BEHAVIOUR OF SWEET POTATO MOISTURE CONTENT IN A HYBRID DRYING SYSTEM

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Abstract

The aim of this study is to investigate different time-dependent drying and moisture content under different infrared (IR) and hot-air drying levels and product quality. In this experiment it was used a hybrid drying system to minimize energy consumption during the drying operation and to reduce environmental impact by reducing product loss in wastes. Three different levels of sweet potato slices thickness (1, 3, 5 mm), were pre-treated by dipping into a solution of 0.5 % sodium meta-bisulphite and 1% citric acid for 30 min. Four different levels of infrared radiation (0.861, 0.973, 1.039 and 1.161 kW.m-^{2}) and three different levels of air-drying temperature (45, 55 and 65°C) were using. The changes in moisture content during the drying process with a constant air velocity of 1.2 m. s-1 were noticed. The moisture content decreased with drying time. To obtain the desired moisture content from (6.92% to 7.52%), the drying time for 1mm and 0.861 kW.m-^{2} was 165,150 and 105 min while for 5mm and 1.161 kW.m-^{2} was 330, 270 and 240 min at 45, 55 and 65 °C, respectively. The total energy consumption decreased from 14.685 kW. h to 5.72 kW. h as the radiation intensity increased from (0.861 to 1.161 kW.m-^{2}).

Key words: *sweet potatoes, moisture content, energy consumption, infrared, hot-air drying*

INTRODUCTION

Keeping a product fresh is the best way to preserve its nutritional value, but most storage techniques require low temperatures, which can be difficult to maintain throughout the distribution chain. On the other hand, drying is a suitable alternative for postharvest management. Fruits, vegetables and their products are dried to enhance storage stability, minimize packaging requirements and reduce transport weight [27].

In recent years, industrial dryers have replaced traditional methods of drying agricultural products. In industrial dryers, drying conditions are better controlled, drying times are reduced and the quality of the end product is improved [28].

The most popular and efficient way to preserve food is convective drying (hot air) drying, the high temperature and long process time induce a series of chemical and biochemical conversions resulting in a change of colour, taste, aroma and nutrient properties [5, 15].

Therefore, it is needed to develop new drying systems and design new dryers. Technique such as infrared drying. Infrared drying technology was developed 30 years ago, but has recently gained popularity due to energy efficiency and lower costs compared to vacuum or microwave drying, good quality of the dried product and reduction in drying time [8, 15].

Also, it can reduce crop losses, improve the quality of dried product such as texture, colour, taste and flavour significantly and is economically beneficial compared to traditional drying methods [9].

Despite advantages, due to the limited penetration depth, IR energy is usually applied in combination with other drying methods, such as hot air, microwave and vacuum drying [26].

Application of combined IR to food processing has gained momentum due to its inherent advantages over hot air heating [4].

Hybrid drying is promising because it can provide high quality with possibly low energy consumption [6].

The combination of IR with convective hot air drying has been informed as an better drying technique with the ability of producing high-quality products in shorter drying time since it combines quick heating of IR and improved dehumidifying ability of convective drying [19].

It was found that drying of apple (Golden Delicious) slices with the Infrared-Hot air setting was 57.5 and 39.1 % faster than Infrared-Cold air and Hot air setting, respectively [10].

Worldwide, sweet potato is the seventh in the world food production after maize, wheat, rice, potato, cassava, and barley. About 90 million tons are produced globally each year from about 18 million feddans area (1,800 hectare); 70% of which are grown in developing countries [14].

In evaluation to other major staple food crops, sweet potatoes have good flexibility to peripheral growing situations, short production cycle, and high yield potential [31]. Sweet potato achieves a number of basic roles in the global food system, all of which have important suggestions for meeting food requirements, reducing poverty, and increasing food security [13].

It is a highly nutritious vegetable and its consumption has been increased in various parts of the world in recent years [29].

The sweet potatoes have a good sources of energy, protein, fibre, and minerals including potassium, vitamin A, carotenoids and phenolic compounds and they are rich in starch, which represents more than 50% of the carbohydrate components so the sweet potatoes have high demand[11].

The beta carotene content would be very useful in alleviating vitamin A deficiency among children below six years, pregnant women and adults [17].

Sweet potato is a low input crop used as vegetable, desert, source of starch and animal feed, [24].

The researches on sweet potato processing focused on fried, dried, flour sweet potato products [16], [21].To produce ready-to-eat dried sweet potato products, chemical pretreatment before drying.

The best pretreatment method before drying of any fruit should reduce drying time while keeping high quality of product (color, nutritional properties, taste, etc.) [12].

On the basis of biochemical parameters of sweet potato flour, the highest retention of ascorbic acid content (42.93 mg/100 g), total sugar (45.56 %), titratable acidity (1.62 %), carotenoid content (2.03 mg/ 100 g), crude fiber content (7.73 %) and protein content (3.04 %) were obtained in treatment 1 % sodium meta-bisulphite + 1 % lemon juice solution for10 minutes followed by solar drying [18].

The moisture content decreased with drying time irrespective of drying air temperatures indicating continuous drying process. The decrease in the drying time of the green peas with increase in drying air temperature (50°, 60°, and 70°C). The drying rate was higher at 70°C when compared to 50°C and 60°C drying air temperature [22].

The effects of infrared radiation intensities of 1,830, 2,385, 2,640, 2,880, and 3,165 W/m^2 and at air velocities of 1.0, 1.5, and 2.0 m/s of Sweet Potato slices dried on drying time. The drying time was shortened with increasing infrared radiation intensity at constant air velocity. the DTs ranged between 168 and 213, 153 and 186, 135 and 178, 135 and 162, and 120 and 157 min, respectively [19]**.**

Energy consumption during drying is affected by many parameters including drying temperature, infrared power, air velocity and structure (porosity, absorption ability, surface properties, etc.), moisture content and amount of the material [32].

In the hot-air and infrared dryer, the apple samples were dried at temperatures of 90, 120 and 150°C and radiation intensity of 0.22, 0.31 and 0.49 W/cm^2. When air temperature and radiation intensity increasing total energy requirement decreases The maximum and minimum value of total needed energy 1.54 and 1 kWh was obtained at a radiation intensity of 0.22 and 0.49 W/cm^2, respectively [26].

A comprehensive analysis of dried products was performed on their drying kinetics, drying time, specific energy consumption, shrinkage, rehydration ratio, color, vitamin C, and lycopene. The results showed that drying time was prolonged with increasing air velocity while it was shortened with increasing infrared radiation intensity [20].

Apple slices were dried in a convective dryer at air temperatures of 50, 60 and 70 °C, and air velocities of 1, 1.5 and 2 m s–1. The total energy consumed in drying apple slices at different air temperatures and flow rates. when air temperature increasing, the air flow rate, energy consumption of drying process decreases [3]. These comments are in agreement with the results informed for tomato [25].

The aims of the research were:

-To assess and monitoring the drying behavior of sweet potato slices moisture content using a hybrid of the infrared radiation and hot air heating method.

-Studying the effect of air temperature, radiation intensity and initial chemical treatment with 0.5% sodium meta bisulfate solution and 1% citric acid for 30 minutes on the changes in the moisture content, total and specific energy consumption of sweet potato slices during drying with the hybrid dryer.

MATERIALS AND METHODS

Fresh sweet potatoes samples were stored in a refrigerator at about 4ºC for experiments. Initial moisture content was determined using the AACC method [1] it was ranged from 3.8 to 4.2 kg water/kg dry matter. Before drying the sweet potatoes were cleaned, peeled. Then, the samples were cut into slices of 3mm using digital Vernier calliper. Then, the samples were pretreated with 0.5 % sodium meta-bisulphite, and 1% citric acid to retain the colour by preventing the browning [30].

Drying Apparatus

The dryer was used for conducting the experimental work for drying sweet potatoes at the Agricultural Engineering Department, Faculty of Agric. Tanta University.

The hybrid infrared-hot air dryer used for the experimental set up. The drying bed consists of three drying shelves. Each shelf was (60* 43 *40) cm (L * W* H). The dryer made of stainless steel, it consists of a box-type drying chamber, two ceramic Infra-red heaters(wavelength of 2-10 μm; length of 24.5 cm/width of 6 cm/max power of 1,000W/ up to 750°C, two an electric heater(1,000W-Turki) were connected to a thermocouple type (K) to control and measure air temperature and digital thermostat (AUTONICS – Korean), connected to the electric circuit for stopping and connecting the heater and keeping the pre-adjusted temperature relatively constant throughout each experimental run, a centrifugal fan(220wzl-10W-1,500 rpm), a drying tray, a 5kg load cell with HX711 Amplifier Rated Output: 1.0±0.15mV/V, Operation temp. range -20~+60°C, Combined error (%RO) : < ±0.03), and two control panels. The air velocity was kept constant at 1.2 m. s^{-1}as recommended by [7]. The distance between the IR emitter and the drying tray was kept constant at 20 cm [12].

Variables under study were:

-Pre-treatments of sweet potato slices included (with a solution containing 0.5 % sodium meta-bisulphite, 1% citric acid for 30 min).

- Four radiation intensity (0.861, 0.973, 1.093 and 1. 161kW.m^{-2}).
- Three hot air-drying temperature (45, 55 and 65 ºC), at constant air velocity (1.2 m. s^{-1}).

Experimental Measurements and Instrumentation ***Moisture measurement***

Moisture content of the samples was determined by drying in an oven at 105°C for 24 hours as recommended by [1].

The average initial moisture content was found to be 380 - 420 % (dry basis).

The moisture of samples was also calculated following Equation:

$$M_d = \frac{W_w - W_d}{W_d} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where:

Md is the moisture content dry basis (%)

Ww is the initial weight of sweet potato samples (gr);

Wd is the dry weight of sweet potato samples (gr).

Air velocity

General LCD digital Anemometer (model DCFM 700) was used for measuring the air velocity.

The unit is a self – contained direct reading portable instrument.

Energy requirements

After the drying tests, the drying curve and hence the drying time can be determined for each specific condition.

The energy amount used in the hybrid infrared-hot air drying is achieved from the totality of the energies consumed by the fan (E_F) and electric heater (E_e) and infrared emitter (E_{IR}).The specific energy consumption which is a measure of the energy needed to evaporate a unit mass of water from the product.

The total energy (E_t) and specific energy consumption (SEC) by hybrid infrared dryer for drying 220 g of sweet potatoes samples at 3mm thicknesses, different drying air temperatures and infrared radiation intensity were calculated following Equation [2]:

$E_t = Ee + E_f + E_{IR}$……………………........(2)

E_{IR}-measured electric energy consumption of infrared emitter, (kW.hr),

E_h-measured energy required for heating the ambient air by electric heater, (kWh),

E_f - measured electric energy consumption of fan, (kW.hr),

SEC is calculated using Equation (3) [23].

SEC = Et /Mw ………………………….(3)

where:

SEC = The specific energy consumption (kW. hr/kg water)

mw = The amount of water removed (kg)

Experimental Procedure

A total of 220 g. sweet potato samples on a perforated tray were used. Initial moisture content was measured before the drying process by taking (5 g) of sample in three replicates.

The treated sweet potato slices were dried at different levels of infrared radiation intensity including 0.861, 0.973, 1.093 with changed air-drying temperature of 45, 55, 65ºC and and 1.161 kW. m^{-2}, at constant air velocity of 1.2 m/s.

RESULTS AND DISCUSSIONS

Influence of drying parameters on the change of sweet potatoes moisture content

Figures 1,2 and 3 shows the variation of moisture content versus drying time for the various drying air temperatures of 45, 55, 65 andf our different levels of infrared radiation intensity including 0.861, 0.973, 1.093 and 1.161 kW. m^{-2}. The sweet potato initial moisture content was ranged from 3.8 to 4.2 kg water/ kg dry matter, after drying reduced to 0.069 to 0.0752 kg water/kg dry matter. The drying shadowed a falling rate period and the increase in temperature faster the drying process. As drying air temperature increased, moisture removal also increased and ultimately resulted in the reduction in drying time. Drying time reduced from 165 to 60 min. as the air temperature and infrared radiation intensityincreased from 45 to 65ºC; 0.861 to 1.161 kW. m^{-2}, respectively.

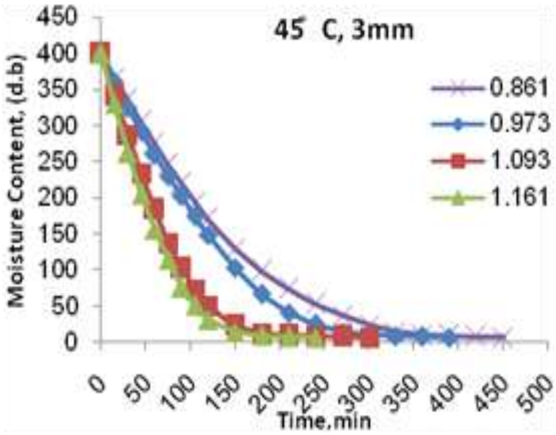

Fig. 1. Effect of drying time and radiation intensity on sweet potatoes slices moisture content at constant drying air temperature of 45 ºC
Source: Authors' determination.

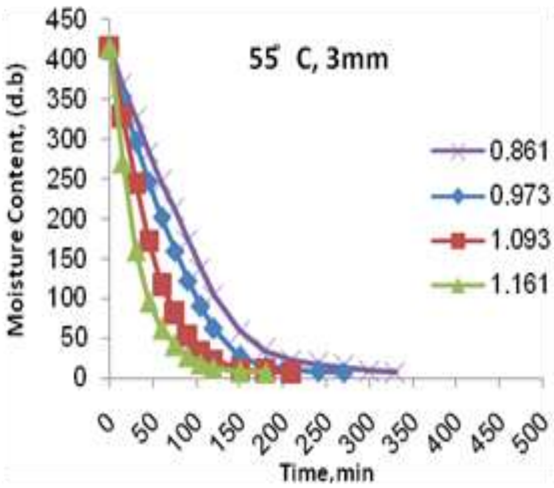

Fig. 2. Effect of drying time and radiation intensity on sweet potatoes slices moisture content at constant drying air temperature of 55 ºC
Source: Authors' determination.

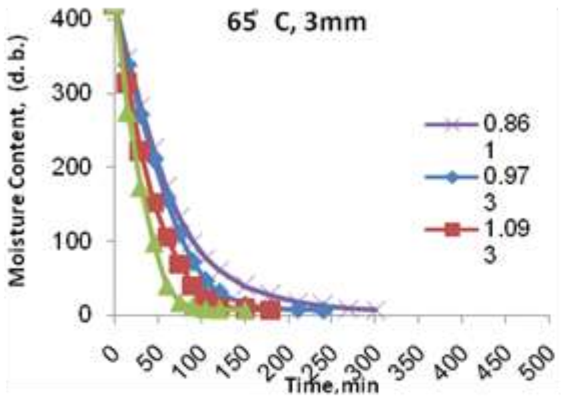

Fig. 3. Effect of drying time and radiation intensity on sweet potatoes slices moisture content at constant drying air temperature of 65 ºC
Source: Authors' determination.

Total energy consumption (ET)

Figure show the effect of different treatments (temperature, thickness and infrared radiation intensity) on total energy consumption, respectively. The highest total energy value 14.685 kWh was obtained at 45 C 0.861kW.m-². Increasing the temperature from 45 to 65 C decreases the total energy while the lowest total energy (5.72 kWh) was obtained at an air temperature of 65 C and 1.161 kW.m-². As showing in Fig.4

Drying temperature increases the rate of moisture removal from the product and reduces the drying time, and total energy value will decrease with increasing temperatures.

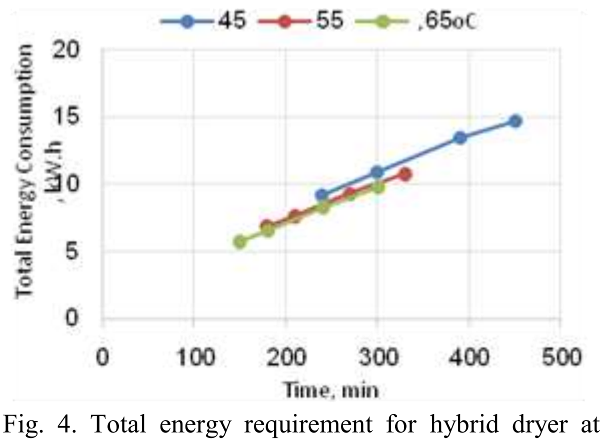

Fig. 4. Total energy requirement for hybrid dryer at different temperatures
Source: Authors' determination.

Specific energy consumption (SEC)

According to Figure 5, the lowest SEC (30.991kWh/kg) was obtained at an air temperature of 65 ºC and 1.161 kW.m-². Additionally, the sample at an air temperature of 45C for drying sweet potato had the highest SEC (79.485 kWh/kg) at an air temperature of 45 ºC and 0.861 kW.m-². This can be due to the low moisture removal from the drying product and the increase in drying time. As the air temperature grows from 45 to 65 ºC, the thermal gradient within the drying product increases. Further, by enhancing the drying temperature from 45 to 65 ºC, the difference between the drying temperature and the ambient temperature increased. As a result, increasing the temperature difference significantly decreased the drying time of the product, which is a strong reason for the reduced energy consumption.

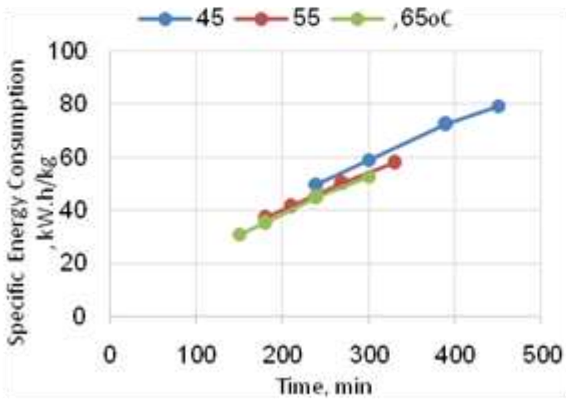

Fig. 5. Effect of drying time and different drying air temperature on specific energy consumption under hybrid drying system.
Source: Authors' determination.

CONCLUSIONS

The intensity of infrared radiation and drying air temperature had a significant effect on the moisture content of sweet potato slices. The moisture content of sample slices decreased when the radiation intensity and the drying air temperature increased.

Changing the radiation intensity from 0.861 to 1. 161kW.m^{-2} and a minimum air temperature of 45°C, the drying time decreased from 450 to 240 min.

Changing the radiation intensity from 0.861 to 1. 161kW.m^{-2} and a maximum air temperature of 45°C, the drying time decreased from 300 to 150 min.

It is clear that the moisture content decreases endlessly with drying time. During the beginning phases of the drying process, the rate of drying was fast, but it became quite slow throughout the drying method.

Comparison between drying data at various conditions revealed that the drying time of slices at higher IR power permissible limits must be determined.

Drying temperature increases the rate of moisture removal from the product and reduces the drying time, Specific energy consumption and total energy value will decrease with increasing temperatures.

Based on the results, the following recommendations are made:

-Sweet potatoes pretreated with 0.5 % sodium meta-bisulphite, and 1% citric acid to retain the color by preventing the browning and reduce drying time.

-In order to achieve the lowest total energy and best color when drying sweet potatoes, it is advised to utilize 1.161 kW m^{-2} as the ideal level of radiation intensity. These conditions include drying air temperature of 65°C, air velocity of 1.2 m/s, and slice thickness of 3 mm.

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