal's Agro-Industry [29]	Mixed survey: Questionnaires, interviews Descriptive analysis and statistical evaluation	Mixed-method case study.	Portugal (central region)
12	Gebresenbet G. et al., 2023, A concept for application of integrated digital technologies to enhance future smart agricultural systems [30]	Literature review; experts with multidisciplinary experience. Synthesis and conceptual modeling	Conceptual analysis plus proposal for an integrated system (AI, IoT, DSS, BC [blockchain])	Europe
13	Giua C. et al. 2022, Smart farming technologies adoption: Which factors play a role in the digital transition? [33]	Online questionnaire (CAWI). SEM and ZIP analysis.	Adapted theoretical UTAUT model	Italy
14	Kernecker M. et al., 2020, Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe.[36]	Questionnaires, interviews Statistical analysis	Mixed method: quantitative (questionnaire), qualitative (interviews).Stratified sampling by: country, farm size, cropping system, SFT adoption	France, Germany, Greece, Serbia, Spain, the Netherlands, United Kingdom
15	Kroupová Z et al. 2024, Drivers and barriers to precision agriculture technology and digitalisation adoption: Meta-analysis of decision choice models.[38]	Meta-analysis	Decision meta-analysis with qualitative and quantitative synthesis	Global
16	Michels M. et al, 2020, A trans-theoretical model for the adoption of drones by large-scale German farmers.[41]	Questionnaire Statistical analysis	Transtheoretical Adoption Model (TTMA), derived from the Transtheoretical Model of behavior change (TTMC)	Germany
17	Mwangakala H.A. et al., 2024, Emerging digital technologies potential in promoting equitable agricultural supply chain: A scoping review [42]	Systematic literature review (2012–2022). Narrative synthesis, analysis by factors and regions	Theoretical framework: Socio-Technical Systems (STS) Theory. Thematic exploration of equity in digital agri-food chains	Global
18	Nowak B. 2021, Precision Agriculture: Where do We Stand? A Review of the Adoption of Precision Agriculture Technologies on Field Crops Farms in Developed Countries [43]	Systematic literature review Statistical analysis	Classification of technologies into three categories: GNSS, within-field diagnostic tools, variable-rate applications.	USA, Canada, Australia, Germany, England, Finland, Denmark
19	Osrof, H., et al. 2023, Adoption of smart farming technologies in field operations: A systematic review and future research agenda.[46]	Systematic review (2010–2023). Narrative analysis, theoretical classification, meta-categorization of factors	TCCM Framework: Theory – Context – Characteristics – Methods	Global
20	Pauschinger D., Klauser F.R., 2022, The introduction of digital technologies into agriculture: space, materiality and the public–private interacting forms of authority and expertise. [48]	Interviews and field observation (2016–2020). Narrative and thematic coding in MAXQDA. Discursive and contextual analysis of actor relationships.	Qualitative case study. Theoretical approach: Foucault/Actor- Network Theory (ANT).	Switzerland
21	Petrovic et al., 2024, Application of precision agriculture technologies in Central Europe—review [50]	Systematic literature review. Thematic analysis	Country-by-country synthesis (PL, CZ, AT, SK, SI, DE, HU)	Poland, Czechia, Austria, Slovakia, Slovenia, Germany, Hungary
22	Isabelle Piot-Lepetit et al., 2019, Understanding the determinants of IT adoption in agriculture using an integrated TAM-TOE model: A bibliometric analysis. [52]	Bibliometric analysis: Thematic classification and frequencies of occurrence	Integrated theoretical analysis TAM–TOE	Europe, Canada, Australia, New Zealand
23	Tey Y.S., Brindal M. 2021, A meta-analysis of factors driving the adoption of precision agriculture. [63]	Meta-analysis Statistical analysis.	Meta-analysis with effect size calculation (Hedges' g).	Mostly USA, the rest from Europe and one study from Brazil
24	Yarashynskaya A. & Prus P. 2022, Smart Energy for a Smart City: A Review of Polish Urban Development Plans [68]	Content analysis, qualitative analysis	Systematic review	Poland
25	Yatribi, T. 2020, Factors Affecting Precision Agriculture Adoption: A Systematic Literature Review. [69]	Systematic literature review: Thematic classification and frequencies of occurrence	Qualitative and quantitative analysis. Classification of factors into four groups: individual, organizational, institutional, technological	Global (USA, New Zealand, Great Britain, Germany, Africa, Asia, etc.)

Source: Authors' compilation based on reviewed studies [1, 4, 6, 10, 15, 20, 21, 22, 23, 29, 30, 33, 36, 38, 41, 42, 43, 46, 48, 50, 52, 63, 68, 69].

Applying the eligibility criteria resulted in a final selection of 25 scientific articles deemed relevant to the study objective. They were analyzed in full following the PRISMA 2020 protocol (Page et al., 2021) [47] (Table 1).

This methodology yielded rigorous and relevant results that not only identified the determinants and barriers to the adoption of digital technologies in agriculture, but also highlighted the opportunities and favorable prospects associated with the transition to digital agriculture. Accordingly, the analysis provides an in-depth understanding of the dynamics of the digitalization process, underscoring both the sector's transformative potential and the future courses of action needed to realize that potential.

RESULTS AND DISCUSSIONS

Part I - Theoretical foundation

To understand the implementation of new technologies, it is essential to delve into the fundamental concepts, theoretical models of technology adoption and the determinants of adopting digitalized agriculture.

The core theoretical lenses—Diffusion of Innovations (DOI), the Technology Acceptance Model (TAM) and the Technology Organization Environment (TOE) framework provide the main explanatory basis for digital technology adoption, supported by empirical evidence in the specialist literature [65].

The Diffusion of Innovations theory explains the social and behavioral mechanisms of adoption [53, 54]; the Technology Acceptance Model analyzes the psychological factors that shape users' decisions [17, 18, 19]; and the Technology Organization Environment (TOE) framework offers a nuanced understanding of the internal and external determinants of technology adoption at the organizational level [23, 45, 49, 52].

Integrating these models can yield a more robust understanding of digitalization and inform effective strategies for implementing new technologies across economic sectors [30, 45]. This approach enables a deeper grasp of how organizations adopt and integrate emerging technologies. The systematic review of studies highlights the factors that influence this process.

A comparative analysis of 25 scientific articles published between 2019 and 2024 revealed a clear trend in the literature: while digital technologies applied in agriculture are perceived as highly promising, their adoption remains partial and unevenly distributed worldwide. In most cases, adoption is conditioned not only by technological features but also by socioeconomic, institutional and perceptual factors [1, 2, 10, 15, 17, 18, 20, 21, 22, 23, 24, 25, 27, 37, 40, 42, 43, 46, 50, 52, 67, 69]. Across the reviewed literature, many studies employed well-established theoretical frameworks to examine agricultural technology adoption. The Technology Acceptance Model (TAM) was used most frequently, followed by Diffusion of Innovations (DOI) and the Technology–Organization–Environment (TOE) framework [49, 64, 65].

Other approaches included the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Technology–Task–Motivation Alignment (TTMA) model [3, 4, 6, 9, 10, 11, 12, 19, 21, 25, 36, 41, 45, 52, 62, 63, 69]. This theoretical diversity reflects a growing tendency to integrate individual, organizational, and technological perspectives to gain a deeper understanding of the decision-making processes that influence the adoption of digital technologies in agriculture.

With respect to research methods, quantitative questionnaires were the most frequently used, featuring in more than half of the analyzed articles (n=25), followed by systematic reviews (36%) and semi-structured interviews (28%). These methodological choices reflect growing interest in capturing both individual perceptions and the institutional contexts that shape adoption behaviors. Furthermore, 17 of the 25 studies (68%) applied quantitative statistical methods, including multiple regression, confirmatory factor analysis (CFA), structural equation modeling (SEM), ANOVA, PCA, and logit/probit models [4, 6, 9, 10, 11, 12, 14, 16, 17, 18, 20, 21, 22, 23, 24, 25, 36]. About 32% of the studies used qualitative or conceptual approaches, such as

narrative analysis, action research, and thematic reviews, emphasizing interpretive depth and contextual understanding.

Across the corpus, 70% of the studies employed quantitative methods; among these, more than two-thirds used samples ranging from 170 to 400 respondents.

Among the most frequently cited enabling factors were: farm size (60% of studies), correlated with greater investment capacity [2, 6, 16, 22, 36, 41, 46]; farmers' education level (56% of studies), associated with increased openness to innovation [10, 36, 46, 52, 68, 69]; and perceived usefulness of the technology (48% of studies), a core component of technology-acceptance models [3, 4, 6, 9, 10, 12, 19, 22, 23, 33, 36, 41, 46, 48, 52, 58, 63, 68, 69]. In addition, access to training and agricultural advisory services was identified as a key factor in building farmers' confidence and reducing reluctance toward new technologies [15, 17, 18, 68]. (Figure 2).

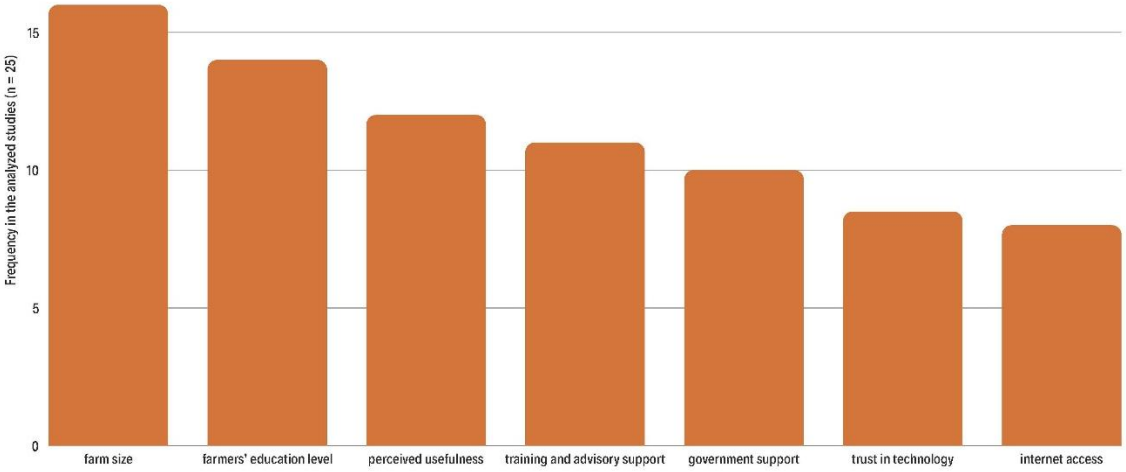


Fig. 2. Main factors enabling the adoption of smart agricultural technologies.
Source: Author's processing based on the reviewed literature.

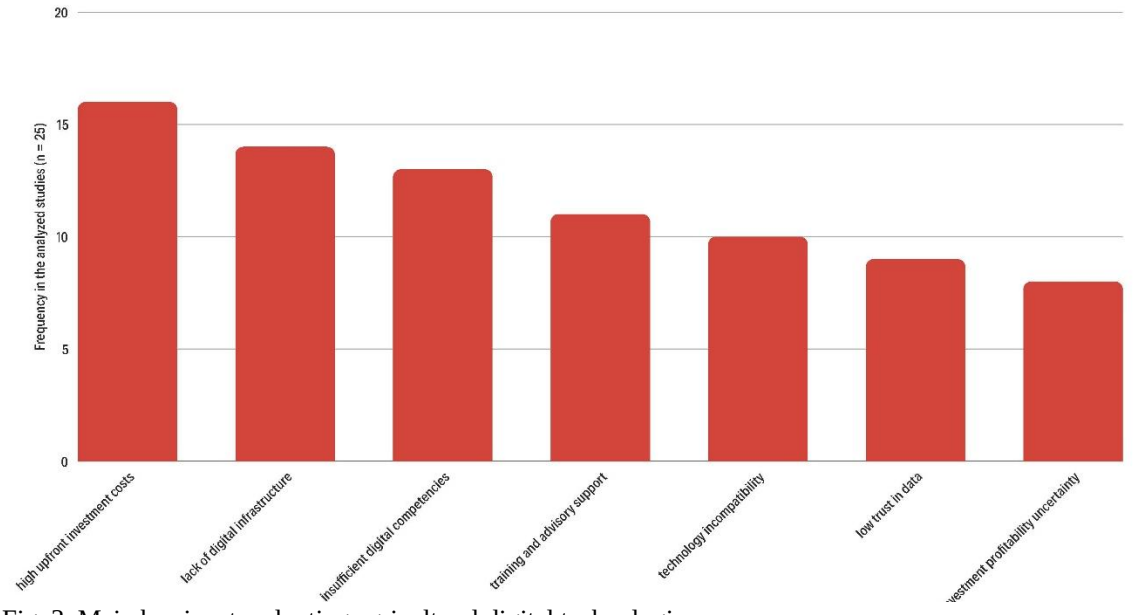


Fig. 3. Main barriers to adopting agricultural digital technologies.
Source: Author's processing based on the reviewed literature.

With respect to barriers, the most significant obstacles are economic, technological, and social in nature. High upfront costs (n=16), the lack of digital infrastructure in rural areas (n=14) and low levels of digital skills (n=13) recur throughout the reviewed literature [1, 2,

3, 5, 6, 10, 14, 17, 18, 20, 21, 22, 23, 24, 25, 31, 43, 47, 49, 50]. According to Phiri et al. (2019) [51], e-agriculture applications in developing countries are often constrained by limited digital literacy and inadequate institutional support, particularly among young farmers. In addition, the lack of interoperability among equipment and uncertainty regarding return on investment (ROI) further heighten farmers' hesitation to adopt new digital solutions at scale (Figure 3).

Adoption of smart technologies is constrained by significant socio-economic barriers, including limited awareness, high upfront costs, long payback periods, and the absence of impact studies demonstrating their effectiveness [1, 4, 15, 20, 21, 22, 23, 40, 43, 50, 64, 65]. Incoherent regulations and public policies, difficulties in farmer training, and gaps between research and on-the-ground realities further hinder implementation [10, 23, 52, 63, 68].

In addition, weak consumer demand and the unequal distribution of costs and benefits along the agrifood chain reduce farmers' incentives to invest in sustainable technologies [42, 43, 46]**.**

Finally, the adoption of precision agriculture varies markedly across European countries—being more widespread in regions with large farms, such as Germany, the Czech Republic, and Slovakia, and lower in areas dominated by small farms, such as Hungary, Poland, Austria, and Slovenia—according to the study by Kroupová et al. 2024 [38]. This differentiation is shaped by national agricultural policies, access to digital infrastructure, specialized training programs, and the promotion of cooperation among agricultural organizations, thereby facilitating equitable and sustainable access to innovation.

Part II - Perspectives and future directions

In this part of the research, the principal findings are synthesized and recommendations are formulated for future lines of inquiry in this field.

Recent analyses by Cisternas et al. (2020) [13] and Rudrakar et al. (2021) [56] emphasize that the evolution toward precision and digital agriculture depends on the integration of information technologies across production processes, supported by adaptive management and policy frameworks.

The results of this study highlight the essential role of socio-economic determinants in the adoption of digital agriculture, but also shows that technology adoption is influenced by both individual and organizational factors. Variables such as education and prior technological experience have a direct impact on the decision to adopt, while farm size and available resources shape the capacity to integrate digital solutions [10, 15, 22, 23, 36, 43, 45, 46, 52, 63, 68].

To overcome these obstacles, coherent public policies, adequate financial support, accessible training programs and communication strategies tailored to farmers' needs are required so that the adoption of smart agricultural technologies becomes more efficient and sustainable in the long term [1, 4, 20, 21, 23, 42, 50, 67, 68].

Future studies should devote greater attention to the long-term use and integration of technologies, in order to understand not only the decision to adopt but also the processes by which farmers accommodate and adapt to new digital solutions. A broader exploration of environmental/contextual factors is needed, considering the effects of digital infrastructure, public policies, and access to resources on technology adoption [15, 22, 29, 30, 33, 38, 41, 43, 46].

Investigating adoption by type of technological solution—such as AI, IoT sensors and agricultural drones—could provide a more granular understanding of how different technologies are perceived and integrated across diverse farming practices [22, 29, 30, 32, 33, 41, 46, 48, 57, 69]. According to Sood et al. (2022) [59], the adoption of artificial intelligence in agriculture is determined by perceived usefulness, ease of use, and sustainability potential. Ghobadpour et al. (2022) [32] note that autonomous robots and off-road electric vehicles offer significant potential for sustainable mechanization but remain constrained by high costs and technological immaturity. Similarly, Strong et al. (2022) [60] highlight persistent IoT

adoption barriers linked to stakeholder coordination and infrastructure constraints, while Tanaka et al. (2022) [62] emphasize that biomimetic drone designs enhance precision and adaptability in agricultural applications.

For public policies and support strategies to be effective, they must be grounded in a detailed understanding of farmers' perceptions.

Competent authorities and institutions should implement research and surveys that analyze farmers' attitudes toward emerging technologies, identifying both barriers and motivating factors. Understanding these perceptions is essential for developing effective digitalization strategies in the agricultural sector.

The results will help shape targeted policies that reflect farmers' particular needs [65].

Thereby facilitating the adoption of digital technologies and ensuring a smoother, more effective transition toward technological transformation in agriculture [6, 10, 15, 21, 23, 36, 42, 62, 64].

Based on the systematic analysis of the specialized literature, the challenges, opportunities and recommendations that emerge are presented in Table 2.

Table 2. Challenges, Opportunities, and Recommendations Identified in the Systematic Literature Review

FACTORS	CHALLENGES	OPPORTUNITIES	RECOMMENDATIONS
ECONOMIC	High technology costs, limited financial access	Access to subsidies and grants, long-term cost reduction and flexible financing for digitalization	Support for small farmers through subsidies and training in digital technology use
TECHNOLOGICAL	Insufficient digital infrastructure, limited technological interoperability	Availability of IoT, AI and Big Data infrastructure, automation of agricultural processes	Investments in digital infrastructure, development of common standards for interoperability
EDUCATIONAL	Insufficient digital skills, difficulties in using agricultural software, and resistance to change	Access to digital training programs, development of user-friendly mobile applications	Ongoing training, accessible platforms, and best practice sharing
SOCIAL AND ORGANIZATIONAL	Small farm size and weak farmer–researcher–IT collaboration	Cooperation networks and farmer–university–IT partnerships	Supportive policies and collaboration incentives
ENVIRONMENTAL AND PUBLIC POLICY	Weak policy, low support, poor infrastructure	Clear data regulations rules, stronger cybersecurity and tax incentives	Integrated digital agriculture policies and farmer support networks

Source: Author's processing based on the reviewed literature [1, 4, 6, 10, 15, 20, 21, 22, 23, 29, 30, 33, 36, 38, 41, 42, 43, 46, 48, 50, 52, 63, 68, 69].

Development of coherent, integrative public policies to support digitalization in agriculture through targeted subsidies, investments in digital infrastructure, and fiscal incentives have been tailored to small and medium-sized farms, which typically face the greatest difficulties in adopting new technologies.

Establishment of professional training structured according to local specificities and involving academic institutions, NGOs, and private-sector actors. These play an essential role in raising digital literacy and reducing resistance to change among farmers.

Technological standardization and assurance of interoperability among equipment, platforms, and digital applications. This is crucial to avoid the fragmentation of digital solutions and to enable their functional integration across different farm types, regardless of size or production profile.

Support for cooperative digital platforms capable of offering a collaborative framework among farmers, thereby democratizing access to technology, reducing implementation costs, and increasing autonomy in managing digital resources.

Implementation of smart, performance-conditioned funding schemes that incentivize the adoption of sustainable digital technologies. These should reward efficient, environmentally sound, and scalable uses of innovation, while helping to reduce gaps between large and small farms.

Limitations of the study and future research directions

The transition to digital agriculture is a multidimensional process at the intersection of technological progress, economic change, and the international policy environment.

In this dynamic context, the present research is subject to limitations inherent to systematic reviews, such as reliance on publicly available sources and methodological variability across the studies analyzed [23, 34, 62]. According to Gough et al. (2017) [34], such reviews are constrained by the heterogeneity of study designs and reporting standards, which may influence the comparability of findings. Moreover, the emphasis on recent literature may omit historically relevant perspectives for understanding the adoption process.

One priority direction for future research concerns the integration of longitudinal methodologies that track the evolution of farmers' decisions over time in relation to economic dynamics, technological change, and agricultural policies. Such an approach would provide deeper insight into how perceptions, barriers and motivations surrounding technology adoption evolve with context [10, 15, 21, 23, 36, 38, 43, 69].

Another area requiring further investigation is the influence of population aging in agriculture on the pace and mode of innovation uptake, given that generational differences often translate into significant disparities in openness to digitalization [42, 46, 69].

Methodological gaps are also evident with respect to the measurement and evaluation of climate-smart and sustainable agriculture (CSA) practices, as well as in the application of rigorous econometric tools for the empirical validation of determinants of adoption [14, 15, 20, 23, 33, 43, 52, 64]. These shortcomings call for the development of more robust analytical frameworks capable of integrating quantitative and qualitative data.

At the institutional and regulatory level, it is essential to build a robust legislative and financial framework that encourages innovation, supports digital education, and facilitates equitable access to emerging technologies [1, 4, 21, 22, 23, 38, 42, 50, 52, 69]. In this regard, international collaboration platforms can play a strategic role in sharing best practices, standardizing digital infrastructures, and fostering inclusive, effective innovation ecosystems.

Collaboration with international organizations is also necessary to define global norms for the responsible use of artificial intelligence, data protection, and digital ethics, ensuring that the transition to smart agriculture is both sustainable and equitable [22, 23, 42, 69, 70].

Finally, greater attention must be paid to the labor-market impacts of these transformations. Emerging technologies not only restructure existing occupations but also create new opportunities for tech entrepreneurship, access to global markets, and innovative business models [4, 6, 15, 22, 23, 38, 42, 68].

In this context, an adapted educational and economic infrastructure is required - one capable of developing advanced digital competencies and supporting access to financial resources for innovation.

Thus, the shift toward digital agriculture becomes not merely a technological necessity but an opportunity to sustainably reconfigure the entire agricultural ecosystem.

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