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SUSTAINABILITY IN SILK PRODUCTION AND SILK TEXTILE INDUSTRY

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Abstract

The goal of the paper was to analyze and present the way in which sericiculture and silk and silk textile industry has succeeded and what it should done to be entirely attain the sustainability goals along the product chain. The statistical data have been provided by International Sericicultural Commission, UNESCO, European Union and have been processed using regression equations to assess the trends in the dynamics of silk production globally and in China and India, the top silk producing countries in the interval 2016-2023. A large number of articles, published in well-known scientific research reviews were carefully studied bringing the novelties regarding the new solutions for a sustainable silk production, textile and clothes industry. The study presents a selection of various opinions, experiments, innovations, sustainable technologies, procedures, products and case studies. The results showed a positive trend in global silk output which in 2023 attained 94 Thousand MT, being by 2.95% higher than in 2022, the main contributors being China by 53.2% and India by 41.4%. Silkworm growing based on mulberry leaves should pass on a larger scale to eco-friendly and animal-friendly solutions like "peace silk" production system, and also important measures must be taken to improve work conditions, gender discrimination, to implement integrated system to sustain productivity, silk and textiles quality and efficiency. Genetic engineering and biotechnology have to be more involved in bringing new solutions for enlarging silk fibers offer, and smart silk-based textiles, silk-based sensors and biomaterials to look for new applications. The revival of silk garments as a feed-back to the end of "fast fashion" must continue to offer new high quality and long lasting clothes in various designs, colors, textures, based on traditional inspirations, and on the minimalist principle, preserving silk precious and unique features, elegance and luxury appearance to better satisfy modern consumers.

Key words**:** *sustainability, silkworm rearing, silk, textiles, clothes, industry*

INTRODUCTION

Silk is "the queen" of the natural fibers, grace to its protein made of fibroin produced by the larvae of some insects which form cocoons. The largest spread type of produced silk comes from the mulberry silkworm *Bombyx mori* [64, 67, 73].

Silk played an important role in the history of mankind by creating the 1st trade route at the global level with deep implications in the exchange of commodities, ideas, technology, arts, culture and gastronomy and in shaping a prosperous future to the producers and traders, in the development of the states and cities by linking Asia, Europe and Africa, and then with Americas and Oceania, sustaining the intercontinental trade, creating a cultural landscape and economy of the entire world [26].

It is unanimously recognized that silk has a lot of wonderful and beneficial properties such as: soft touch, biocompatibility based on its no allergic texture, high moisture absorbency, high breathability reducing the risk of overheating, moderate to poor elasticity,

thermal regulation of the wearer's body, drying speed, shining and biodegradability, and all these have led to its use especially in the silk fabrics and clothing industry with a high importance in the development of a special niche in the international trade [48, 49].

Silk is a symbol of luxury, splendid and elegant clothes of a large variety making the wearer to feel beautiful, confident, luxuriating and proud [13].

Besides its use in textile and clothing industry, silk has proved to be an important raw material utilized in furnishing applications, in producing other industrial products, medicine, and in the sector of biomaterials [41, 52, 74].

There are different types of silk: Mulberry silk, Tasar silk, Eri silk, and Muga silk.

But, the development of sericiculture is based mainly on silkworms rearing because the silk fiber has a high quality, strength and length. About 2,500 silkworms could produce a pound of raw silk, and from each cocoon, it is possible to obtain about 600-900 m of usable silk [15].

Silkworms growing requires the existence of mulberry trees plantations from which leaves are harvested and used to nourish the worms.

Silkworms rearing is an important sub-branch of agriculture with a high economic and social importance in many countries mainly in the developing ones: it creates jobs, assures full employment, it is suitable for women involvement as labor force, it brings income to the growers [62], it supports cooperative activities, strengthens social networks and stimulates setting up partnership projects, it assures economic development and improve life quality for the people living in the rural areas, it is an antipoverty factor and prevents migration to urban area [31, 47].

However, silkworm rearing has also some disadvantages among which it deserved to be mentioned:

-limitations caused by climate change which affects mulberry leaves production;

-a high consumption of chemicals like fertilizers and pesticides in mulberry tree growing;

- much man work because many operations are still manually done;

- a high water, energy and time-consumption across the silkworm growing and cocoons processing [17, 54];

- a high production cost for silk as raw material and silk fabric, taking also into consideration the expenses with mulberry trees growing;

-silk extraction from cocoons involves the killing of the larvae which does not compile with animal welfare [13];

- silk wastes pollute soil and waters [19, 57];

- worms could have diseases and workers could develop respiratory problems working in non proper conditions in the silkworm rearing rooms [78].

- being an animal-based product, silk has a high environmental footprint (carbon monoxide is produced during the rearing process) compared to other natural fibers like cotton and wool.

Nowadays, silk and silk products demand and offer are increasing, but the higher and higher competitiveness in the international market [16], climate change [6], production costs, price fluctuations [65], and environment problems have obliged silk industry to remodel its strategies towards a sustainable development, high tech solutions and a new orientation to better satisfy consumer preferences for clothes and accessories, home decorations, medicinal products etc.

In silk textile and fashion industry, sustainability means to use as organic inputs as raw materials, to avoid chemicals, recycling the remains according to the circular economy, to offer fair work and health conditions for the employees, to practice an environmental-friendly production system which must also assure animal well-being, collecting and processing the wastes to avoid environment pollution [2].

In this context, the paper aimed to approach how sustainability should be carry out in the field of sericiculture from mulberry tree growing to silk worm raising, and till obtaining silk filament, fibers and textiles and even how fashion industry prospects the future of sustainable silk in luxury garments.

The study continues our researches in the actual conditions when sustainability must be adopted for diminishing climate change, for increasing production using eco-friendly technologies and procedures and assuring high quality products to better satisfy the needs of the actual consumers.

MATERIALS AND METHODS

For setting up this research, it was started with a large documentation based on a selection of over 80 published papers on the topic in important international scientific research journals and also from other information sources like reports published by various international bodies: International Sericicultural Organization, UNESCO, European Union and other opinions in order to pick up the main ideas about sustainability in general and how it should be implemented in the field of silk production and processing from fiber to textiles and clothes.

The material presents, in the authors' own vision, the situation of silk and silk textiles production and market at the global level, a synthesis of the consulted literature pointing out the main new technologies, procedures, solutions, research results for assuring sustainability on the whole silk chain.

The statistical data regarding silk production were provided by International Sericicultural Commission for the period 2016-2023 and have been processed using regression equations and the determination coefficient R square to characterize the dynamics of the global silk production, and also its evolution in the two top silk producers: China and India.

A special accent is put on the ways how silk could be produced in a sustainable way, making a comparative analysis of the production systems and showing which of them is relevant and must be maintained in order to name the silk industry sustainable.

A series of novelties in science, resulting from the experiments carried by various researchers, the challenges and opportunities, and trends in the field of silk textile and clothing industry are also mentioned.

Finally, the main conclusions have been issued regarding how silk production and silk textile industry succeeded to become more sustainable and it has to continue its efforts in the future to meet the sustainability goals.

RESULTS AND DISCUSSIONS

Global Silk production

The higher and higher demand had determined an increased silk production which at the global level, in 2023 reached 94 Thousand MT, being by 2.95% higher than in 2022 (Fig. 1).

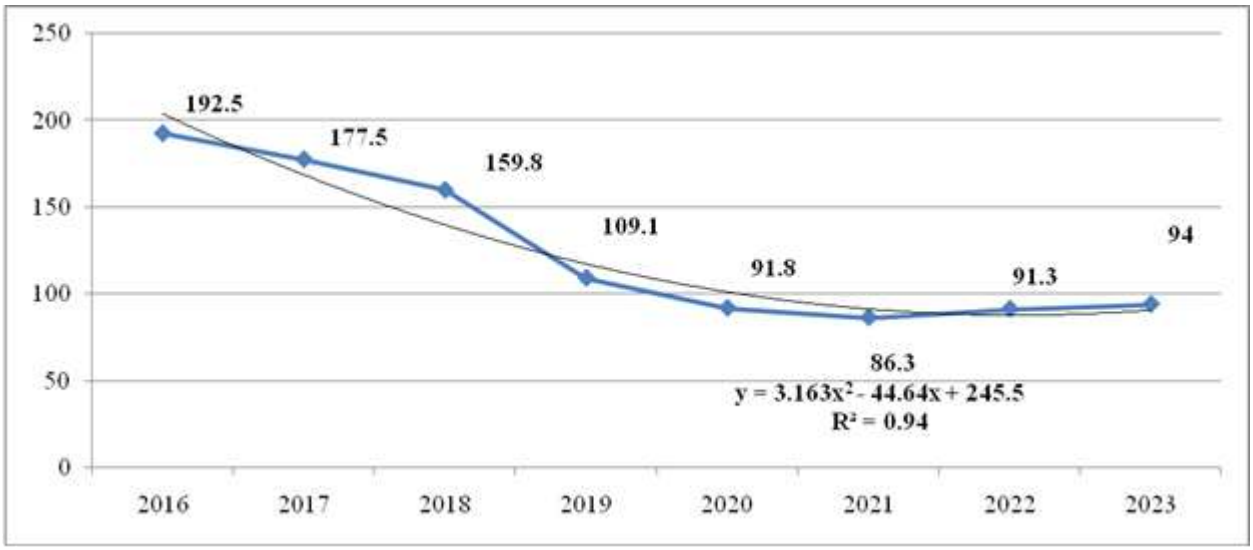

Fig. 1. Dynamics of the world silk production, 2016-2023 (Thousand metric tonnes)
Source: Own design based on the data from [20].

However, since 2016, the graphic shows a continuous decline from 192.5 Thousand MT to the lowest level, in the analyzed interval 2016-2023, reached in the year 2021 and accounting for 86.3 Thousand MT, which was by 55.2 % less than in the first year.
After this moment, silk production restarted to raise so that in the year 2022 it was by 5.79% higher than in 2021 and din 2023, by 2.95% higher than in the previous year.
The largest silk producers are China and India, which maintain their top positions, in 2023, together producing 94.6% of the global silk production (China 53.2% and India 41.4%). They are followed by Uzbekistan and Vietnam, with much smaller contributions, summing 3.7%. All these four countries together carried out 98.3% of the global silk production (Fig. 2).
The trend lines in Figure 2 are different in India than in China. It is obviously, that in China silk production decreased from 158.5 thousand MT in 2016 to 46.7 thousand MT in 2021, but in the coming two years it slightly went up to 50 thousand MT. India registered a continuous ascending trend in silk production from 30.3 thousand MT in 2016 to 38.9 thousand MT in 2023, meaning by 28.2% more than in the first year of the interval.

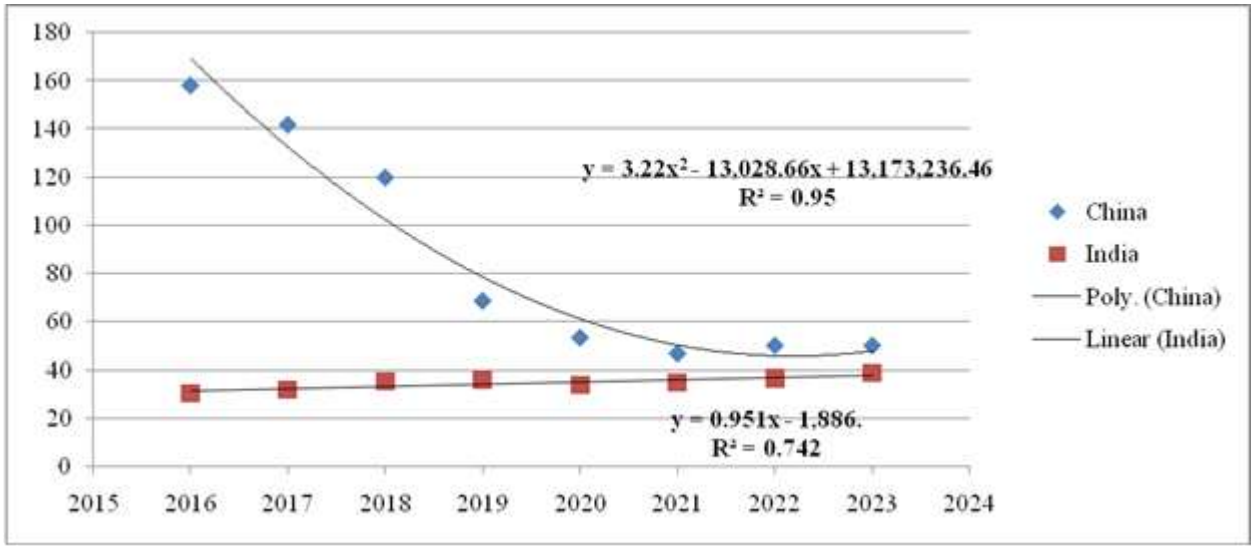

Fig. 2. Dynamics of Silk production in China and India, 2016-2023 (Thousand metric tons)
Source: Own design based on the data from [20].

Global production of natural fibers of animal origin including silk and wool increased in the last decade as mentioned [50], while the trade with raw silk has intensified its flow worldwide, the main directions being oriented from the Asian countries which are the top producers and exporters to the EU countries (Italy, Germany, France, Spain etc) where raw silk is processed into sofisticated garments and other products as mentioned [51].
Global Silk market size accounted for USD 19.51 Billion in 2023 and from 2024 till 2030 it is expected to grow at a CAGR of 7.6%. Therefore, in 2030, silk market value will attain USD 32.59 Billion.
These figures are very small compared to the market size of other fibers, silk market accounting for only 0.2% in total value of global textile fibers which reached 109 Million tonnes in the year 2020 and it is projected to grow to 145 Million tonnes in 2025 and to 160 Million tonnes in 2030 [11, 66].
However, taking into account silk and silk commodities, the share of silk in the value of global textile fibers is much higher because raw silk costing is 20 times higher than cotton.
Compared to production costs of other fibers, silk production costs are much smaller because the silkworm growing technology does not require expensive machinery or equipment, only low investment, but more labor force.

The high demand for silk for producing textiles, cosmetics, medicines etc favors silk market growth.

China and India are the main players, the former for garments and the latter for apparel market.

Silk market is dominated about 60% by Tussar silk, 20% by Eri silk, and 10% by other types.

China is the leader in silk exports, whose value reached USD 945 Million in 2023, while Italy is the top silk importing country, its import accounting for USD 322 Million [63].

Photo 1. Chinese silk blouse
Source: Original.

Global Silk textile market size

In 2023, global silk textile market had a value of USD 124.2 Billion and it is expected that by 2030 to increase by a growth rate (CAGR) of 8%.

The market structure by product reflects that apparel keeps about 50%, followed by accessories with about 20%, beddings accounting for about 10% and the remaining for other products.

By end-use, the world silk textile market is structured in: 51% fashion, 25% home furnishings, 8% health care, 9% automotive and 6% others [18].

Factors influencing silk market

Silk production is influenced by the existence of land, mulberry tree plantation, silkworm eggs from high genetic potential breeds and hybrids, fertilizers, pesticides, medicines, water, energy, labor force, price of inputs, production cost, experience and training level of the farmer, silk worm growing system (conventional or organic, peace and mixed organic peace), financial resources of the grower, state policy in the field of sericiculture, the existence or not of an integrated farm management, market demand for silk and silk textiles and products etc.

-Labour availability is very important in a sericicultural farm, as production is a work-intensive activity. Labour cost depends on the workforce market availability, the business size and salary that the employer's offer.

-Silk demand and offer ratio on the domestic and international market, which have a deep impact on silk price;

-Trade policy could be favorable or not and in a close relationship with the exchange rate of the national currency against USD or Euro, whose level could fluctuate and have a substantial impact on production, consumption, export etc.

- In case of export, the level of silk and silk textiles and other products quality, and also the amounts available to be sold on external market, the level of tariffs and product controls have a influence on silk competitiveness on various markets;

-If the exporting country has a weak currency against USD or Euro, its silk and silk products are very attractive for the foreign importing countries in the international market. If the country has a strong currency versus a foreign country's currency which is more expensive, then, sales on the international market decline being not competitive and unprofitable.

-Sales depend on consumer preferences and their purchasing power and behavior. Silk and the products made of silk are expensive products all over the world. Therefore, they are required by a special market segment of people with high incomes in general.

-Consumer preferences depends on their age, education level, needs and differ from a client to another.

-Also, consumer habits are changing, year by year depending on the level of demand satisfaction in the previous times, information accumulated in the meanwhile, the need to change the taste and to try to be aligned to the

fashion trends. Being more conscious of sustainability, more and more consumers are oriented to eco-friendly products and which also respect the ethical rules regarding the use of animals. Product quality in relation to price level is the most determinant factor to draw the final decision: to buy or not to buy. In many cases, the fidelity for a special brand is the decisive factor.

- The increased offer of sustainable silk garments has shift consumers' preferences to this kind of products which are of high quality, durability, elegance and also made in a safe environment and respect human and animal rights. The labels of the products give information about the origin of the raw material, on what technology the mulberry leaves were produced to feed the silkworms, how the silk cocoons were extracted and if the sustainability standards have been respected along the product chain. "Green" products are more and more required which is a guarantee of the correlation exiting between the product quality, price and the respect for humans, animals and environment.

The "fast-clothing" era is at the end, a new orientation to high quality textiles and clothes favor silk products to pay a high price and benefit of that product for a longer period of time.

Photo 2. Chinese silk scarf
Source: Original.

Silk revival is reflected by the growth of production and export intensification at the global level.

Market offer is more and more diversified, as the interest of producers is to better satisfy consumers preferences for more and more sophisticated products, not only from the field of fashion, but also for home deco, furnishing, medical sector and other domains [13].

The negative impact of the textile and fast fashion industry on the environment

At present, fashion and clothing industry is based 66% on synthetic fibers which have a low production cost and attractive price of the final product across its chain from design, production, distribution and sale to consumers. The length of garments manufacturing is short of about two to eight weeks depending on the producing company, and for this reason this type of fashion is nicknamed "fast fashion industry".

The increased consumption of "fast fashion" products, which are cheap and of low quality, has led to a negative impact on the environment.

For example, in the EU, it the year 2020, it was estimated that the annual textile consumption per citizen is on average: 400 m^2 land, 9 m^3 water, 391 kg raw materials and causes 270 kg carbon footprint [12] and

if we take into consideration the EU population in 2024 of 449.2 million inhabitants, this means 18 Million a land, 40.4 Billion m^3 water, 1,756.4 Million Tonnes raw materials and 121.4 Tonnes carbon footprint.

Fashion industry comes on the 2nd position among the water consuming industries diminishing the water resources, it has a high carbon footprint, representing about 10% of the world carbon dioxide emissions, it needs high amounts of chemicals degrading the land and polluting the waters and soil. About 85% of textiles are thrown to dumps, 20% of waste waters pollute the rivers and 500 thousand tonnes microfibers are released into the ocean yearly. All these aspects accuse fashion industry, besides other industries, as being a highly polluting economic sector and responsible of the climate crisis and also of affecting health of the local population,

wildlife, ecosystems and biodiversity. Also, in some countries this industry has a negative social impact, exploiting children as labor force [12, 30, 40, 59, 81].

The negative impact of sericulture practices in the conventional production system

Conventional silkworm rearing is largely practiced as it has a high economic and social role in assuring jobs, and incomes sustaining the rural population and communities in many countries like China, India, Uzbekistan, Vietnam, Iran, North Korea, Brazil, Thailand, Tajikistan and Bangladesh. The obtained filament is of the highest quality and length, which allow to have a large variety of utilizations in textile, home and fashion industry.

Silk production in the conventional or traditional production system involves the cultivation of mulberry trees, from where the leaves are harvested to nourish the silkworms. At the beginning of the process, the silkworm eggs need special conditions to hatch into larvae, whose growth is sustained by feeding with mulberry leaves. After several weeks, the silkworms develop cocoons of silk fiber. Before the moths to emerge from the cocoons, these cocoons are boiled or steamed, killing the worms as, only in this way, the sericin could be softened and silk filaments could be continuously extracted and then twisted together to become silk threads or yarns, which later on are dyed and woven into fabric. In many countries it is still practiced the traditional weaving technique which is manually done and carry out beautiful and unique artisanal silk fabric. But, nowadays, in more and more countries, to increase output efficiency, modern mechanical looms have replaced the traditional and low efficient methods and also reducing the labor force [14].

The negative impact of silk producing could be approached from, three points of view:

(a) from the point of view of environmental impact, during the silkworm growing and processing the cocoons into silk filament it is needed, firsts of all, of *land*, for cultivating the mulberry trees, which sometimes requires deforestation, affecting the landscapes, habitat loss for animals, disrupting the balance of the ecosystems. Secondly, sericiculture requires *a lot of water*, for irrigating and sustaining mulberry trees and silkworm growing, for degumming and dyeing the silk fibers. Thirdly, sericiculture needs *a lot of chemicals*, in terms of fertilizers and pesticides to sustain the mulberry leaves production, but all these pollute soil, water sources and air. Also, chemicals are used in the degumming process and the less treated resulting waters could pollute soil and the water sources. Fourthly, *a lot of energy* is involved in the reeling and spinning of the silk fibers, in the units where the process is mechanized using modern machinery and equipment and this led to the increase of gas emissions and climate change. In the units where the traditional process is still used based on *more workforce*, energy footprint is lower, and *productivity and efficiency* as well. Fifthly, sericiculture release *a lot of wastes* resulting from the silk production and processing affecting water bodies, aquatic systems, and human health. Also, the solid wastes could favor environment pollution, if silkworm pupae are not recycled for other purposes such as: animal feed, food products, medicines, compost etc.

Therefore, to raise the worms during several weeks till the moment of silk is obtained and processed into fabric, sericiculture produce ecological degradation by polluting soil, waters and air.

(b)from the point of view regarding the social impact, we may emphasize the negative influence on the employees, working in silk worm rearing, who are obliged to work *long hours a day* across of the weeks, and at the end of the day to be exhausted and, more than this, their work is carried out in *closed rooms*, where the microclimate is favorable for silkworms, but not for workers, who could contract respiratory diseases. The *salary is very low* many times as working in the silkworm growing requires a large manpower. Another negative social aspect is related to the fact that, in various developing countries, some employers *exploit children* as work force.

(c) from the point of view regarding animal well being, the conventional system of silkworms rearing, which is the most practiced systems all over the world, *requires the killing of the silkworms* by boiling or steaming them before the emergence of moths, which raises ethical concerns on animal cruelty [80].

Only by studying the silk production process along various stages of sericiculture and its environmental implications, assessing the resource consumption and pollution, it is possible to offer solutions for good, ethical and eco-friendly practices for obtaining silk filament and fabric in the local communities [14].

It is obviously that the conventional silk production system does not compile with sustainability in silk production, as it has the following disadvantages:

- it is limited to the use of a genetic fund of silkworm breeds and hybrids mainly of mulberry type, which does not sustain biodiversity;
- in the rearing process, silkworms are exposed to a high risk to contract diseases and to be attacked by pests;
- silkworm growing requires land for cultivate mulberry trees, chemicals: fertilizers, pesticides, treatments for pest control, high consumption of water and energy, resulting in relatively high costs [46];
- work is exhausting and being run in non proper conditions, and do not justify a small salary;
- the resulting wastes pollute environment;
- this system does not compile with animal well-being standards, because it involves silk extraction by boiling of silkworms alive.

-therefore, the conventional system of silk and textile production is not eco-friendly, not animal-friendly and not a human-friendly production system.

Therefore, the whole process does not reflect that silk and textile industry compiles with the objectives and principles of the sustainable development.

Sustainable Silk and Textile Production

In UNESCO's vision, sustainability is defined as "*a resolution to meet the needs of the present without compromising the future"* and this *"encompasses populations, animal and plant species, ecosystems, natural resources – water, air, energy"* [75].

The five definitions of sustainability given by University of Rochester are: *"(1)Integration of environmental, social, human and economic goals in policies and activities. (2)Equal opportunity and community participation/sustainable community. (3)Conservation of biodiversity and ecological integrity. (4)Ensuring inter-generational equity. (5)Recognizing the global integration of localities"* [77].

Also, UNESCO, in its "Agenda for Sustainable Development 2030" adopted on 6 July 2017 mentioned the 17 SDGs indicators as follows: *"G1-No poverty, G2-Zero hunger, G3-Good health and well-being, G4-Quality education, G5-Gendre equality, G6-Clean water and sanitation,G7-Affordable and clean energy, G8-Decet work and economic growth, G9-Industry, Innovation, Technology and Infrastructure, G10-Reduced inequality, G11-Sustainable cities and Communities, G12-Responsible consumption and production, G13-Climate action, G14-Life below water, G-15,Life on land, G16-Peace, justice and string institutions and G17-Partnerships for the Goals"* [76].

Photo 5. Italian silk dress
Source: Original.

Taking into account the new orientation in consumer demand and the need to develop a "green" textile industry in order to face the pressure of a higher and higher competitiveness, sericiculture and silk textile industry have to adapt the technological process to become more friendly with the environment and to compile with ethical practices regarding employees and animals. In a word, it has to become a sustainable sector.

But this must start with silk production system which is practiced in various countries and farms and after a critical analysis to identify which alternative is more sustainable and what other solutions could be adopted as silk along its chain to be entirely a sustainable product.

New sustainable alternatives for silk production in an eco-friendly and animal-friendly system

From this point of view, "organic silk", "peace silk" and "organic peace silk" are seen as alternatives to conventional silk.

-*Organic silk production* is based on the use of an environmental friendly silkworm growing, according to the ecological standards, characterized by feeding the worms with mulberry leaves organically cultivated, without synthetic fertilizers and pesticides and GMOs [55].

Also, organic silk is obtained under the condition to assure silk worms well-being till the end of their life cycle into moths, to use a lower water consumption, to protect environment, preserve biodiversity maintaining a balanced ecosystem.

Organic silk and textile production processing involves innovations in the cocoons processing into filament and yarn, using eco-friendly degumming and dyeing methods to mitigate the environmental impact [3, 72, 85].

Also, in the sustainable production practices must be used biodegradable chemicals [23], recycled wastewaters [28], energy-efficient technologies [56, 61], recycled silk wastes [29].

Natural dyes based on plants and minerals could have a beneficial effect on environment and also, the use of closed-loop water recycling systems in silk processing could preserve water and diminish pollution [68].

However, organic silkworm rearing does not entirely respect the ethic treatment as long as the worms are still killed.

-*Peace silk (Ahimsa) production* is another alternative to conventional silkworms growing, the only difference being the fact that during silk extraction process, animal well-being is assured across the whole life cycle of the worms till the moment when the moths emerge from the cocoons which are then broken. The disadvantage of peace silk production is the lower quality of the filament due to its shorter length which leads to rougher fabrics [60].

-*Organic peace silk production* is an alternative system practiced by a silkworm growers who combines the advantages of the organic silk with the ones belonging to the peace silk, concerning the standards for animal well-being and environmental friendly silk production [13, 80].

Sustainable practices in silk production and processing

-Organic Farming Methods, such as: using manure for improving soil fertility, and increasing the yield of mulberry leaves, using integrated soil and disease and pest management, which make sericiculture to become an eco-friendly and farmers-friendly sector, and also a more profitable business. Biocomposting, green manuring, micro-bio-fertilizers, bio pest control improves mulberry productivity and leaves quality [53].

-Integrating farming in mulberry tree culture which combines multiple agricultural practices to optimize resource utilization for enhancing soil fertility and leaves yield, leading to additional incomes for farmers and silkworm growers [25].

- ***The Integrating Mulberry Cultivation, Sericulture and Fish Farming*** is one of the models of integrated mulberry cultivation, silkworm rearing and fish farming, promoting silk reeling and other processing industries [4].

-Integrating sericiculture with agro-forestry system including mulberry growing, silkworm rearing, field crops, fruit plants, and fodder grasses and rice cropping had lead to higher returns in the hilly and valley land of north-eastern India [8].

-Integrated Pest Management in sericiculture, for example: using Uzi trap solution which is safe to silkworms, pets and also to human beings, as it eliminates the use of toxic chemicals [9].

-Integrated sericiculture in family reproduction farms. A model of integrated family reproduction sericicultural farms was developed in Romania by Matei and Popescu (2013). The farm needs 1 ha land which is used 50 % for mulberry plantation and 50 % for seed plantation, layer making field, sowing field), and 150 m^2 for silkworms rearing space. Such a farm could produce 400 kg silk cocoons, of which: the most could be used for producing 1,000 egg boxes for selling to other farmers, 10 kg cocoons for silk filament, 25 kg pupae for pharmaceutical purpose, 50 kg unreeling cocoons for producing handicrafts in the farm, 10 kg lint, 2,000 kg layer wastes for fish feeding. From the 30 variants of this model, 10 variants could assure a profit varying between Euro 80,223 Euro and respectively Euro 126,088 to the farmer [37].

-Integrated sericiculture between Mulberry tree culture, Silk worm rearing and Silk cocoon processing (unreeling cocoons) in handicrafts (knitted belts), has proved to be a model with the highest Net Present Value as proved by the feasibility study [45].

-Integrated production in silkworm rearing [42].

-Integrated production and diversification in sericiculture [43, 44].

-Ethical Treatment of Silk-Producing Insects In this case, Ahimsa silk production is a humane alternative as silk cocoons are collected and processed after the moth has hatched from the cocoon [82].

-Eco-Friendly Dyeing Processes in silk fabric For example, using an optimum amount of bio and chemical mordants for bio-dying silk fabric, there were obtained moderate to good and excellent colour fastness ratings [70].

-Waste Reduction, Recycling, Circular economy

-Waste reduction and converting into organic manure using vermicomposting technology and *earthworms.* Such a biomanure is used for soil fertilization in the mulberry tree plantation and increase yield of leaves [5].

-Waste reduction and recycled into organic manure for fertilizing mulberry tree plantation:

The wastes generated by sericiculture are: surplus mulberry twigs, leaves, fruits, bed waste and cocoon reeling waste like pupae from silkworm rearing. It is estimated that 45% of the ingested leaves by silkworms are expelled as waste, of which 250–300 kg could be used for 2,500 kg of farm manure, fertilizing about 0.067 ha as mentioned Wenhua (2001) cited by Kannihalli et al. (2024) [22, 79, 15].

-Waste reduction and used as a source of renewable energy. The seri waste including leaves residues mixed with excrements from silkworms could be used for producing biogas as affirmed Mao et al. (2015) cited by Kannihalli et al. (2024) [32].

-Waste reduction and the use of fermented mulberry leaf meal as fishmeal replacer [1].

-Waste cocoons and silk could be used for producing handicrafts enhancing the farmers' profit and sustainability in sericulture [5].

-Ethic and Social Responsibility in sericiculture involves an ethical behavior versus silkworm growers, employees, silkworms, customers, local community, respecting regulations and laws, international norms of behavior, and human rights.

Jayakumari et al (2024) [21] carried out a comprehensive synthesis of the main aspects related to ethical and social responsability problems in the textile industry: "*human exploitation* (long working hours, low salary, unsafe working conditions, child labor, forced labor, gender discrimination"; "*environmental impact* (resource spoliation: land, water, energy, soil degradation, chemical pollution, carbon footprint, gas emissions, waste generation, deforestation etc)"; "*supply chain transparency*: visibility and accountability at each stage of production, traceability"; "*risk management, stakeholder engagement*"; "*consumer awareness and involvement*"; "*animal well-being*"; "*worker health and safety*, work place safety"; "*waste management, reuse and recycling*";

"*renewable energy*"; "*producer responsibility*" etc. [21].

Sustainable silk production, Traceability and Certification [10].

Photo 4. Japanese silk scarf
Source: Original.

Impact of the sustainable sericiculture on rural areas and communities

The development of a sustainable sericiculture by silk producers will sustain their business bringing a higher income and profit and improving their lives and living standard for their families too.

The farmers who are successful in their business with sustainable sericiculture will be a good example for others to follow their model.

Farmers will be interested to invest and implement innovations resulting from the scientific research for strengthen their efforts to obtain a higher silk and fabric output based on an eco-friendly, human-friendly and animal-friendly production system.

In this way, the local communities will prosper and have a better life.

In addition, sustainable sericiculture applying eco-friendly technologies will contribute to the maintenance of a clean environment (soil, waters, air, landscapes) with a positive influence on eco-systems maintaining their balance and biodiversity.

Also, farmers, stakeholders, and local authorities should keep a close relationship and collaboration with government and non-government organizations, so that the best practices to be sustained with responsibility at all the levels and along the life cycle. In this way, silk market could have a larger resilience and inclusiveness.

Consumers' attitude versus sustainable sericiculture and textile industry

Consumers have become more and more aware of the role and economic, social and environment importance that sustainable sericiculture has and will be more interested to chose and buy silk sustainable products and to spread information to other potential beneficiaries.

In this way, consumers could become "the drivers" of demand of natural and healthy silk products and brands and promote the new sustainable technologies and products.

During the last decade, consumers have become more conscious of the need to buy and use healthier products made of natural fibers and obtained by using eco-friendly technologies, textile and fashion products being included, women looking to be more attracted to change their behavior than man [27].

The consumer perception of eco-friendly products is positive and the decision to buy them is closely connected to the knowledge if the products were achieved in an environment friendly manner, if they are certified and labeled, and have a higher price that the products carried out in a conventional way [38].

Consumer choice is also much more determined by the circular product attributes such as: durability, recyclability, repairability, and recycled content, than by price [24].

Consumers' decision to buy high quality and comfortable garments is also positively influenced by social media which plays an more and more significant role in increasing consumers' awareness and knowledge which have to justify their purchasing choice [58].

The role of Scientific Research, Development and Innovation in sustainable silk production and textile industry

A high importance in finding new alternatives, solutions, innovations will have scientific research which is called to continue its work destined to diminish climate change impact, to offer more sustainable and ethical practices, innovations in farming and processing technologies, and waste management in silk and textile industry.

-***Innovation in sericiculture for increasing productivity using a reeling machine*** *in a peasant individual farm* [34].

-***The achievements of new technologies and biotechnology*** could increase sustainable silk production, fiber quality and multiply the fields of application by a multidisciplinary approach and collaboration between sciences like biology, genetics, chemistry, and physics.

-*Technological advancements regarding the new achievements in silk worm breeds and hybrids,* and genetic engineering could improve the quality of silk fiber as never before. For example, Teule et al.(2012) succeeded to create "transgenic silkworms encoding chimeric silkworm/spider silk proteins" which is a stronger silk fiber with improved mechanical properties that spider silk could not have. this new type of fibers could be used as biomaterials with large applications in medicine and other fields [39, 71].

-*Studying the phenotipic and genetic characters variability of the egg and larva* from native genetic stock of Silkmoth *Bombyx mori* L.sp**.** [33, 35].

-*Optimization of the silkworm breeds stock from the gene stock Sp. Bombyx Mori* L. [36].

Biotechnology is of much help in the creation of synthetic silk fibers, with similar features like the natural fiber, and which are produced by inserting the genetic information for creating silk protein into bacteria under a fermentation process. These synthetic silk fibers are a sustainable solution in silk production technology eliminating the technological stages of mulberry tree growing, silkworm raising, saving the land and silkworms, and assuring a health environment and also synthetic fibers enlarge the opportunities to find new utilizations in various fields [7].

Smart silk-based textiles are intelligent and multifunctional fibers and textiles, as natural silk is largely required in medicines and smart fiber technology because the accessibility, biocompatibility, mechanical properties of the silk [84].

These features of silk fiber are used in silk-based technology for producing ***silk-based sensors, conductive fibers and actuators***, which are utilized in wearable garments and accessories which could provide information on heartbeat and body temperature, for the people with health problems, sportsmen, fitness lovers [83].

In addition, ***the nanotechnology for high performance and functional silk-based intelligent textiles*** are used in the benefits of the wearers providing them information on "moisture management, ultraviolet rays protection, antimicrobial and anti-odour uses and temperature regulation". The fabrics offer comfort to the wearer who feels cool and while is making sport or exercises [69].

Trends in Silk Fashion and Design

Silk lives and enjoys its revival for traditional dresses of a splendid beauty, so that both fashion and design are flourishing again.

Silk keeps pace with the changes regarding materials, but it preserves its first position of "Queen", accepting cultural changes, traditional diversity and quiet elegance at different levels.

Revival of traditional silk garments is combined with new trends regarding the kimonos, saris, qipaos, which are redesigned from a modern perspective.

Various colors, designs and textures are combined with embroideries reflecting the cultural inheritance. Artisanal-made silk products look to be well received and appreciated. At present, the designers proceed to make artisanal products such as: jackets, blouses, gowns, dresses, accessories, home decorations, which are requested by buyers to be personalized. Production is many times at a small scale which does not affect environment.

The actual trends put an accent on minimalist fashion, with a sharp contour of silhouette and high quality and luxurious appearance with a long length of wearing as silk could assure a

sustainable fashion. The clients are conscious consumers desiring clothes achieved from eco-friendly and luxury materials.
Silk could be combined with other materials (cotton, bamboo) resulting a new fabric and hybrid blends, which keep silk softness, breathability and durability. Also, silk could be mixed with synthetic fibers (nylon, spandex) resulting stretch and quick-drying fabrics of which the designers create exactly what the customers desire according to the modern trends and demand [13].

CONCLUSIONS

The study presents the actual study of silk production at the global level, pointing out its revival since the year 2022 after a long period of decline. I, 2023, the world silk output reached 94 Thousand MT, being by 2.95% higher than in 2022.
China and India maintain their top positions, together accounting for 94.6% of the world silk production, China contributing by 53.2% and India by 41.4%. While China's production is maintained at 50,000 Thousand MT, India's production has a continuous increase. Uzbekistan and Vietnam have just a small contribution together (3.7%). China remained the top silk exporting country, while Italy is the top importing country.
In 2023, the value of Global Silk market was USD 19.51 Billion and it is forecasted to reach USD 32.52 Billion in 2030.
In 2023, the value of global silk textile market accounted for USD 124.2 Billion and it is expected to raise by 8% CAGR by 2030.
Silk market is influenced by consumer preferences and purchasing power, farm land, labor force, potential of the genetic resources, financial resources, demand/offer ratio, trade policy, inflation and exchange rate., opportunities in the international market.
The paper presents a comparison between the conventional silk worm rearing and other eco-friendly alternatives like organic silk and peace silk. The best variant assuring an eco-friendly and animal friendly silk is "peace silk".
The study presents a large variety of sustainable solutions for solving different problems raised in sericicultural practice which could be used by farmers: peace silk farming system, the use of micro-bio fertilizers, bio pest control, integrated farm management, integrated sericiculture with agro-forestry system, integrated pest management, integrated sericiculture in family reproduction farms, integrated production and silk processing at the farm level, eco-friendly dyeing using bio and chemical mordants, waste reduction by biocomposting for green manure, by producing bioenergy, by transforming wastes into meals for fishes, poultry, pigs etc, the use of the results of the genetic engineering for increasing production, of biotechnology and biomaterials for creating new sorts of silk fibers, textiles and garments etc. and other silk-based solutions for other fields of activity (industries, medical sector, sport sector etc).
Fashion industry is passing through a crucial moment in its history, the sustainability goals obliging this sector to stop the era of "fast fashion" which has proved to be a polluting system and to pass to an offer of high quality and long lasting eco-friendly, human-friendly and animal-friendly garments.
At present, fashion changing its orientation to produce new high quality and long lasting garments in various designs, colors, textures, compiling with the minimalist principle and inspired from the traditional style, but also conserving the silk precious and unique characteristics, brilliant, luxury and elegant appearance to better satisfy modern consumers.
Consumers must be more and better informed about the environmental and ethical impact of their demand for textiles and fashion products, for becoming aware that they must apply for silk products achieved in organic and other alternative production systems which are friendly with the environment and respect animal well-being standards. Only in this way, textile and fashion industry could become sectors aligned to a sustainable development of the economy.
Sustainability requires to join all the forces: farmers, stakeholders, local communities, governments, consumers etc in finding the

best solutions for a sustainable development of the silk textile and fashion sectors.

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