

Article

Research on the Process of Convective Drying of Apples and Apricots Using an Original Drying Installation

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Abstract: After being harvested, fresh apples and apricots have a high moisture content and are put through a drying process to reduce waste and lengthen shelf life. This study intends to evaluate the physicochemical parameters during moisture removal and product heating in order to conduct an experimental investigation of the convective drying of apples and apricots in a pilot drying installation. The drying agent’s temperature and/or speed can be adjusted using the pilot installation. About the raw materials: the apricots (Neptun variety) were dried and cut into halves, while the apples (Golden Delicious variety) were dried and cut into 4 mm thick slices. The fruits’ drying properties were observed at 50 °C, 60 °C, 70 °C, and 80 °C, air speeds of 1.0, 1.5, and 2.0 m/s, and relative air humidity levels of 40–45%. Findings of the ascorbic acid content, color, heating, and dimensional fluctuations are provided and examined. Increased air velocity and temperature had the expected effect of increasing water loss, solid gain, and shrinking. Depending on the drying conditions, different color characteristics were applied.



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Keywords: fruits; convective drying; moisture content; quality; color

1. Introduction

According to FAO, the apple (*Malus domestica*) and the apricot (*Prunus armeniaca*) are significant fruits that are produced in great amounts, both globally and in Europe. In the European Union (EU), Poland is the main producer of apples, while Italy is the major producer of apricots [1,2]. At the 2021 level, Romania ranks ninth in the production of apples (593,700 tons) and eighth in the production of apricots (26,840 tons). Apples are popular because they are available year round in a variety of forms, including fresh and dried apples, juice, cider, and puree. It is generally known that eating apples has a number of positive effects on one’s health [3,4]. Due to its appealing look and distinct aroma, the apricot (*Prunus armeniaca*) is one of the most prized stone fruit species growing in the temperate climatic zone. It contains a lot of vitamins, minerals, and antioxidants. In addition to being used in its fresh state, it is a great raw material for items that need to be dried, frozen, or processed (gelled products, compotes, juices, and alcoholic beverages). Local cultivars of the different apricot species typically receive preference in most nations [5,6]. The apricot is regarded as one of the most valuable stone fruits among fruit trees in the temperate zone because of its alluring beauty and exceptional aroma. Fruits are the most popular super or functional food, but because they have a high moisture content (over 80%), bacteria that cause rotting are particularly attracted to them. Fruits and vegetables should be kept fresh to maintain their nutritional value, but most storage techniques call for low temperatures, which are challenging to maintain throughout the supply chain [7,8].

Fruits may be preserved by drying, and the resulting dried goods can be stored and transported for comparatively little money [9–11]. According to Kowalska et al. [12], dried

fruits ensure satiety, have a positive impact on the glycemic index and blood pressure, and promote excellent health just like fresh fruits. Fruits are abundant sources of nutrients that are good for human health, such as vitamins, minerals, dietary fiber, phenolics, carotenoids, etc. Traditional (sun drying), automated (solar drying, cabinet drying, tray drying, tunnel drying, drum drying, spray drying, fluidized bed drying), and advanced (freeze drying, vacuum drying, osmo-dehydration, heat pump drying, low-pressure superheated steam drying, electromagnetic radiation techniques, refractance window technology, microwave drying, infrared heating, radio frequency drying, and combined drying methods [13–19]) drying techniques can all be broadly categorized under this heading.

There are various studies on the topic of fruit drying where researchers have discussed the drying of fruit under different methods. Low product quality and product contamination led to the development of sophisticated drying technologies. The most commonly reported method is convective drying. Several advanced drying methods, such as microwave, vacuum, infrared, freeze, oven drying and various combination drying technologies, have been developed and are successfully used for a variety of fruits. Conduction, convection, and radiation are the three main methods for causing water to vaporize during drying, with forced air being used to promote vapor removal, with freeze-drying and osmotic dehydration being the exceptions [20–22].

Progress in drying fruits and vegetables is essential as the market for new, healthier ready-to-eat foods with long shelf lives and better rehydration capabilities grows. The quality and price of the finished product are greatly influenced by the drying process. The benefits of new drying techniques may include increased energy efficiency, improved product quality, lower costs, and reduced environmental effect. Agriculture product dehydration is a crucial step that needs to be done carefully.

Each drying method depends on a number of variables, including the type of fruit needed, its size, ripeness level, structure, color, and aroma, as well as its chemical and nutritional makeup, projected ultimate quality, dryer accessibility, and cost.

There are many studies present on drying, considering the literature. The drying method presented in this work, namely convective drying of fruits with the help of an original drying installation, presents a series of advantages, among which we list: fast drying speed, low capital and maintenance costs, flexible operation, reduced water activity to a level that inhibits the growth of microorganisms, influences the variables processing, e.g., temperature, air speed, humidity [23].

Hot air drying is a quick, safe, and nontoxic drying method. It has been routinely utilized to increase the shelf life of numerous fruits during postharvest storage [24]. Hot air drying is known to cause changes in composition and nutritional concentrations. For instance, after hot air drying, the polyphenol levels and antioxidant activity of fruits were significantly decreased [25–27]. Other researchers discovered that hot air drying was the best method for producing mulberries with a good texture and more antioxidants [28]. The impact of hot air drying on bioactive components in fruits and vegetables thus differs depending on the issue. In particular, anthocyanin has particularly unstable chemical characteristics as a heat-sensitive compound of water-soluble flavonoids, and light and heat frequently compromise its stability [29,30].

Low energy efficiency, quality loss, prolonged drying times during the slump stage, and generally poor quality control, since food dries quickly if near a heat source, are some of the drawbacks of hot air drying of fruit [23]. Progress in drying fruits and vegetables is essential as the market for new, healthier ready-to-eat foods with long shelf lives and better rehydration capabilities grows. The quality and price of the finished product are greatly influenced by the drying process. The benefits of new drying techniques may include increased energy efficiency, improved product quality, lower costs, and reduced environmental effect. Agriculture product dehydration is a crucial step that needs to be done carefully.

The objective of this work is to conduct an experimental investigation of the convective drying of apples and apricots in a pilot drying installation, evaluating the physicochemical

parameters during moisture removal and product heating, taking into account the final product's quality, the process' duration, and the energy required to carry it out.

2. Materials and Methods

2.1. Raw Material

According to the research strategy and using the technique outlined by Seiedlou et al. [31], the experimental research was conducted in the “equipment in the food business” laboratory. The raw material used in the research was chosen based on their oxidative properties, in that three varieties were selected for each fruit under study; in the end the variety that recorded the lowest values of the color change caused by oxidation was chosen. The Iasi Orchard Research and Development Station, renowned for its centuries-old heritage of growing fruit trees, particularly apples and apricots, provided the fruits used in this study. Until the investigation was conducted, the fruits were kept after harvesting in boxes in rooms with a 4 °C temperature. The raw material used in the research was chosen according to their oxidative properties, in that three varieties were selected for each fruit studied; in the end, the variety that recorded the lowest values of the color change caused by oxidation was chosen. Thus, three varieties were selected for apples (Idared, Jonagold, Golden Delicious) which were divided into 4 mm thick slices and exposed at room temperature for 24 h. Additionally, of the three varieties, Golden Delicious apples contain the most ascorbic acid. After 24 h, the color change caused by the oxidation process was calculated. In the case of apricots, 3 varieties were selected (Neptun, Olimp, Selena), after which they were divided into halves and exposed at room temperature for 24 h.

2.2. Drying Equipment

The method by which the kinetics of the drying process of fruits was studied was that of exposing the product to be dried in a stream of hot air. Heat transfer from the drying agent to the product is carried out by convection, and at the surface of the boundary layer of the product, heat and mass transfer is carried out by conduction [32,33]. The drying equipment is composed of a thermally insulated parallelepiped shaped tunnel, which has a centrifugal fan and three electrical resistances mounted at the bottom. The upper part has a working chamber equipped with a stainless steel grate for positioning the products for drying [34]. The drying chamber is suspended on an electronic scale for weighing the products. Also, the dryer is equipped with temperature and humidity sensors both on the bottom and on the top (Figure 1a,b).

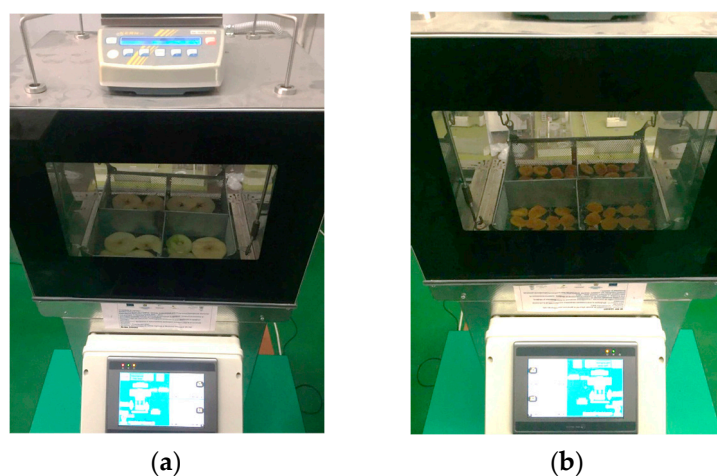


Figure 1. —Equipment for drying agricultural products: (a)—dried apples; (b)—dried apricots.

The electric heating resistors (3 resistors of 1.5 kW each) are made of kantal, being embedded in a stainless steel tube, which gives a high level of safety when using the installation. When the temperature of the air as a drying agent exceeds the prescribed

value, the sensor commands the reduction of the caloric flow, and when the temperature thus reduced tends to fall below the prescribed value, the sensor commands the connection of electrical resistances to the network.

Air is moved vertically, from bottom to top, as a drying agent. The moisture left over after the drying process, together with the air that the fan circulates, is removed to the atmosphere at the top after passing through the electrical resistances and reaching the drying grate. The operating principle of the hot air drying installation consists in the taking of a quantity of moisture by the drying agent from the products subject to drying, after which it is completely or partially removed from the dryer. The drying agent (air at ambient temperature) taken by the fan of the drying installation is heated in the heating battery and circulates from the bottom up over the product to be dried, absorbing part of its moisture, after which it is removed from the dryer. After placing the tray with the products to be dried inside the drying enclosure, close the installation door, enter the essential parameters of the drying regime (temperature and speed of the drying agent) and the duration of the drying cycle on the installation screen, specific for each product; after that, the air heating system is turned on as a drying agent (electrical resistances are connected to the network); the air drawn in by the fan located at the bottom is circulated upwards through the heating installation, is heated and then passes through the products placed in the dryer tray. The air loaded with moisture removed from the products is discharged through the discharge windows, located at the top of the technological compartment. The parameters of the drying process are controlled and monitored by means of temperature sensors, humidity sensors and the speed sensor of the drying agent. Mass losses due to the removal of water from the products are tracked using the electronic balance mounted above the drying chamber.

The installation has a PID Controller (proportional integral derivative controller) automation system, which manages independent heating and maintains a steady air temperature using a separate thermostat. A temperature sensor is used to regulate the drying temperature; it is situated beneath the grill of the drying box. Humidity sensors positioned at three locations—at the air entry to the dryer, beneath the drying grate, and at the air departure from the dryer—help to measure the humidity of the drying agent. The automated system regulates the drying agent's velocity by adjusting the fan's speed. The drying installation described previously was designed by the present research team, its execution being carried out by a specialized unit [34,35].

2.3. Methods

2.3.1. Sample Preparation

According to the procedure described by Royen et al. [33], with minor adjustments, the variety of apples and apricots to be dried was decided upon after evaluating the oxidation status of three distinct types of apples and apricots. The thermobalance drying technique was used to determine the initial moisture content of fruits. The fruits underwent a washing and sorting process after being received in terms of quantity and quality.

The division into rounds with 0.5 cm thickness was carried out with the help of an automatic divider. In the case of apples, no pretreatment was applied. Before drying, the apples were divided into rounds with a thickness of 0.5 cm.

The division into halves was carried out with the help of a knife with a ceramic blade.

No preliminary treatment was carried out on the fruits because it is desired to continue the research on their drying using a series of preliminary treatments.

2.3.2. Drying Process

After choosing the variety, in order to carry out the drying process, physical-chemical analyses were conducted, establishing several experimental variants, as they are presented in Table 1. The method by which the kinetics of the fruit drying process was studied was that of exposing the product to be dried in a stream of hot air.

Table 1. Experimental variations regard drying of fruits, according to temperature and velocity of the drying agent.

Product	Experimental Variants	Drying Agent Temperature (°C)	Drying Agent Velocity (m/s)	Activity
Apples	V ₁ /V ₂ /V ₃	50	1.0/1.5/2.0	Physical determination: weight of the products; the volume of the products; the internal temperature of the product. Determination of chromatic indices.
	V ₄ /V ₅ /V ₆	60	1.0/1.5/2.0	
	V ₇ /V ₈ /V ₉	70	1.0/1.5/2.0	
	V ₁₀ /V ₁₁ /V ₁₂	80	1.0/1.5/2.0	
Apricots	V ₁₃ /V ₁₄ /V ₁₅	50	1.0/1.5/2.0	Physical and chemical determination: moisture content; dry matter; water activity; ascorbic acid content. Energy consumption.
	V ₁₆ /V ₁₇ /V ₁₈	60	1.0/1.5/2.0	
	V ₁₉ /V ₂₀ /V ₂₁	70	1.0/1.5/2.0	
	V ₂₂ /V ₂₃ /V ₂₄	80	1.0/1.5/2.0	

V1—experimental variant for apples dried at 50 °C and drying agent speed: 1.5 m/s; V2—experimental variant for apples dried at 50 °C and and drying agent speed: 2.0 m/s; V3—experimental variant for apples dried at 50 °C and drying agent speed: 2.5 m/s; V4—experimental variant for apples dried at 60 °C and drying agent speed: 1.5 m/s; V5—experimental variant for apples dried at 60 °C and and drying agent speed: 2.0 m/s; V6—experimental variant for apples dried at 60 °C and drying agent speed: 2.5 m/s; V7—experimental variant for apples dried at 70 °C and drying agent speed: 1.5 m/s; V8—experimental variant for apples dried at 70 °C and and drying agent speed: 2.0 m/s; V9—experimental variant for apples dried at 70 °C and drying agent speed: 2.5 m/s; V10—experimental variant for apples dried at 80 °C and drying agent speed: 1.5 m/s; V11—experimental variant for apples dried at 80 °C and and drying agent speed: 2.0 m/s; V12—experimental variant for apples dried at 80 °C and drying agent speed: 2.5 m/s. V13—experimental variant for apricots dried at 50 °C and drying agent speed: 1.5 m/s; V14—experimental variant for apricots dried at 50 °C and and drying agent speed: 2.0 m/s; V15—experimental variant for apricots dried at 50 °C and drying agent speed: 2.5 m/s; V16—experimental variant for apricots dried at 60 °C and drying agent speed: 1.5 m/s; V17—experimental variant for apricots dried at 60 °C and and drying agent speed: 2.0 m/s; V18—experimental variant for apricots dried at 60 °C and drying agent speed: 2.5 m/s; V19—experimental variant for apricots dried at 70 °C and drying agent speed: 1.5 m/s; V20—experimental variant for apricots dried at 70 °C and and drying agent speed: 2.0 m/s; V21—experimental variant for apricots dried at 70 °C and drying agent speed: 2.5 m/s; V22—experimental variant for apricots dried at 80 °C and drying agent speed: 1.5 m/s; V23—experimental variant for apricots dried at 80 °C and and drying agent speed: 2.0 m/s; V24—experimental variant for apricots dried at 80 °C and drying agent speed: 2.5 m/s.

Heat transfer from the drying agent to the product is carried out by convection, and at the surface of the boundary layer of the product, heat and mass transfer is carried out by conduction.

The determination of the parameters of temperature and humidity of fruits subjected to drying takes place continuously with the recording time when the dryer is in operation. For a certain speed, temperature and current frequency of the variation of the fruit's moisture and specific energy consumption will be recorded. Measurements will be performed with both sensors and acquisition systems (velocity, temperature for drying agents, fruit's humidity and temperature, current frequency) and a data acquisition system for determining energy consumption continuously. To gauge the weight and temperature while the samples (10 pieces) were drying, they were regularly removed from the dryer. Up until the ultimate moisture content, the drying process' weighting frequency was every hour. Fruits' temperatures were gauged by inserting the tip of a J-type thermocouple 5 mm below the surface. The moisture ratio (MR) and drying rate (DR) were computed using the following formulas to demonstrate the kinetics of hot air drying. Equation (1) [36,37]:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

where M_t is moisture content (%) at t time; M_0 and M_e are initial and equilibrium moisture contents (%), respectively.

The following Equation (2) was used to calculate drying rate (DR) [38]:

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

where M_{t+dt} and M_t are moisture contents (%) at $t+dt$ and t time, respectively.

The *theoretical yield* (expressed in percentage) of the drying process is determined using Equation (3):

$$R = \frac{100 - X_1}{100 - X_2} \times 100 \quad (3)$$

where: R_t represents the theoretical yield of the drying process, X_1 —the initial moisture content of the product (%); X_2 —final water content in the product (%).

The *practical yield* of dehydration is calculated using the Formula (4):

$$R = \frac{(m_1 - m_2)}{m_1} \times 100 \quad (4)$$

where: R represents the practical yield of the drying process, m_1 —the initial mass of the product (g); m_2 final product mass (g).

2.3.3. Quality Analysis

The water content is an indicator of the quality of fruits, representing a criterion of stability. In standards or other quality norms related to food products, the water content is specified as a percentage, in the form of moisture (wet basis). The moisture content of fruits was determined by the thermobalance method. The thermobalance method is based on the mass loss of the sample through the evaporation of water from the sample to be analyzed, which is heated to 160 °C under conditions of intense air circulation, for 30 min. The moisture content of the products is the arithmetic mean of three determinations carried out in parallel (three repetitions) [39].

By using the oven-drying method, the *moisture content* (% w.b.) was calculated; 5 g of fruit from each sample was weighed and dried at 105 °C until constant weight [40].

Using the AquaLab Lite *water activity* meter, water activity (aw) was calculated (Decagon, Pullman, WA, USA). All samples were measured in triplicates, and the measurements were made at a temperature of 25 °C. About 3 g of the sample were placed in a specific cuvette, which was then put in an aw chamber where the water activity was monitored and shown on the screen of the water activity meter [41]. The chromatic indices (in the $L^*a^*b^*$ system) were determined using the HunterLab spectrophotometer (HunterLab spectrophotometer, MiniScan™ XE Plus, Spectral range: 400 nm–700 nm, Color system: CIELAB'76 ($L^*a^*b^*$)). Based on the recorded spectral data, the CIELAB'76 color parameters are calculated L^* (luminance), a^* (red-green coordinate) and b^* (yellow-blue coordinate). The CIE (Commission Internationale de l'Eclairage) recommendation is to use CIE $L^*a^*b^*$ [42].

The *visual appearance* of fruits (especially the color) is one of the determining parameters of their quality, with a direct effect on the final consumer. In the past, the evaluation of the color of fruits was done subjectively, based on visual evaluation. For this purpose, a black box was designed and built for photometric determinations regarding the change in fruit color (due to oxidation processes) during to exposure at room temperature, according to the method described by Ropelewska [43] and Baigts-Allende et al. [44]. Three varieties of apples were chosen: Golden Delicious, Jonagold and Idared; they were subjected to the oxidation process. Additionally, three varieties of apricots were chosen to determinate oxidation state: Neptun, Selena, Olimp. The fruits were divided into 0.5 cm slices, respectively halves (for apricots), and kept in the laboratory at room temperature for 24 h. After choosing the variety (depending on the degree of oxidation), they were subjected to drying processes according to the plan presented above.

The total color difference (ΔE) of fruits before and after the drying process were calculated according to the following formula [45]:

$$\Delta E_{L^*a^*b^*} = \sqrt{[(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]} \quad (5)$$

where: L_0^* , a_0^* , b_0^* , respectively, represent the parameters of the fresh product sample

(before drying). The highest value of the color difference (ΔE) coefficient is associated with the highest change in the color of the product under analysis.

The total color difference (ΔE) represents the most important color variation parameter, a value to consider in establishing the differences between $L^*a^*b^*$ of the fresh product and the one to be analyzed [46].

The color index (*Chroma*) is the factor that makes the difference from a pure shade to a gray shade. Changes to this parameter can be from 0 (zero)—matte, to 60 (intense) and was calculated with the relation:

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad (6)$$

Hue angle (h°) is one of the main properties of a color; technically, color hue is defined as the degree to which a stimulus can be described as red, green, blue, and yellow. The hue angle is defined according to the following relations [46]:

$$\text{when } a^* > 0 \text{ and } b^* \geq 0 \quad h_{L^*a^*b^*}^\circ = \text{tg}^{-1} \times \left(\frac{b^*}{a^*} \right) \quad (7)$$

$$\text{when } a^* < 0 \quad h_{L^*a^*b^*}^\circ = 180 + \text{tg}^{-1} \times \left(\frac{b^*}{a^*} \right) \quad (8)$$

where: the values of a^* and b^* are calculated and expressed in degrees: 0° —red, 90° —yellow; 180° —green, 270° —blue.

Browning index (BI) represents the brown color purity, due to enzyme activity in the apple [46], and was calculated according to Equation (7).

$$\text{BI} = \frac{100}{0.17} \times \left(\frac{a^* + 1.75 \times L^*}{5.645 \times L^* + a^* - 3.012 \times b^*} - 0.31 \right) \quad (9)$$

The ascorbic acid content was determined by the titrimetric method with 2,6-dichlorophenolindophenol. The dosage of ascorbic acid is carried out from fruits by the titrimetric method with 2,6-dichlorophenolindophenol, according to ISO 6557-2:1984 [47]. The ascorbic acid (A.A.) content, expressed in mg/100 g product, is calculated as follows [48]:

$$\text{A.A.} = \frac{[V_0 - (V_1 - V_2) \times V_3 \times C]}{V_4 \times m} \quad (10)$$

where: V_0 = the volume of the indophenolic dye solution used to titrate the sample (cm^3); V_1 = the volume of the indophenolic dye solution used to titrate the control sample (cm^3); V_2 = the volume of the indophenolic dye solution used for the titration of reductones (cm^3); V_3 = the volume to which the sample taken for analysis was brought (cm^3); V_4 = the volume of the acid extract of the sample taken for analysis (cm^3); C = the amount of ascorbic acid corresponding to 1 cm^3 of indophenol dye solution (0.088); m = mass of the sample taken in the analysis.

Specific energy consumption—The specific energy consumption of different drying method was calculated by the following Equation (11). [49]:

$$E = \frac{W_1 - W_0}{M} \quad (11)$$

where E is the specific energy consumption (kWh/kg); W_0 and W_t are the watt hour meter readings (kWh) at the beginning and the end of drying, respectively; m is the mass of moisture loss (kg).

2.3.4. Data Analysis

The results obtained from the research on the drying of fruits were statistically processed, calculating the statistical indicators: arithmetic mean ($\bar{X}$), variance (R^2), standard deviation (s), standard deviation of the mean ($s_{\bar{X}}$), coefficient of variation ($V\%$) [50].

The significance of the existing differences between the obtained experimental variants was calculated by means of the statistical program IBM SPSS 20.0, with the help of the Anova Post Hoc test—LSD (*least significant difference test*). Its value is calculated using the formula:

$$\text{LSD} = t \times \sqrt{\frac{2\text{MSE}}{n^*}} \quad (12)$$

where t is the critical value, presented by the t distribution with the degrees of freedom associated with the mean square error (Mean Square Error) and n^* is the number of repetitions.

The significance threshold (p) refers to the probability of obtaining the recorded results, it only shows the probability of obtaining the observed data starting from the premise that the null hypothesis is true. The statistical significance of p is as follows: $p < 0.05$ —* significant; $p < 0.01$ —** distinctly significant; $p < 0.001$ —*** highly significant; $p > 0.05$ —n.s.—insignificant.

3. Results and Discussions

3.1. Physicochemical Parameters of Dried Apples

It is common knowledge that the temperature and duration of drying will impact the quality of dried fruits. Fruits will become more enzymatically browned if the drying temperature is too low, and most nutrients will be destroyed if the temperature is too high. Consequently, it is crucial to choose the ideal drying temperature.

3.1.1. Color Changes of Apples Caused by the Oxidation Process

The results of the oxidation process were visible after about 2 h of exposure for the Idared and Jonagold varieties, respectively, after 3½ hours for the Golden Delicious variety (Figure 2).

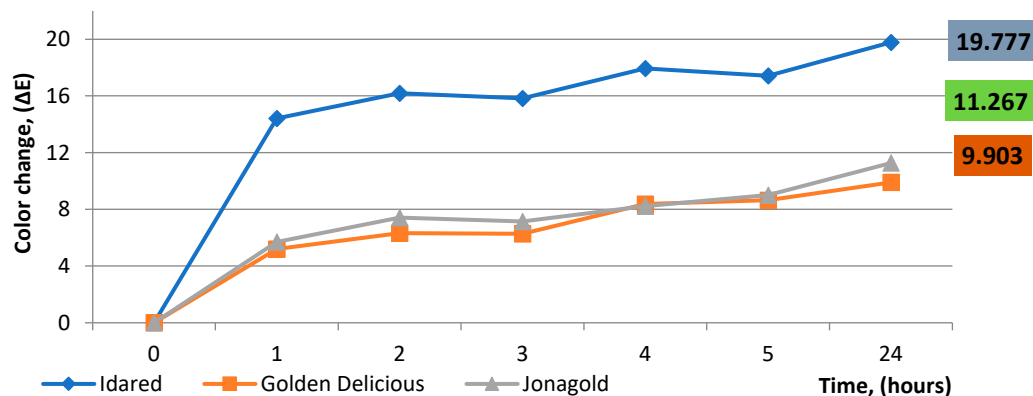


Figure 2. Total color change (ΔE) of apple exposed to ambient.

The color index (*total color change*— ΔE) represents a combination of the values of the color parameters being used in determining the color changes of food products. An increase of this parameter was observed with the passing of the exposure time in the ambient environment, the highest value being recorded for the *Idared* variety, of 17.416 and 19.777, respectively (after 5 and 24 h, respectively) (Figure 2).

For apples of the *Jonagold* variety, values of (ΔE) of 8.997 and 11.267, respectively (after 5 and 24 h), were obtained. The lowest value was obtained for the *Golden Delicious* variety, being 8.640 and 9.903, respectively (after 5 and 24 h, respectively).

Medium-sized, ripe, regular-shaped Golden Delicious apples with a total dry-matter content of 25.85–27.62% were subjected to the drying process. The geometric dimensions of the apples ranged from 7 cm to 9 cm in longitudinal section and from 6 cm to 8 cm in cross section. The weight of a fruit was between 150 g to 165 g. The apples had an oblong conical shape; the skin was hard, smooth, golden yellow in color; the flesh was light yellow, firm, juicy.

3.1.2. Water Activity and Moisture Content of Apples

Water activity demonstrates how tightly apple water is bonded. The food has low water activity, and most enzyme activities are slowing down if a_w values are less than 0.8. The overall level limit for the growth of molds, yeasts, and bacteria is $a_w = 0.6$, which is taken into consideration to be the target value for dried foods. Five days of room temperature storage were used to examine the a_w of fresh and dried apple samples. The fresh apple recorded a value of a_w at 0.908. The water activity values for dried apples range from 0.320 to 0.410, with apples dried at 80 °C yielding the highest value. The results are quite similar to those published by Paunovic et al. ($a_w = 0.442$) [36] and Polat et al. ($a_w = 0.386$) [49].

The fresh apple has a moisture level between 72.38 and 74.23%. Figure 3 displays the experimental outcomes for the experimental variants V_1 , V_2 , and V_3 , respectively.

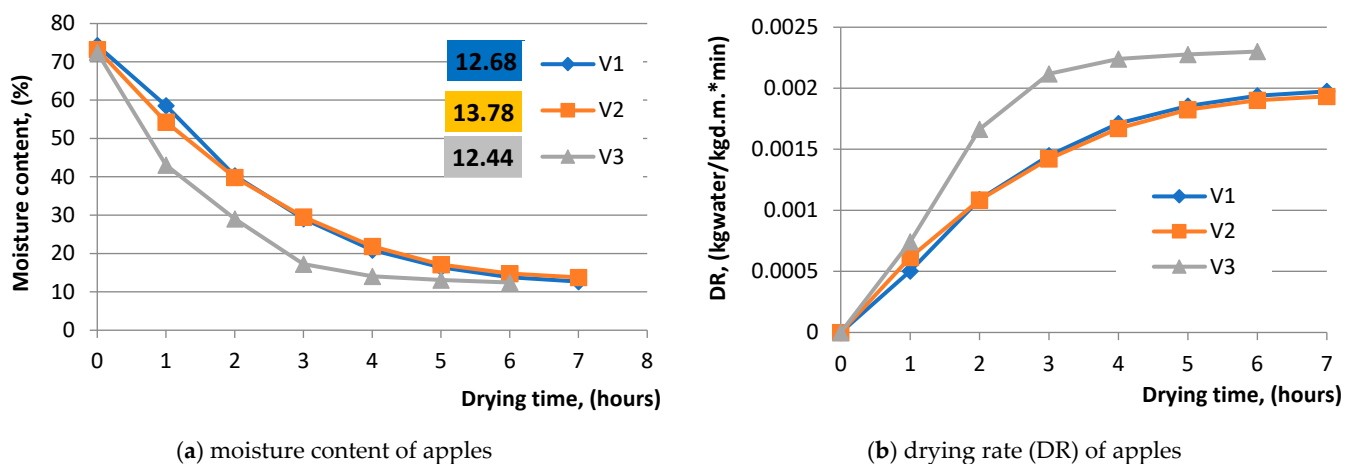


Figure 3. Moisture content and drying rate (DR) of apples dried at 50 °C.

Apple slices, having a moisture content between 72.45–74.23% w.b. were dried to a moisture content of about 12.44–13.78% w.b., until the moment when changes in their mass were no longer observed. Figure 3a shows the continuous decrease in moisture content during the drying process. To reach the final moisture content, the duration of the drying process was 360 min for V_3 and 420 min for V_1 and V_2 , respectively. We can conclude that increasing the velocity of the drying agent (for V_3) leads to a decrease in the drying time (until the desired moisture content is reached) by approximately 15%, compared to the variants V_1 and V_2 , respectively.

Differences with statistical significance were highlighted from the first experimental variants, where they were found to be insignificant between variants V_1 and V_2 ($p = 0.527$), respectively, distinctly significant between variants V_1 and V_3 ($p = 0.002$) and between variants V_2 and V_3 ($p = 0.001$). Specifically, the moisture content of apples at the end of drying was 12.68% for V_1 , 13.78% for V_2 and 12.44% for V_3 .

Figure 3b illustrates how air temperature and velocity affect the hot air drying of apples' drying rate (DR). Given the same moisture content values, V_3 had the highest drying rate, with a rate that was greater in the early stages of the drying process.

The character of the drying curves does not differ from the one known from the specialized literature. As the drying agent velocity increases, the value of the drying rate increases: at the drying agent velocity of 2.0 m/s (V_3), the drying rate shows a high value in the first two hours of drying, then it decreases continuously with decreasing the moisture content of the fruit or increasing the drying time.

The mass of the apple sample when entering the drying plant was 19.9–22.7 g and that of the finished product was 3.4–4.7 g, resulting a practical yield of 81.92–82.91%, and theoretical yield range between 68.53 to 70.48%.

The experimental results obtained for the experimental variants V_4 , V_5 , V_6 (drying at a temperature of 60 °C) (Figure 4a) indicate that the moisture content of apples decreases continuously during the drying process, having initial values of 73.42–73.46–73.50% w.b. for variants V_6 , V_4 and V_5 , respectively. From the data presented in figure, it can be seen that the duration of the drying process of apples divided in the form of rounds is influenced by the temperature of the heating agent and its velocity.

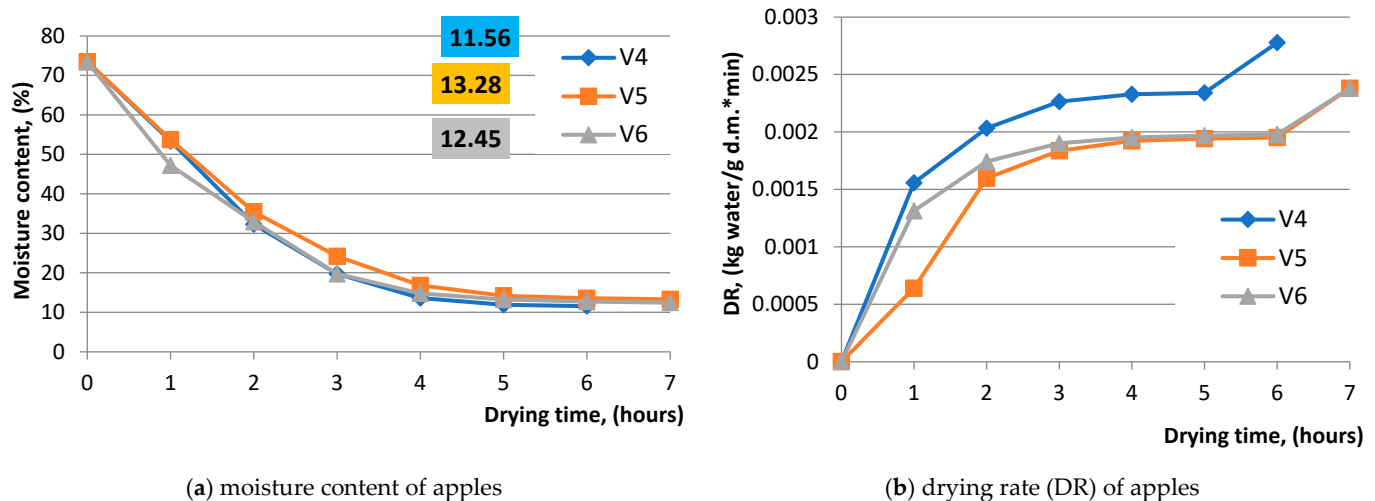


Figure 4. Moisture content and drying rate (DR) of apples dried at 60 °C.

The influence of the experimental factors left its mark on the moisture content of the apples when they were dried, with significant differences being recorded between V_4 and V_6 variants ($p = 0.042$), respectively, insignificant differences between V_4 and V_5 variants ($p = 0.103$), respectively, between V_5 variants and V_6 ($p = 0.678$).

As anticipated, a significant relationship between temperature and fruit moisture content was found. Figure 4b displays the findings of the drying speed of apples for the experimental versions V_4 , V_5 , and V_6 in turn. It took 360 min for V_4 and 420 min for V_5 and V_6 to obtain a final moisture content of 11.56 (V_4), 12.45 (V_6), and 13.28% (V_5), respectively. Figure 4b illustrates that the drying time for apple slices is not constant. Diffusion is the factor that combats dehydration the best. It is clear from this example that the drying process does not significantly depend on the drying agent's velocity. This is because the air and apple are transferring heat more quickly, which causes the water within to move around more quickly. For the three variations, V_4 , V_5 , and V_6 , around 70% of the water required to evaporate through drying is required in order to achieve the desired moisture content.

The average mass of an apple sample when entering the drying plant was 21.60–28.30 g and that of the finished product was 3.4–4.8 g, resulting in practical yield of 81.92–84.25%, and theoretical yield range to 69.44–69.99%.

Figure 5a displays the outcomes of apple drying at a temperature of 70 °C for the drying agent. The fresh apple's moisture content ranged from 72.58% to 74.05%. Following drying, the apple's moisture content was measured at 11.28% (V_7), 11.55% (V_8), and 12.91% (V_9).

Following the comparative analysis of the experimental results, there were statistically significant differences between the variants as follows: between variants V_7 and V_8 ($p = 0.21$); between V_8 and V_9 ($p = 0.158$), there were insignificant differences; between variants V_7 and V_9 , there are distinctly significant differences ($p = 0.004$).

The average mass of a sample when entering the drying plant was 20.9 g and that of the finished product was 3.4 g, resulting in an average practical yield of 83.69%.

The same patterns as in the case of drying at 80 °C were highlighted in the case of drying apples using experimental variants V₇, V₈, and V₉, respectively: the longer the drying agent temperature is, the longer the drying process shrinks.

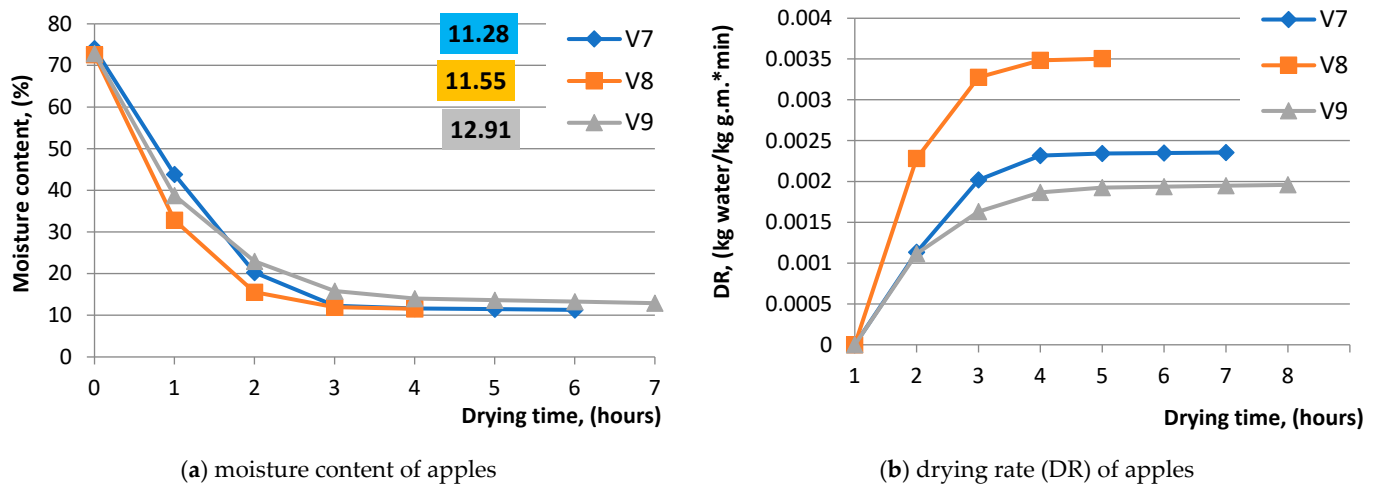


Figure 5. Moisture content and drying rate (DR) of apples dried at 70 °C.

The effect of the drying agent temperature of 80 °C during the drying of apple slices can be seen in Figure 6a. The average mass of an apple sample when it was introduced into the drying plant was 20.3–22.3 g and of the finished product was 3.2–3.6 g, resulting in an average practical yield of 82.26–84.75%.

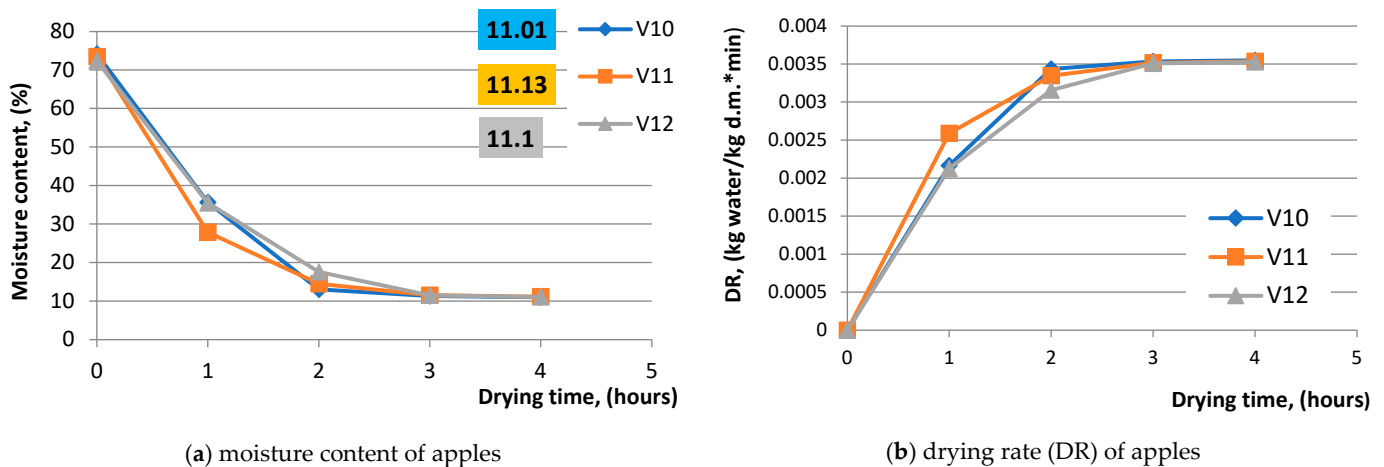


Figure 6. Moisture content and drying rate (DR) of apples dried at 80 °C.

For the variants V₁₂, V₁₁, and V₁₀, the initial moisture content of the apples ranged from 72.38 to 73.5 to 74.15% w.b. As one might anticipate, the moisture content drops significantly as the desiccant temperature rises. Due to the drying agent's high temperature, a significant amount of water evaporates during the first hour of drying, causing the moisture content to drop to 35.62% (V₁₀), 35.47% (V₁₂), and 27.84% (V₁₁), respectively. There were negligible differences between each experimental version for the variants when the drying agent's temperature was 80 °C.

The apples' final moisture content after 4 h of drying was 11.10% for variant V₁₂, 11.30% for variant V₁₁, and 11.01% for variant V₁₀. The drying rate (DR) of apples, for the temperature of the drying agent of 80 °C (Figure 6b), recorded close values in the three experimental variants, being very high in the first hour of the drying process, due to the rapid elimination of the contained water.

This demonstrates the significance of drying agent temperature—the higher the temperature, the quicker the drying rate and the shorter the process time. Several works in the field have also reported on this [51,52].

Analyzing the results obtained in the case of drying apples, it can be concluded that the duration of their drying process decreases continuously with the increase in the temperature of the heating agent. Another determining factor in the drying process of apples is the speed of the drying agent.

The hot air- drying process of apples belongs to the lowered drying rate category, according to drying rate (DR) data. Compared to the initial DR at 50 °C (0.0007 g/g min d.b.), the initial DR at 80 °C is higher (0.0025 g/g min d.b.).

Figure 6b shows that the DR decreases as the drying temperature rises, indicating that higher temperatures may increase the rate at which apples dry. Regarding the temperature inside the products subjected to the drying process, it can be observed that it gradually increases during the drying process, eventually reaching values close to that of the drying agent. This is valid for all experimental variants. It can also be mentioned that in the first two hours of the drying process, a rapid heating of the product takes place, a fact that can be seen in the drying speed.

The drying rate curves derived from the various process conditions are shown in Figures 3–6. The rate of drying was computed taking into account the decline in apple moisture content relative to the prior control at each drying period. It is clear from an analysis of these curves that the drying technique had an impact on the kinetic behavior. Diffusion is the primary physical process controlling the transport of moisture in the apple slices during hot air drying because the drying rate continuously decreases as the moisture content rises. As a result of its significance, several researchers have looked into apple drying. These are a few instances. Many research investigations on product shapes and their impact on moisture removal may be found in the literature [53–55]. Apple slices were dried by Winiczenko et al. [56] at 50°C, 60°C, 70°C, and 80 °C; at 80 °C, the influence of hot air temperature on drying rate is twice that seen at 50 °C. Hot air drying is thought to be the most widely used drying technique [57]. Royen et al. [33] dried apples at temperatures of 40, 45, and 50 °C with air speeds of 0.6, 0.85, and 1.1 m/s. In order to achieve a moisture content of 20% (w.b) and a product water activity of 0.450.05, the samples were dried from an initial moisture content of 86.7%. Up to 96% of the apples' total water content evaporated during the trial. The drying time was reduced by around 300 min by raising the drying chamber's temperature from 40 to 50 °C while maintaining an air speed of 1.1 m/s. The drying time increased by around 100 min when the air speed was raised from 0.60 to 0.85 m/s. The sample thickness had the biggest impact; as the slice thickness went from 4 to 12 mm, it took more than 500 min longer to get a 20% moisture content. According to Srednicka-Tober et al.'s study [58], dried fruits are unquestionably a rich source of polyphenols. The concentrations of these compounds in various brands of products, however, varied greatly. For example, dried apricots had a concentration of 219.03 mg/100 g, dried apple rings had a concentration of 95.24 mg/100 g, dried cranberries had a concentration of 14.64 mg/100 g, and prunes had a concentration of 134.65 mg/100 g. Dried apricots have carotenoids in amounts ranging from 2.72 ± 0.31 to 17.49 ± 0.17 g/g. Several pretreatment techniques are used, including sulfite treatment, osmotic dehydration, steam blanching, and ultrasonic treatment, which may affect the qualities of dry products [59–61]. In order to comprehend and confirm the impacts of pretreatment on the drying kinetics and appearance deformation. Bai et al. [62] noticed that the microstructures of the dried potato slices were considerably altered under the various pretreatments.

3.1.3. Color Parameters of Apples

The color of fruit is one of the most important characteristics of dry products, changing during the drying process and long-term storage as a result of chemical and biochemical reactions. The selection criterion regarding the optimal apple drying conditions was the

evaluation of the $L^*a^*b^*$ color parameters. The product with the highest value of the luminosity parameter (L^*) and with the lowest ratio a^*/b^* , represents the best sample. The results of color measurements performed on fresh and dried apple rounds at different temperatures of the drying agent and its velocity are presented in Table 2.

Table 2. Effect of drying temperature and air velocity on color parameters of apples.

Experimental Variant	L^*	a^*	b^*	a^*/b^*
Fresh apple	78.61 ± 0.139	0.88 ± 0.056	30.64 ± 0.058	0.0287 ± 0.0018
V₁	65.37 ± 0.292	5.51 ± 0.202	37.60 ± 0.318	0.1468 ± 0.0062
V₂	67.83 ± 0.169	5.38 ± 0.073	34.11 ± 0.098	0.1577 ± 0.0025
V₃	72.13 ± 0.092	4.92 ± 0.089	31.39 ± 0.086	0.1567 ± 0.0026
V₄	72.35 ± 0.328	5.12 ± 0.183	30.24 ± 0.249	0.1694 ± 0.0064
V₅	70.61 ± 0.116	5.35 ± 0.028	30.39 ± 0.138	0.1760 ± 0.0012
V₆	65.44 ± 0.133	7.55 ± 0.031	30.52 ± 0.048	0.2471 ± 0.0009
V₇	67.48 ± 0.168	8.90 ± 0.216	33.72 ± 0.264	0.2640 ± 0.0007
V₈	67.55 ± 0.155	8.60 ± 0.030	33.44 ± 0.099	0.2572 ± 0.0003
V₉	67.59 ± 0.173	7.50 ± 0.048	32.71 ± 0.067	0.2292 ± 0.0010
V₁₀	66.87 ± 0.291	7.10 ± 0.273	27.21 ± 0.273	0.2605 ± 0.0083
V₁₁	66.14 ± 0.133	6.95 ± 0.017	26.35 ± 0.061	0.2637 ± 0.0005
V₁₂	65.36 ± 0.141	6.37 ± 0.098	25.20 ± 0.078	0.2527 ± 0.0032

Values represent the mean and standard deviation(s) of the color parameters L^* , a^* , b^* . V1—experimental variant for apples dried at 50 °C and drying agent speed: 1.5 m/s; V2—experimental variant for apples dried at 50 °C and drying agent speed: 2.0 m/s; V3—experimental variant for apples dried at 50 °C and drying agent speed: 2.5 m/s; V4—experimental variant for apples dried at 60 °C and drying agent speed: 1.5 m/s; V5—experimental variant for apples dried at 60 °C and drying agent speed: 2.0 m/s; V6—experimental variant for apples dried at 60 °C and drying agent speed: 2.5 m/s; V7—experimental variant for apples dried at 70 °C and drying agent speed: 1.5 m/s; V8—experimental variant for apples dried at 70 °C and drying agent speed: 2.0 m/s; V9—experimental variant for apples dried at 70 °C and drying agent speed: 2.5 m/s; V10—experimental variant for apples dried at 80 °C and drying agent speed: 1.5 m/s; V11—experimental variant for apples dried at 80 °C and drying agent speed: 2.0 m/s; V12—experimental variant for apples dried at 80 °C and drying agent speed: 2.5 m/s.

The results show that all color parameters ($L^*a^*b^*$) underwent significant changes during the hot air-drying process.

The value of the luminosity parameter (L^*) for apples was significantly reduced by an average of 18% after the hot air-drying process for all experimental variants, decreasing to values range between 65.36–72.35. During the drying process, the change in color can be caused either by degradation of the pigments in the product, or by browning processes, or even by both processes. The value of the luminosity parameter was significantly lower for apples dried at temperatures of 50° and 60 °C compared to those dried at 70 °C and 80 °C. The apples dried at 50 °C and 60 °C reached the desired moisture content after a longer period of time (approx. 7 and 6 h, respectively) compared to the samples dried at 70° C and 80 °C (5 and 4 h, respectively). Lower temperature, for a long time, can cause more damage to products than drying at higher temperatures for short periods of time. Statistical analysis (Student's t-test by comparison of means) demonstrated that the temperature of the drying agent has a significant influence on the color parameter L^* ($p < 0.05$). On the other hand, the value of the luminosity parameter (L^*) of apples divided into rounds decreases with the increase in the temperature of the drying agent and with the increase in the duration of the drying process. Since the color determination is a lightness-darkness determination, this decrease in the parameter indicates that the samples tend to change color from a lighter color to a darker color. The specialized literature states that the variation in brightness of dried apples can be considered a measure of browning [54]. The decrease in the luminosity (L^*) parameter can be attributed to the formation of the brown pigment during the drying process, which leads us to the idea that the browning process intensifies with the increase in the temperature of the drying agent and the increase in the drying time. Similar results were recorded by other authors in the case of drying other fruits [63]. We can conclude that the luminosity parameter (L^*) is inversely correlated proportionally with the duration of the drying process but especially with the temperature of the drying agent.

In addition, the yellow/blue parameter (b^*) registered a decrease from 30.64 ± 0.058 to 25.2 ± 0.078 for experimental variants V_{10} , V_{11} and V_{12} , and for the other experimental variants registered an increase of 10.41%. It was found that the temperature of the drying agent has a significant influence on this parameter, except for the temperature of 60°C , where insignificant differences were recorded between the averages obtained in the experimental variants. The decrease intensity of the yellow color of the apple samples is also expressed by low values of the b^* parameter, the most important cause for the color change being nonenzymatic browning (Maillard reactions).

The value of the red/green ratio (a^*) increased from 0.88 ± 0.056 to 8.9 ± 0.216 ; the temperature of the drying agent caused browning of the apples subjected to the drying process ($a^* > 1$). In this case, the differences recorded between the means were significant ($p < 0.05$).

However, the ratio a^*/b^* increased significantly, following the drying process, due to the increase in the value of the a^* parameter. The highest value for the a^*/b^* ratio was obtained in the V_7 variant.

The values of the color parameters of the apple rings closest to those of the fresh product were obtained at the temperatures of the drying agent of 60°C and 70°C , respectively.

The color differences (total color change ΔE) for all experimental variants, in relation to the fresh product, are presented in Figure 7.

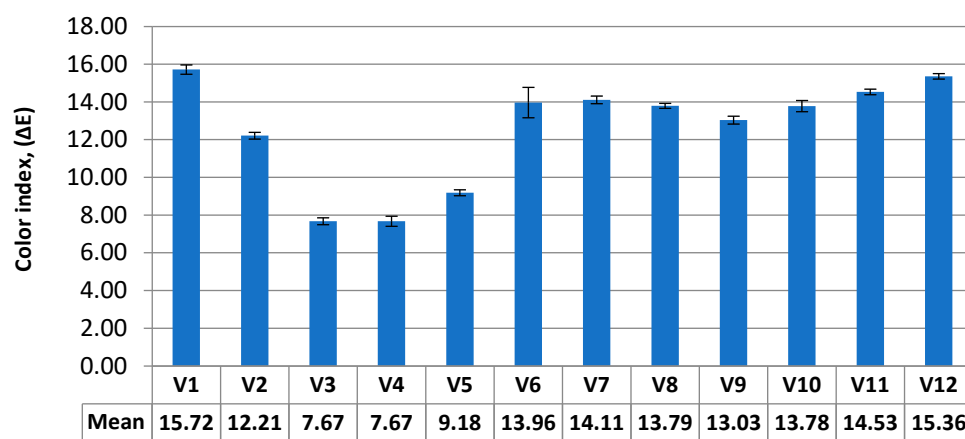


Figure 7. Effect of drying parameters on total color of apples. V_1 —experimental variant for apples dried at 50°C and drying agent speed: 1.5 m/s; V_2 —experimental variant for apples dried at 50°C and drying agent speed: 2.0 m/s; V_3 —experimental variant for apples dried at 50°C and drying agent speed: 2.5 m/s; V_4 —experimental variant for apples dried at 60°C and drying agent speed: 1.5 m/s; V_5 —experimental variant for apples dried at 60°C and drying agent speed: 2.0 m/s; V_6 —experimental variant for apples dried at 60°C and drying agent speed: 2.5 m/s; V_7 —experimental variant for apples dried at 70°C and drying agent speed: 1.5 m/s; V_8 —experimental variant for apples dried at 70°C and drying agent speed: 2.0 m/s; V_9 —experimental variant for apples dried at 70°C and drying agent speed: 2.5 m/s; V_{10} —experimental variant for apples dried at 80°C and drying agent speed: 1.5 m/s; V_{11} —experimental variant for apples dried at 80°C and drying agent speed: 2.0 m/s; V_{12} —experimental variant for apples dried at 80°C and drying agent speed: 2.5 m/s.

The color index (total color change ΔE) is an important factor in the study of product quality preservation during the drying process; it shows how much the color of the product has changed. These changes are determined by the simultaneous transfer of heat and mass that occurs at the surface and inside the product and depend on the temperature of the drying agent and its speed. The analysis of variance showed that the influence of temperature on the color index ΔE was significant and that increasing the temperature of the drying agent causes an increase in the value of the ΔE index.

Drying temperature, hot air velocity, drying time had an important effect on the total color change of apples. The lowest value of ΔE was recorded in the case of the V_4 variant (7.67 ± 0.267); on the other hand, the highest values of this parameter are associated with temperatures of 50 °C and 80 °C, the speed of 1.0 m/s and 2.0 m/s, respectively, which correspond to the experimental variants V_1 and V_{12} , recording values of $15, 72 \pm 0.247$ and 15.36 ± 0.145 , respectively.

The values of ΔE recorded for the experimental variants V_1 , V_2 and V_3 can be explained by the long drying time and the low temperature of the drying agent, which causes changes in the color associated with the browned products. When analyzing the trend of color change (ΔE) at constant desiccant temperature, a decrease in value is observed with increasing desiccant velocity up to 2.0 m/s.

The effects of drying agent speed and temperature on chroma, hue angle and browning index (BI browning index) are shown in Table 3.

Table 3. Effect of drying temperature and hot air velocity on color parameters of apples.

Experimental Variant	Chroma*	Hue Angle*	Browning Index* (BI)
Fresh apple	30.65 ± 0.059	-3.740 ± 2.445	48.75 ± 0.207
V_1	38.03 ± 0.297	-1.046 ± 0.781	87.65 ± 0.999
V_2	34.53 ± 0.087	3.200 ± 1.794	73.24 ± 0.377
V_3	31.77 ± 0.094	2.499 ± 1.092	60.55 ± 0.362
V_4	30.67 ± 0.242	-2.526 ± 0.239	57.93 ± 0.617
V_5	30.86 ± 0.136	-1.541 ± 0.143	60.34 ± 0.328
V_6	31.44 ± 0.051	0.787 ± 0.023	69.52 ± 0.181
V_7	34.89 ± 0.250	1.719 ± 0.400	76.78 ± 0.766
V_8	34.53 ± 0.130	1.083 ± 0.013	75.53 ± 0.228
V_9	33.56 ± 0.076	0.366 ± 0.023	72.29 ± 0.430
V_{10}	28.12 ± 0.317	1.638 ± 0.453	58.89 ± 0.940
V_{11}	27.24 ± 0.061	1.311 ± 0.022	57.42 ± 0.236
V_{12}	25.99 ± 0.098	0.974 ± 0.101	54.86 ± 0.423

* Values represent the mean and standard deviation (s) of the color parameter. V_1 —experimental variant for apples dried at 50 °C and drying agent speed: 1.5 m/s; V_2 —experimental variant for apples dried at 50 °C and drying agent speed: 2.0 m/s; V_3 —experimental variant for apples dried at 50 °C and drying agent speed: 2.5 m/s; V_4 —experimental variant for apples dried at 60 °C and drying agent speed: 1.5 m/s; V_5 —experimental variant for apples dried at 60 °C and drying agent speed: 2.0 m/s; V_6 —experimental variant for apples dried at 60 °C and drying agent speed: 2.5 m/s; V_7 —experimental variant for apples dried at 70 °C and drying agent speed: 1.5 m/s; V_8 —experimental variant for apples dried at 70 °C and drying agent speed: 2.0 m/s; V_9 —experimental variant for apples dried at 70 °C and drying agent speed: 2.5 m/s; V_{10} —experimental variant for apples dried at 80 °C and drying agent speed: 1.5 m/s; V_{11} —experimental variant for apples dried at 80 °C and drying agent speed: 2.0 m/s; V_{12} —experimental variant for apples dried at 80 °C and drying agent speed: 2.5 m/s.

The values of the chroma index show the same downward trend as in the case of the b^* parameter. The chroma index indicates the degrees of color saturation and is proportional to the intensity of the color. This index exhibits resistance against color changes. Regarding the results of the analysis of variance, the effects of the drying agent temperature on the chroma index were significant: increasing the drying agent temperature caused the reduction of this index.

This finding highlights that the high temperature of the drying agent causes little resistance to color changes. The minimum of the chroma index was obtained in the case of the experimental variant with drying at 80 °C (V_{10} – V_{11} – V_{12}), and the closest value to that of fresh apples (30.65 ± 0.059) was obtained in the V_4 variant (30.67 ± 0.242), respectively, V_5 (30.86 ± 0.136).

On the other hand, the hue angle value also showed a decrease in value from -3.74 ± 2.445 to 0.974 ± 0.101 during the drying process. This indicates an orange-red color (hue < 90°) of apples (hue > 90° green color).

Another color index is the browning index (BI), which represents the purity of the brown color and is also an important factor in enzymatic and nonenzymatic browning processes. The value of the browning index (BI browning index) for fresh apples was

48.75 ± 0.207 . The highest value of this index, of 87.65 ± 0.999 , was recorded for the experimental version V_1 , where the temperature of the drying agent was $50\text{ }^{\circ}\text{C}$, and its speed was 1.0 m/s . The appearances of the samples prepared under different drying conditions are compared in Figure 8.

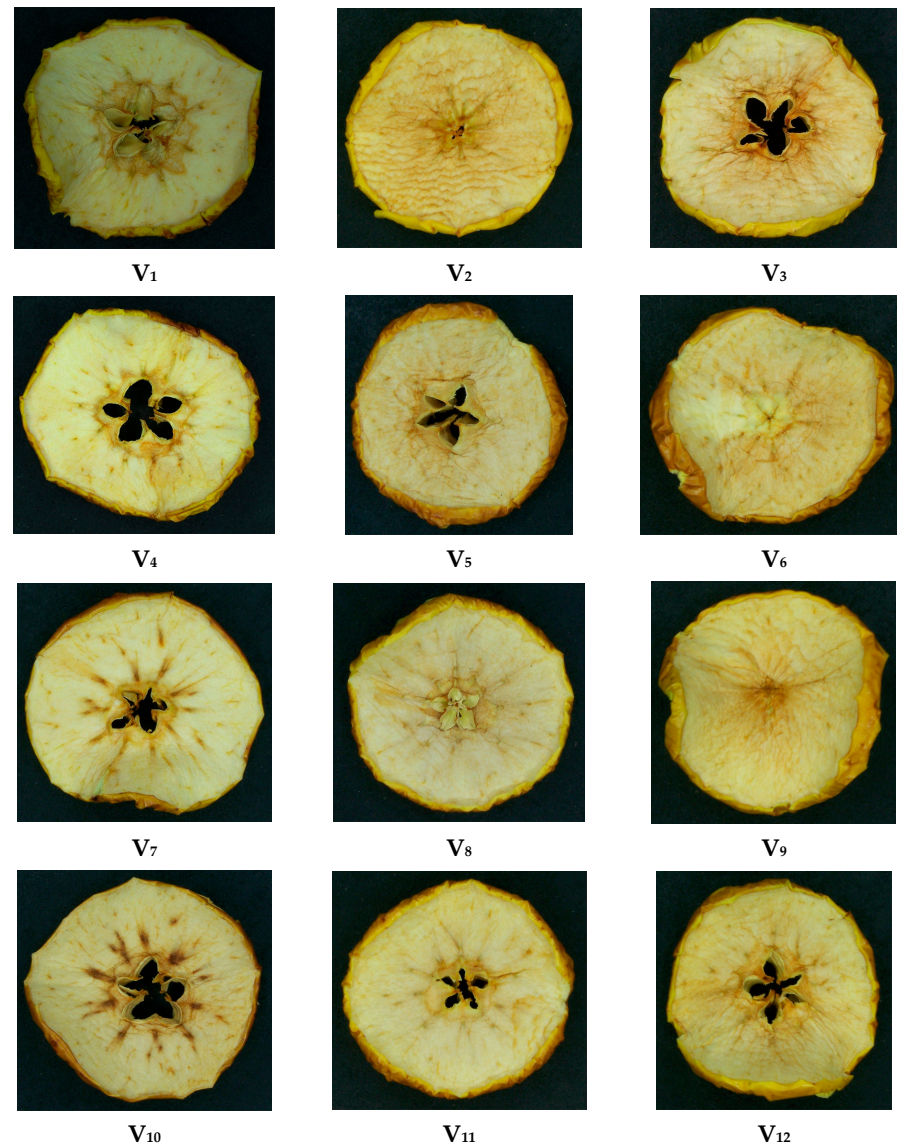


Figure 8. Appearance of dried slices apples. V_1 —experimental variant for apples dried at $50\text{ }^{\circ}\text{C}$ and drying agent speed: 1.5 m/s ; V_2 —experimental variant for apples dried at $50\text{ }^{\circ}\text{C}$ and drying agent speed: 2.0 m/s ; V_3 —experimental variant for apples dried at $50\text{ }^{\circ}\text{C}$ and drying agent speed: 2.5 m/s ; V_4 —experimental variant for apples dried at $60\text{ }^{\circ}\text{C}$ and drying agent speed: 1.5 m/s ; V_5 —experimental variant for apples dried at $60\text{ }^{\circ}\text{C}$ and drying agent speed: 2.0 m/s ; V_6 —experimental variant for apples dried at $60\text{ }^{\circ}\text{C}$ and drying agent speed: 2.5 m/s ; V_7 —experimental variant for apples dried at $70\text{ }^{\circ}\text{C}$ and drying agent speed: 1.5 m/s ; V_8 —experimental variant for apples dried at $70\text{ }^{\circ}\text{C}$ and drying agent speed: 2.0 m/s ; V_9 —experimental variant for apples dried at $70\text{ }^{\circ}\text{C}$ and drying agent speed: 2.5 m/s ; V_{10} —experimental variant for apples dried at $80\text{ }^{\circ}\text{C}$ and drying agent speed: 1.5 m/s ; V_{11} —experimental variant for apples dried at $80\text{ }^{\circ}\text{C}$ and drying agent speed: 2.0 m/s ; V_{12} —experimental variant for apples dried at $80\text{ }^{\circ}\text{C}$ and drying agent speed: 2.5 m/s .

During the hot air-drying process, nonenzymatic reactions, Maillard reactions, and ascorbic acid oxidation cause apples to brown to a great degree. Based on the data, it is

obvious that the drying agent's temperature, speed, and duration have an impact on the dried apple's color parameters.

In reality, studies in the area have shown that a variety of factors, such as modifications to the cellular structure, adjustments to the pH and redox potential, the addition of fats or oils, etc., contribute to the alteration in color of fruit products [64]. The apple color parameters, results from drying at various temperatures, and drying agent speed are presented in Tables 2 and 3, respectively. Consumers judge taste and scent last, followed by color and visual appeal. Fruit that has been dried has changes in color and sensory qualities [65]. The color characteristics of apples alter during their hot air drying, as demonstrated by Kowalska et al. [66], who dried apple slices of a thickness of 4 mm at a temperature of 60 °C and a speed of 1.5 m/s. In order to reduce browning on apple slices over the course of three different air exposure times at room temperature, Shrestha et al. [67] investigated the effects of physical (hot water, steam blanching) and chemical (enzyme, ascorbic acid, citric acid) treatment, as well as the combination of these two. Elstar and Golden Delicious both displayed a tendency of beginning the trial with a small amount of color alteration. However, with the applied treatments at 30 min and 60 min air exposure at room temperature, the two apple cultivars (Golden Delicious and Elstar) displayed significant variance in color discoloration and sensitivity to the enzyme. Only after both cultivars had been exposed to the air for 30 min did the effects of the treatments become clearly apparent. Ascorbic acid treatment of apple slices was successful in reducing discoloration at the start of processing but resulted in greater browning susceptibility with prolonged air exposure at room temperature. Even when the enzyme was lowered by a higher blanching temperature, the surface color change was still caused.

The drying process can alter the color of the dried apple, causing it to deepen and shift from green to red or yellow to blue. Polyphenol oxidase and nonenzymatic reactions may be to blame for product darkening, according to Marzec et al. [65]. During the dehydration process, it is thought that the fruit's water activity drops, affecting the enzymatic activity and potential modification [68]. Apple drying reduces water activity to a level that ensures microbiological safety.

According to Velickova et al. [69], the browning processes that result from the activity of the enzyme polyphenol oxidase are what cause the change in color after drying. In general, browning gets worse as the temperature rises.

3.1.4. Ascorbic Acid Content of Apples

The effect of drying temperature and air velocity on ascorbic acid content (vitamin C) determined for all experimental variants is presented in Figure 9. Both for fresh apple samples and for those dehydrated at different temperatures of the drying agent (50 °C; 60 °C; 70 °C; 80 °C), no reductones were identified in the sample with indophenol.

It was found that when the temperature of the heating agent increases, the ascorbic acid content of apples is lower. The losses of ascorbic acid at the heat agent temperature of 70 °C–80 °C are very high (in which case vitamin C was not found), compared to drying regimes at low temperatures (50 °C–60 °C).

The average amount of ascorbic acid determined in apples dried at a temperature of 50 °C was 4.67 ± 0.030 mg/100 g (V_1), 4.92 ± 0.015 mg/100 g (V_2), 5.13 ± 0.020 mg/100 g (V_3), and in apples dried at a temperature of 60 °C, it was range of 1.42 ± 0.011 – 1.62 ± 0.017 mg/100 g product.

The kinetics of ascorbic acid oxidation during apple air drying revealed that drying time, air temperature, and moisture content all had an impact on variations in vitamin C content. The amount of thermolabile ascorbic acid in the dried product decreases as a result of the drying agent's temperature being significantly raised. Similar findings for drying apples, pears, peppers, etc., were found in other studies [70–74]. The Wojdycio et al. study's [70] drying methods and parameters had a substantial impact on the red fresh apple's physical, chemical, and particularly bioactive qualities. The convective drying process, particularly for samples dried at 50 and 60 °C or microwave drying at 420° W, produced the largest qualitative alterations among the employed procedures. During freeze

drying, the alterations were the most minimal. The preservation of important bioactive compounds, including anthocyanins, polymeric procyanidins, and essential features of color (a^* parameter), was improved by hybrid drying, which combined convective drying at 70 °C, followed by vacuum-microwave drying at 120 W.

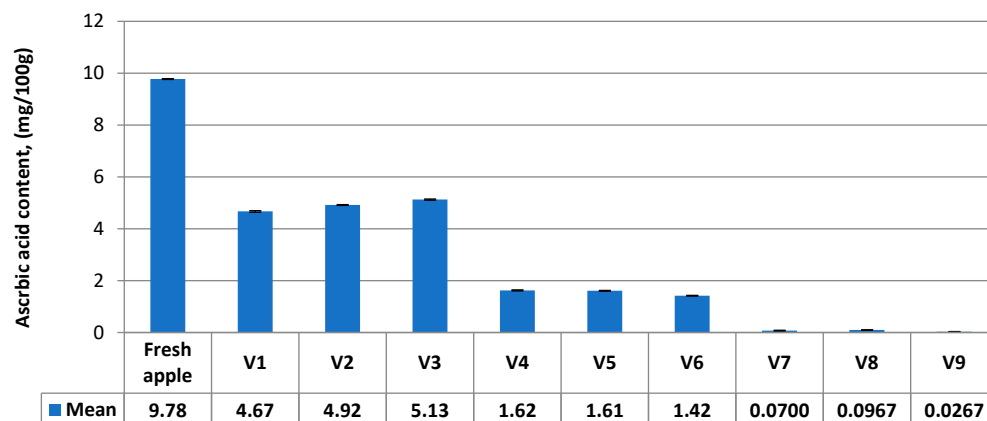


Figure 9. Ascorbic acid content of apples. V1—experimental variant for apples dried at 50 °C and drying agent speed: 1.5 m/s; V2—experimental variant for apples dried at 50 °C and drying agent speed: 2.0 m/s; V3—experimental variant for apples dried at 50 °C and drying agent speed: 2.5 m/s; V4—experimental variant for apples dried at 60 °C and drying agent speed: 1.5 m/s; V5—experimental variant for apples dried at 60 °C and drying agent speed: 2.0 m/s; V6—experimental variant for apples dried at 60 °C and drying agent speed: 2.5 m/s; V7—experimental variant for apples dried at 70 °C and drying agent speed: 1.5 m/s; V8—experimental variant for apples dried at 70 °C and drying agent speed: 2.0 m/s; V9—experimental variant for apples dried at 70 °C and drying agent speed: 2.5 m/s.

Many studies have been done on the drying of apple chips at temperatures ranging from 35 to 85 °C (microwave, infrared, or vacuum freeze-drying) [74], as well as between 40 °C and 90 °C (convective drying) [69,75]. Apples dried at 65 °C appear to be a good method for creating nutritious, high-quality snacks for both customers and the food industry, according to Kowalska et al. [66].

3.1.5. Energy Consumption for Drying Apples

The lowest specific energy value of 1.78 kWh/kg necessary to implement the drying process is obtained at parameters of the drying agent $T = 50$ °C and $v = 1.5$ m/s. The process duration is $dt = 420$ min. The minimum duration of the drying process $dt = 240$ min. is obtained at parameters of the drying agent $T = 80$ °C and $v = 2$ m/s. The energy necessary to implement the process is 6.2 kWh/kg.

3.2. Physicochemical Parameters of Dried Apricots

Apricots from the Neptun variety, very large (the fruit can reach 95 g), ripe, spherical in shape and orange in color, with bright orange pulp, excellent flavor and a total water content between 85.4 were subjected to the drying process and 87.90%. The geometric dimensions of the apricots ranged from 5 cm to 6 cm in longitudinal section and from 4.1 cm to 5 cm in transverse section. Before drying, the apricots were divided into halves, being sectioned along the carpel seam. The mass of a fruit has values between 35 and 65 g. The volume of an apricot varies between 15–19 cm³

3.2.1. Color Changes of Apricots Caused by the Oxidation Process

When a fresh apricot is cut open and left in the air, enzymatic oxidation causes the flesh to turn brown quickly. The preparation of apricots for drying depends greatly on this phenomena.

Oxidations state were visible after 2 h of exposure for the *Neptun* and *Selena* varieties, respectively, after 3 h for the *Olimp* variety. The *Selena* variety registered the fastest color change in terms of oxidation; changes can be observed after the first hours of exposure at room temperature. The highest value was recorded for the *Selena* variety, 92.55 and 94.02, respectively, after 5 and 24 h, respectively (Figure 10).

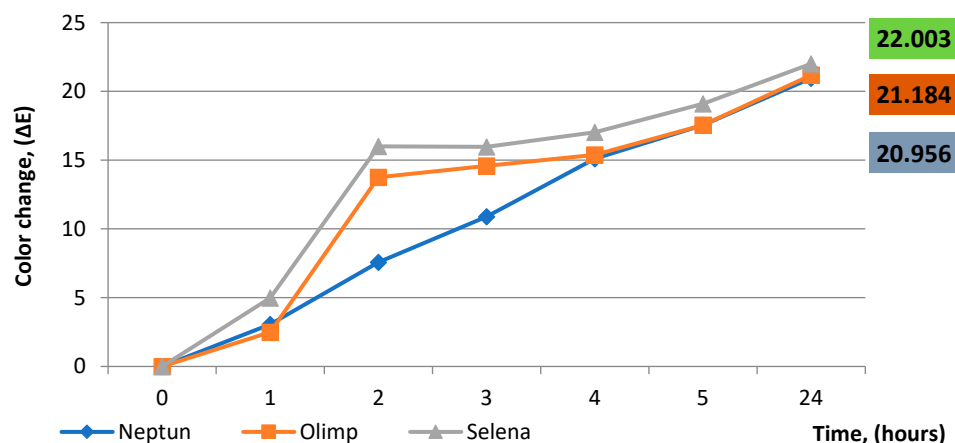


Figure 10. Total color change (ΔE) of apricots exposed to ambient.

For *Neptun* variety, color change (ΔE) was 80.65 and 93.75, respectively, after 5 and 24 h were obtained. The lowest value was obtained for the *Olimp* variety, with values of 75.92 and 91.84, respectively, after 5 and 24 h, respectively.

3.2.2. Water Activity and Moisture Content of Apricots

If the enzymes are not activated by heating, enzymatic reactions might take place in foods with low moisture content. Hence, lowering the water activity in the finished product is a crucial step in ensuring the stability of dried meals. Final products with sufficiently low water activity are generally resistant to enzymatic deterioration because microbial growth is not possible in active water. The effectiveness of fresh and dried apricot samples was examined after 5 days of storage at room temperature. A value of a_w 0.828 was recorded for the fresh apricot. The water activity ratings for dried apples range from 0.401 to 0.423, with apricots dried at 80 °C yielding the greatest value. Moisture content in the fresh apple was in the range of 85.91 to 86.94% w.b. The experimental results obtained for the experimental variants V_{13} , V_{14} and V_{15} , respectively, are presented in Figure 11a. When determining the influence of the parameters of the drying agent on the product, an average weight of half an apricot, when introduced into the drying facility, was 15.104 g, and that of the finished product was 4.060 g.

Figure 11a illustrates how the moisture content continuously decreases as the material dries. The drying procedure took 720 min for V_{13} , V_{14} , and V_{15} , respectively, to obtain the desired moisture content (14.30–23.28% w.b.), while it took 600 min for V_{15} . As a result, we can say that for variant V_{15} , increasing the drying agent's speed results in a 17% reduction in the amount of time needed to dry the material to the desired moisture content.

Statistically significant differences were emphasized starting with the first experimental variants, where they were discovered to be clearly significant across all variants ($p = 0.423$). Figure 11b depicts the variations in drying speed over time for the experimental variants V_{13} , V_{14} , and V_{15} . The value of the drying rate (DR) rises as the drying agent velocity rises. For example, with a drying agent velocity of 2.0 m/s (V_{15}), the drying rate initially displays a high value before steadily declining as the fruit's moisture content falls or drying time is extended.

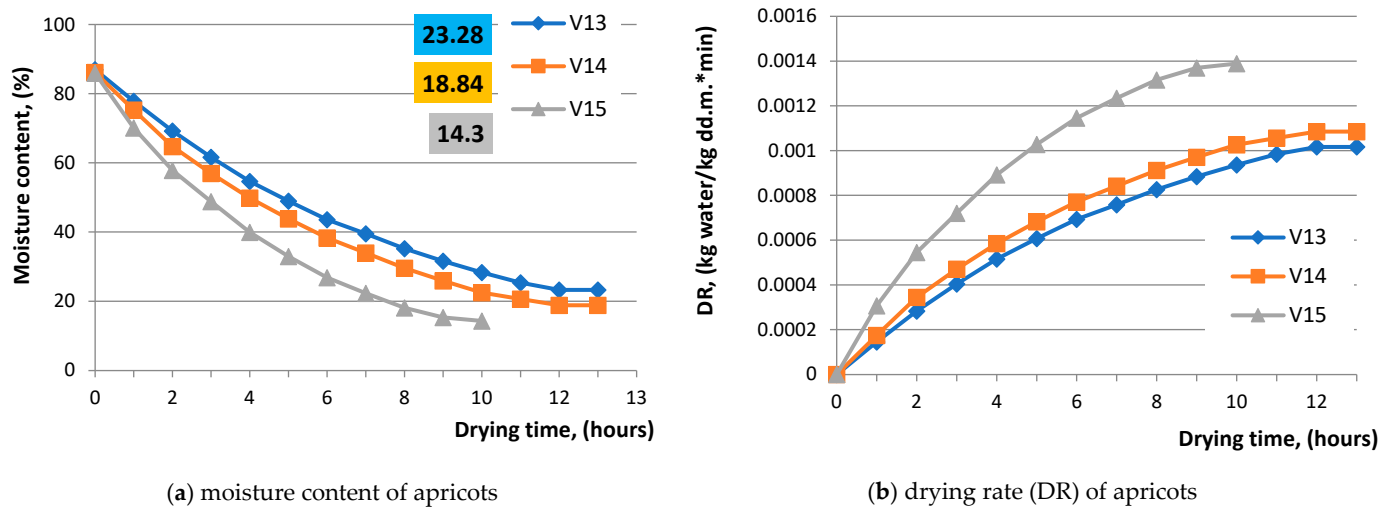


Figure 11. Moisture content and drying rate (DR) of apricots dried at 50 °C.

The character of the drying curves does not differ from the one known from the specialized literature [76,77]. The value of the drying rate rises as the drying agent velocity rises: with a drying agent velocity of 2.0 m/s (V_{15}), the drying rate exhibits a high value during the first two hours of drying before steadily declining as the fruit's moisture content falls or drying time is extended.

At the end of drying, the moisture content had values between 14.3 and 22.28, with a practical yield of 67% and theoretical yield of 84% being recorded.

The experimental results obtained for the experimental variants V_{16} , V_{17} , V_{18} (drying at a temperature of 60 °C) indicate that the moisture content of apricots decreases continuously during the drying process, having initial values of 80.05–81.30% w.b. for variants V_{16} , V_{17} and V_{18} , respectively. From the data presented in Figure 12a, it can be seen that the duration of the drying process of halves apricots is influenced by the temperature of the heating agent and its velocity.

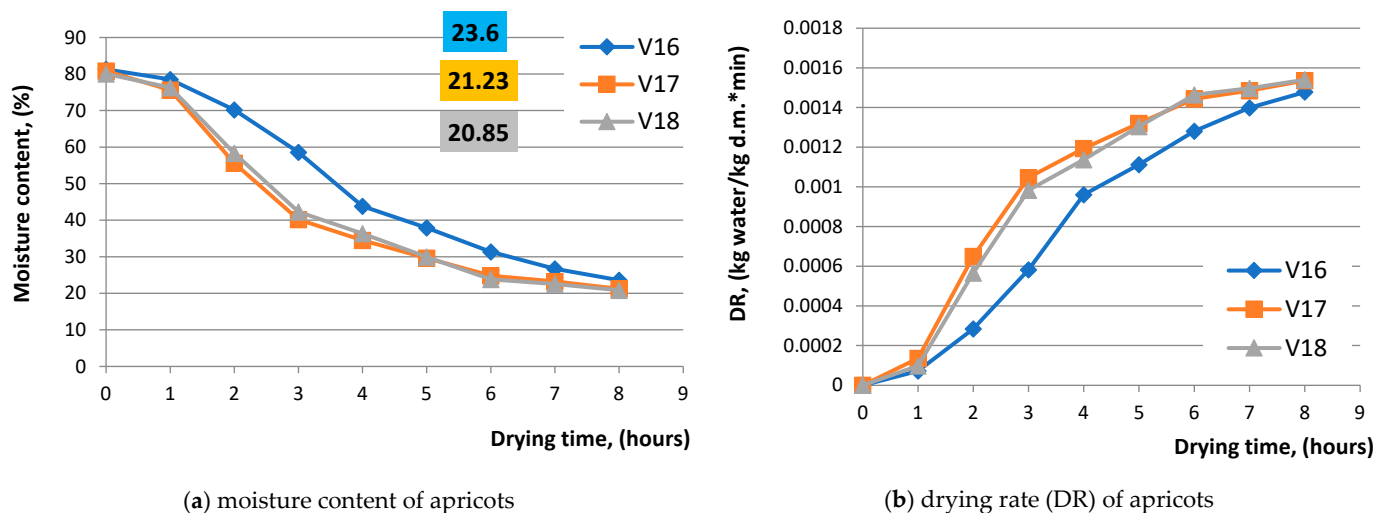


Figure 12. Moisture content and drying rate of apricots dried at 60 °C.

The average mass of an apple sample when entering the drying plant was 12.59 g, and that of the finished product was 3.68 g, resulting in an average practical yield of 64% and a theoretical yield ranged between 74.79–75.68%.

The influence of the experimental factors left its mark on the moisture content of dried apricots, with significant differences being recorded between V_{17} and V_{18} variants

($p = 0.044$), respectively, insignificant differences between V_{16} and V_{17} variants ($p = 0.102$), respectively, and between V_{16} variants and V_{18} ($p = 0.687$).

As anticipated, a significant relationship between temperature and fruit moisture content was found. Figure 12b displays the results of the drying rate (DR) of apricots. It took 480 min to attain a final moisture content of 20.85 (V_{18})–21.23 (V_{17})–23.60% w.b. (V_{16}). As can be observed, the drying time for apple slices is not continuous. The most effective force on dehydration is diffusion. It is clear from this example that the drying process does not significantly depend on the drying agent's velocity. This is brought on by the water rapidly evaporating off fruit as a result of the increased heat transmission between the air and the fruit. For the three variations, V_{17} , V_{18} , and V_{19} , around 60% of the water required to be evaporated during drying in order to obtain the desired moisture content.

Figure 13a shows the results obtained when drying apricots at a temperature of 70 °C for the drying agent. In addition, the values for each of the three experimental types' drying rates (DR) are shown (Figure 13b).

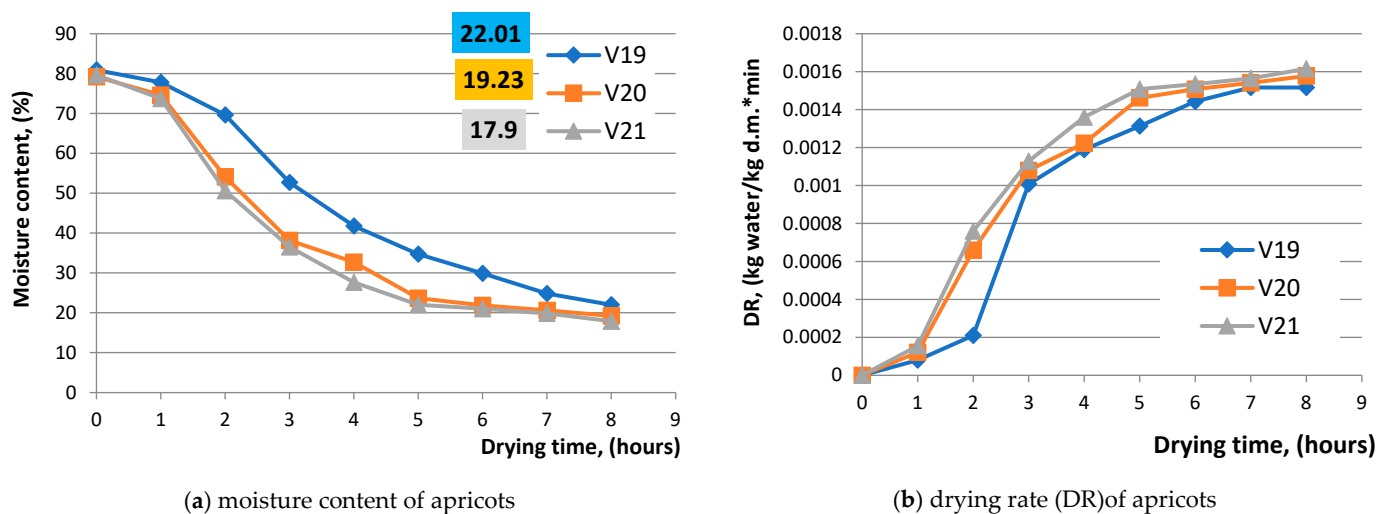


Figure 13. Moisture content and drying rate (DR) of apricots dried at 70 °C.

The average mass of a sample when entering the drying plant was 16.37 g and that of the finished product was 3.21 g, resulting in a practical yield of 63.91%, and theoretical yield was ranged between 74.26 to 75.52%.

The drying rate in this instance reached high levels during the initial drying hours, with hot air speeds of 2.0 m/s producing the quickest drying results. The same patterns that emerged after drying at 80 °C were highlighted: the drying process takes longer to complete at higher drying agent temperatures. Following the comparative analysis of the experimental results, there were statistically significant differences between the variants as follows: between variants V_{19} and V_{21} ($p = 0.041$) was significant; between V_{20} and V_{21} ($p = 0.22$) insignificant differences; between variants V_{19} and V_{20} there are distinctly significant differences ($p = 0.004$).

Figure 13b displayed the apricot drying rate (DR) curves at various air velocities and a temperature of 70 °C. Also, it stated that apricots are dried using hot air in a decreased rate procedure. During the first few hours of hot air drying, the initial DR at is higher.

Another set of experiments was conducted to ascertain the impact of 80 °C temperature at various air speeds on apricot halves. The effect of temperature on the moisture content can be seen in Figure 14a. The average mass of apricot sample when it was introduced into the drying equipment was 13.27 g and of the finished product was 4.96 g, resulting in an average of practical yield to 63%, and 74.99% for theoretical yield.

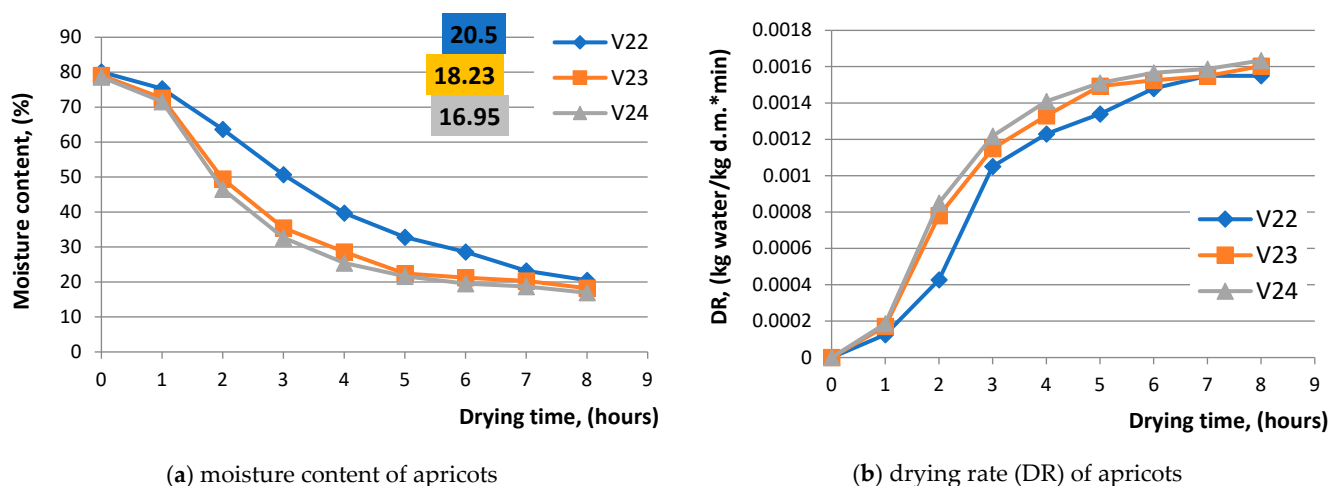


Figure 14. Moisture content and drying rate (DR) of apricots dried at 80 °C.

The initial moisture content was ranged between 78.62–80.10% w.b. reaching after 8 h of drying to values between 16.95 and 20.5% w.b. As expected, the moisture content decreases considerably with increasing desiccant temperature. Due to the high temperature of the drying agent, a large amount of water is evaporated in the first hour of the drying process, the moisture content decreasing to the level of 39.71% w.b. (V₂₂), 28.6% w.b., (V₂₃) 25.42% w.b. (V₂₄), respectively.

For the experimental variants where the temperature of the drying agent was 80 °C, insignificant differences were recorded between V₂₃ and V₂₄, significant for V₂₂–V₂₃, V₂₂–V₂₄.

The drying rate (DR) recorded close values for two experimental variants (V₂₃, V₂₄), being very high in the first hour of the drying process, due to the rapid elimination of the contained water (Figure 14b).

This shows the importance of drying agent temperature, the higher the drying agent temperature, the faster the drying rate and the shorter the process time. This has also been reported in other papers in the field [78–80].

Regarding the temperature inside the apricots subjected to the drying process, it can be observed that it gradually increases during the drying process, eventually reaching values close to that of the drying agent. This is valid for all experimental variants. It can also be mentioned that in the first two hours of the drying process, a rapid heating of the product takes place, a fact that can be seen in the drying rate.

Apricot halves were subjected to the hot air drying at 50 °C, 60 °C, 70 °C and 80 °C. Drying parameters of dried samples can be explored in Figures 10–13. It is seen that the higher temperature reduces the drying time 4 h as it is expected. Experiments with apricots, carried out by different authors, have shown that decreasing the temperature of the drying agent leads to a decrease in the rate of evaporation of water from the fruit, concluding that the optimal temperature for dehydration of apricots is between 50 °C and 60 °C [81,82].

Thus, internal barrier to water diffusion and intrinsic product features both influence mass transfer. When researching the hot air drying of apricots, various authors found that their findings were consistent. However, following the induction period, the drying rate remained consistent (Figures 10–13), showing that the rate at which water looks to diffuse from the core of the product to its surface appears to be identical to the rate at which it evaporates to the product–air interface. When additional fruits were dried, other authors found comparable results [14,83,84].

3.2.3. Color Parameters of Apricots

The major sensory quality characteristic of color is important for consumers to assess when making a purchase. Table 4 lists the values for L* (brightness), a* (red–green), and b* (yellow–blue).

Table 4. Effect of drying temperature and hot air speed on color parameters of apricots.

Experimental Variant	L*	a*	b*	a*/b*
Fresh apricot	41.57 ± 0.307	9.38 ± 0.038	22.46 ± 0.124	0.418 ± 0.002
V ₁₃	52.27 ± 0.253	3.92 ± 0.044	10.08 ± 0.061	0.389 ± 0.004
V ₁₄	52.31 ± 0.109	3.91 ± 0.058	11.2 ± 0.132	0.349 ± 0.007
V ₁₅	51.83 ± 0.105	3.97 ± 0.029	11.72 ± 0.087	0.339 ± 0.004
V ₁₆	51.270 ± 0.206	6.17 ± 0.061	11.92 ± 0.074	0.518 ± 0.006
V ₁₇	50.84 ± 0.148	6.09 ± 0.029	12.31 ± 0.088	0.498 ± 0.004
V ₁₈	51.49 ± 0.094	6.34 ± 0.056	12.37 ± 0.115	0.513 ± 0.006
V ₁₉	49.54 ± 0.133	6.26 ± 0.042	13.74 ± 0.082	0.456 ± 0.003
V ₂₀	49.84 ± 0.156	6.32 ± 0.045	13.71 ± 0.114	0.461 ± 0.004
V ₂₁	49.72 ± 0.130	6.29 ± 0.051	13.82 ± 0.052	0.455 ± 0.004
V ₂₂	47.69 ± 0.135	6.47 ± 0.075	14.35 ± 0.061	0.451 ± 0.006
V ₂₃	46.87 ± 0.119	6.59 ± 0.069	14.53 ± 0.098	0.454 ± 0.004
V ₂₄	46.93 ± 0.111	6.61 ± 0.066	14.62 ± 0.076	0.453 ± 0.006

V₁₃—experimental variant for apricots dried at 50 °C and drying agent speed: 1.5 m/s; V₁₄—experimental variant for apricots dried at 50 °C and drying agent speed: 2.0 m/s; V₁₅—experimental variant for apricots dried at 50 °C and drying agent speed: 2.5 m/s; V₁₆—experimental variant for apricots dried at 60 °C and drying agent speed: 1.5 m/s; V₁₇—experimental variant for apricots dried at 60 °C and drying agent speed: 2.0 m/s; V₁₈—experimental variant for apricots dried at 60 °C and drying agent speed: 2.5 m/s; V₁₉—experimental variant for apricots dried at 70 °C and drying agent speed: 1.5 m/s; V₂₀—experimental variant for apricots dried at 70 °C and drying agent speed: 2.0 m/s; V₂₁—experimental variant for apricots dried at 70 °C and drying agent speed: 2.5 m/s; V₂₂—experimental variant for apricots dried at 80 °C and drying agent speed: 1.5 m/s; V₂₃—experimental variant for apricots dried at 80 °C and drying agent speed: 2.0 m/s; V₂₄—experimental variant for apricots dried at 80 °C and drying agent speed: 2.5 m/s.

The dried apricot pulp was, in various degrees, browner than the fresh pulp, which was orange. In comparison to fresh samples, dried samples at various temperatures had considerably different L*, a*, and b* values. The L* value fell as the drying temperature rose, but there was no discernible difference between the dried samples. The dried apricots' a* and b* values, which represent redness and yellowness, respectively, were noticeably lower than those of the fresh samples.

Also, it is evident that when temperature rose, the a* and b* values for the dried samples increased. This might be the case because drying at 50 °C takes longer and results in more anthocyanin degradation than at 80 °C. The value of the L* parameter was significantly lower at temperatures of 50 °C and 60 °C compared to those of 70 °C and 80 °C. The apricots dried at 50 °C and 60 °C reached the desired moisture content after a longer period of time (approx. 12 and 8 h, respectively) compared to the samples dried at 70 °C and 80 °C (7 h).

With a rise in the drying agent's temperature and a longer drying time, the value of the luminosity parameter (L*) drops.

Table 4 presents the color parameter results for L*, a*, and b* values, respectively. These results are similar to those reported in [85,86]. As can be observed from the graph, samples that had the lowest values of L* and low air temperatures of 50 °C browned. Donka et al. [84] reported the same outcomes. L*, a*, and b* values as well as color characteristics like chroma and hue angle are frequently used to illustrate the optical characteristics of fruits. The oxidation of ascorbic acid, enzymatic and nonenzymatic browning processes, and pigment loss are the causes of the discoloration that occurs in dried apricots during hot air drying [87,88]. The primary causes of the apricot's yellow to orange hue are polyphenols and β-carotene. Browning of the product during drying is indicated by a sharp decrease in L* value (lightness) and a sharp increase in a* value (redness) [89]. Hue angle explains color as 0°/360° for red-purple, 90° for yellow, 180° for green, and 270° for blue. Chroma, which represents color saturation, ranges from 0 (dusty) to 60 (bright) [90].

Since the color determination is a lightness-darkness determination, this decrease in the parameter indicates that the samples tend to change color from a lighter color to a darker color.

Due to the formation of the brown pigment during the drying process, the luminosity (L^*) parameter decreases, which supports the notion that the browning process becomes more intense as drying time and drying agent temperature rise. Lower temperature, for a long time, can cause more damage to products than drying at higher temperatures for short periods of time. According to statistical analysis, the drying agent's temperature significantly affects the color parameter L^* ($p < 0.05$).

The value of the red/green ratio (a^*) decreased from 9.38 ± 0.038 to 3.91 ± 0.058 ; the temperature of the drying agent caused browning of the apricots subjected to the drying process ($a^* > 1$). And in this case, the differences recorded between the means were significant ($p < 0.05$).

The yellow/blue parameter (b^*) saw a reduction as well, going from 22.46 ± 0.124 to 10.08 ± 0.061 . It was discovered that this parameter is influenced by the drying agent's temperature. The V_{15} variant produced the highest value for the a^*/b^* ratio.

On the contrary, the color change value (ΔE) was negatively correlated with temperature, and the sample dried at 50°C had the highest total color difference value (Figure 15).

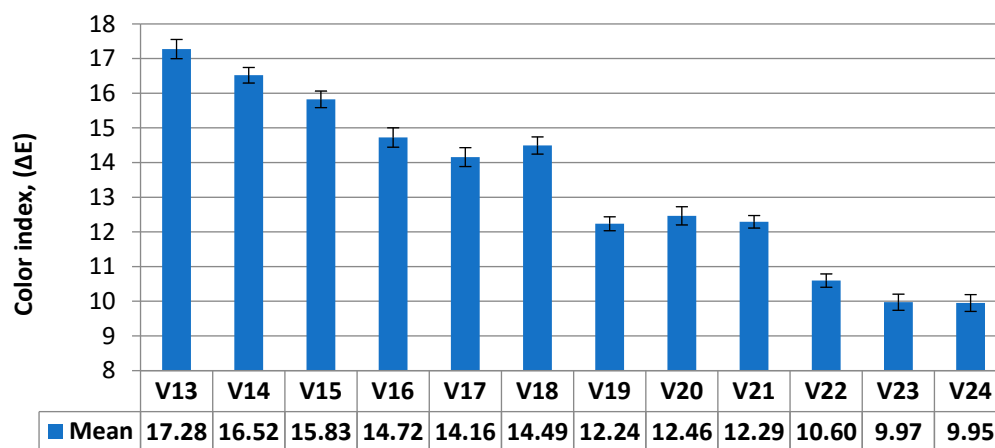


Figure 15. Effect of drying parameters on total color of apricots. V_{13} —experimental variant for apricots dried at 50°C and drying agent speed: 1.5 m/s; V_{14} —experimental variant for apricots dried at 50°C and drying agent speed: 2.0 m/s; V_{15} —experimental variant for apricots dried at 50°C and drying agent speed: 2.5 m/s; V_{16} —experimental variant for apricots dried at 60°C and drying agent speed: 1.5 m/s; V_{17} —experimental variant for apricots dried at 60°C and drying agent speed: 2.0 m/s; V_{18} —experimental variant for apricots dried at 60°C and drying agent speed: 2.5 m/s; V_{19} —experimental variant for apricots dried at 70°C and drying agent speed: 1.5 m/s; V_{20} —experimental variant for apricots dried at 70°C and drying agent speed: 2.0 m/s; V_{21} —experimental variant for apricots dried at 70°C and drying agent speed: 2.5 m/s; V_{22} —experimental variant for apricots dried at 80°C and drying agent speed: 1.5 m/s; V_{23} —experimental variant for apricots dried at 80°C and drying agent speed: 2.0 m/s; V_{24} —experimental variant for apricots dried at 80°C and drying agent speed: 2.5 m/s.

The color index (total color change ΔE) is an important factor in the study of product quality preservation during the drying process; it shows how much the color of the product has changed. These changes are determined by the simultaneous transfer of heat and mass that occurs at the surface and inside the product and depend on the temperature of the drying agent and its velocity.

On the overall color change of the apricots, drying temperature, hot air velocity, and drying duration all played a significant role. The experimental variant V_{24} recorded the lowest value of ΔE (9.95 ± 0.242); in contrast, the experimental variant V_{13} , which correspond to temperatures of 50°C and 1.0 m/s, reported the highest values of this parameter (17.28 ± 0.275).

The values of ΔE recorded for the experimental variants V_{13} , V_{14} and V_{15} can be explained by the long drying time and the low temperature of the drying agent, which causes changes in the color associated with the browned products.

Table 5 displays the impact of temperature and drying agent velocity on chroma, hue angle, and browning index (BI). In the case of the experimental variant with drying at 50 °C, the Croma index was reduced to its lowest value.

Table 5. Effect of drying temperature and hot air speed on color parameters of apricots.

Experimental Variant	Chroma*	Hue angle* (h°)	Browning Index* (BI)
Fresh apricot	24.34 ± 0.118	2.253 ± 0.015	91.56 ± 1.124
V_{13}	10.81 ± 0.064	2.442 ± 0.030	26.53 ± 0.248
V_{14}	11.85 ± 0.121	2.755 ± 0.065	29.13 ± 0.338
V_{15}	12.37 ± 0.079	2.839 ± 0.036	30.81 ± 0.229
V_{16}	13.41 ± 0.067	1.756 ± 0.025	34.83 ± 0.208
V_{17}	13.72 ± 0.080	1.853 ± 0.018	36.04 ± 0.264
V_{18}	13.89 ± 0.104	1.777 ± 0.028	36.04 ± 0.350
V_{19}	15.09 ± 0.078	2.014 ± 0.020	41.24 ± 0.291
V_{20}	15.09 ± 0.108	2.014 ± 0.023	40.96 ± 0.329
V_{21}	15.18 ± 0.048	2.045 ± 0.032	41.34 ± 0.236
V_{22}	15.74 ± 0.056	2.068 ± 0.032	45.19 ± 0.235
V_{23}	15.95 ± 0.103	2.052 ± 0.024	46.83 ± 0.408
V_{24}	16.04 ± 0.060	2.060 ± 0.031	47.06 ± 0.262

* Values represent the mean and standard deviation of the mean ($\pm$ s) of the color parameters. V_{13} —experimental variant for apricots dried at 50 °C and drying agent speed: 1.5 m/s; V_{14} —experimental variant for apricots dried at 50 °C and drying agent speed: 2.0 m/s; V_{15} —experimental variant for apricots dried at 50 °C and drying agent speed: 2.5 m/s; V_{16} —experimental variant for apricots dried at 60 °C and drying agent speed: 1.5 m/s; V_{17} —experimental variant for apricots dried at 60 °C and drying agent speed: 2.0 m/s; V_{18} —experimental variant for apricots dried at 60 °C and drying agent speed: 2.5 m/s; V_{19} —experimental variant for apricots dried at 70 °C and drying agent speed: 1.5 m/s; V_{20} —experimental variant for apricots dried at 70 °C and drying agent speed: 2.0 m/s; V_{21} —experimental variant for apricots dried at 70 °C and drying agent speed: 2.5 m/s; V_{22} —experimental variant for apricots dried at 80 °C and drying agent speed: 1.5 m/s; V_{23} —experimental variant for apricots dried at 80 °C and drying agent speed: 2.0 m/s; V_{24} —experimental variant for apricots dried at 80 °C and drying agent speed: 2.5 m/s.

Hue angle value also showed a decrease in value from 2.253 to 1.756 during the drying process. This indicates an orange-red color (hue < 90°) of apricots (hue > 90° green color).

Another color index is browning index (BI), which represents the purity of the brown color and is also an important factor in enzymatic and nonenzymatic browning processes. The value of the browning index (BI browning index) for fresh apricot was 91.56 ± 1.124. The highest value of this index, of 47.06 ± 0.262, was recorded for the experimental version V_{24} , where the temperature of the drying agent was 80 °C, and its velocity was 2.0 m/s.

The high degree of browning of apricots occurs during the hot air-drying process as a result of nonenzymatic reactions, Maillard reactions and ascorbic acid oxidation. From the recorded results, it can be concluded that the temperature and speed of the drying agent, the duration of drying, clearly affect the color parameters of dried apricots.

It can be said that the drying temperature and time had an impact on the apricots' color. Fresh samples and dried foods have different colors, which can be attributed to pigment deterioration, enzymatic browning, and nonenzymatic processes. The outcome showed that 50 °C was the temperature that induced the greatest color variation. This might be due to the fact that, in this situation, pigment degradation is largely outweighed by enzymatic browning and the Maillard reaction [87].

Figure 16 compares the looks of the samples made under various drying settings.

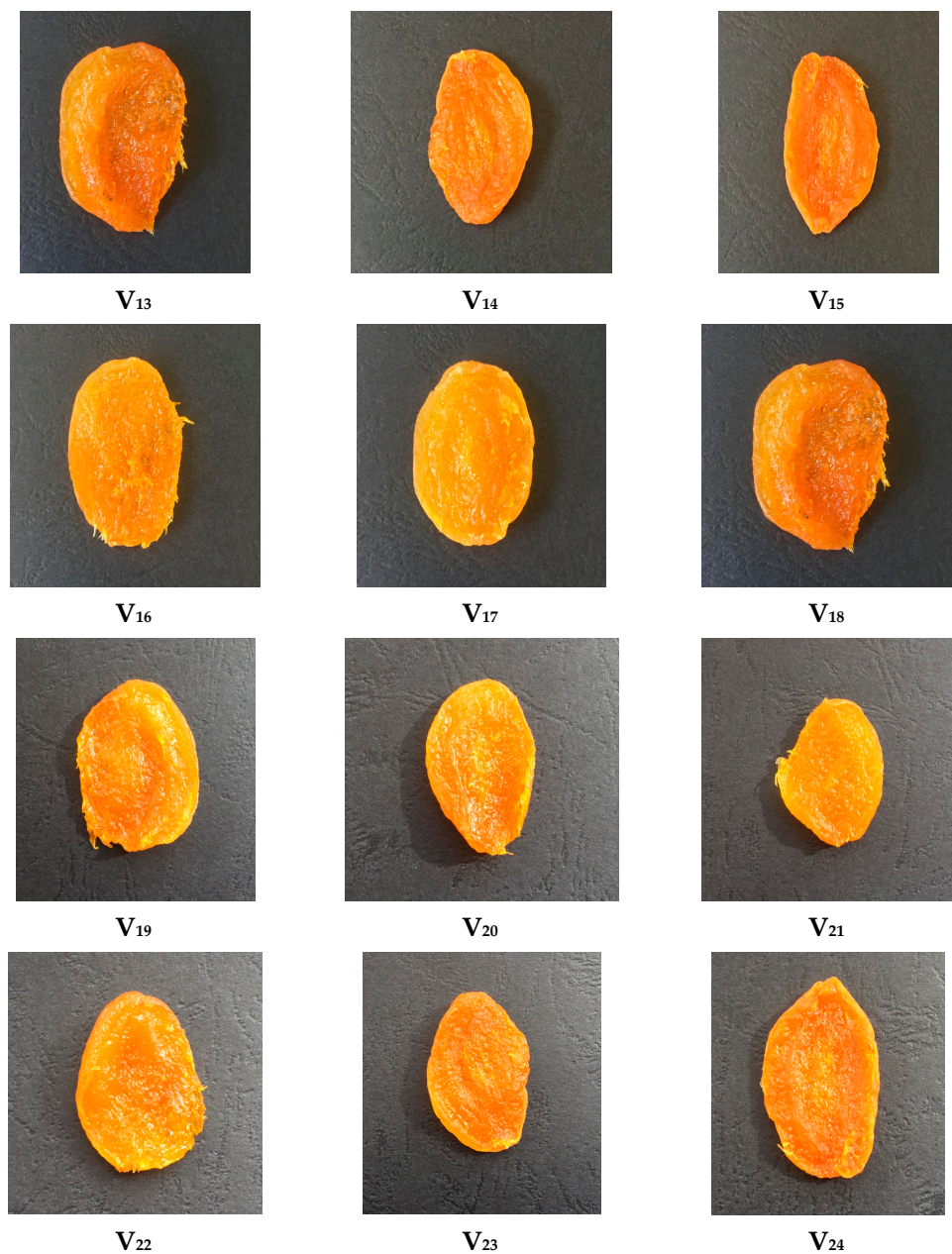


Figure 16. Appearance of dried apricots. V₁₃—experimental variant for apricots dried at 50 °C and drying agent speed: 1.5 m/s; V₁₄—experimental variant for apricots dried at 50 °C and drying agent speed: 2.0 m/s; V₁₅—experimental variant for apricots dried at 50 °C and drying agent speed: 2.5 m/s; V₁₆—experimental variant for apricots dried at 60 °C and drying agent speed: 1.5 m/s; V₁₇—experimental variant for apricots dried at 60 °C and drying agent speed: 2.0 m/s; V₁₈—experimental variant for apricots dried at 60 °C and drying agent speed: 2.5 m/s; V₁₉—experimental variant for apricots dried at 70 °C and drying agent speed: 1.5 m/s; V₂₀—experimental variant for apricots dried at 70 °C and drying agent speed: 2.0 m/s; V₂₁—experimental variant for apricots dried at 70 °C and drying agent speed: 2.5 m/s; V₂₂—experimental variant for apricots dried at 80 °C and drying agent speed: 1.5 m/s; V₂₃—experimental variant for apricots dried at 80 °C and drying agent speed: 2.0 m/s; V₂₄—experimental variant for apricots dried at 80 °C and drying agent speed: 2.5 m/s.

3.2.4. Ascorbic Acid Content of Apricots

Fresh apricots have an ascorbic acid level of 11.8 0.129 mg/100 g. Figure 17 displays the vitamin C content of dried apricots at various temperatures and speeds. As the drying agent's temperature rises, so does its ascorbic acid level. At 50 °C, the drying agent's

velocity has a significant impact because increasing the speed also lowers the ascorbic acid level. The velocity has a minimal effect at 80 °C of the drying agent, registering near values for the three experimental variants. Both for fresh apricot samples and for those dehydrated at different temperatures of the drying agent (50 °C; 60 °C; 70 °C; 80 °C), no reductones were identified in the sample with indophenol.

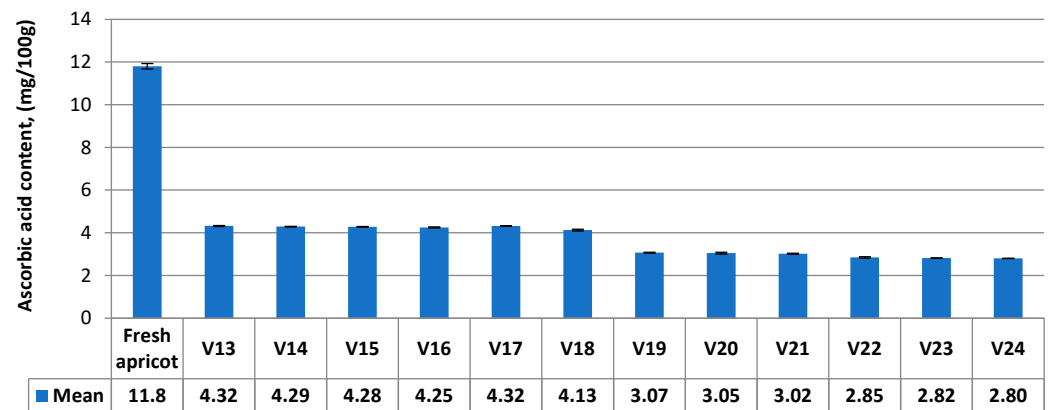


Figure 17. Effect of drying parameters on ascorbic acid content of apricots. V₁₃—experimental variant for apricots dried at 50 °C and drying agent speed: 1.5 m/s; V₁₄—experimental variant for apricots dried at 50 °C and drying agent speed: 2.0 m/s; V₁₅—experimental variant for apricots dried at 50 °C and drying agent speed: 2.5 m/s; V₁₆—experimental variant for apricots dried at 60 °C and drying agent speed: 1.5 m/s; V₁₇—experimental variant for apricots dried at 60 °C and drying agent speed: 2.0 m/s; V₁₈—experimental variant for apricots dried at 60 °C and drying agent speed: 2.5 m/s; V₁₉—experimental variant for apricots dried at 70 °C and drying agent speed: 1.5 m/s; V₂₀—experimental variant for apricots dried at 70 °C and drying agent speed: 2.0 m/s; V₂₁—experimental variant for apricots dried at 70 °C and drying agent speed: 2.5 m/s; V₂₂—experimental variant for apricots dried at 80 °C and drying agent speed: 1.5 m/s; V₂₃—experimental variant for apricots dried at 80 °C and drying agent speed: 2.0 m/s; V₂₄—experimental variant for apricots dried at 80 °C and drying agent speed: 2.5 m/s.

The average amount of ascorbic acid determined in apricots dried at a temperature of 50 °C was a range of 4.28 ± 0.018 mg/100 g to 4.32 ± 0.020 mg/100 g, 4.13 ± 0.041 to 4.32 ± 0.014 mg/100 g for drying at 60 °C; in apricots dried at a temperature of 70 °C, it was a range between 3.02 ± 0.021 – 3.07 ± 0.020 mg/100 g product, 2.80 ± 0.002 – 2.85 ± 0.027 mg/100 g for drying at 80 °C.

The kinetics of ascorbic acid oxidation during apricot air drying showed that differences in vitamin C concentration were influenced by drying time, drying air temperature, and moisture content. The dried product becomes less thermolabile ascorbic acid due to the large increase in drying agent temperature. Other studies found comparable results for drying apples [72–74].

The kinetics of ascorbic acid breakdown during apricot air drying revealed that drying duration, drying air temperature, and moisture content all had an impact on variations in vitamin C concentration. It was found that when the temperature of the heating agent increases, the ascorbic acid content of apricot is lower. The losses of ascorbic acid at the heat agent temperature of 70–80 °C are high, compared to drying regimes at low temperatures (50–60 °C).

There are no comprehensive comparisons of the ascorbic acid content of different apricot cultivars in the literature. Its composition primarily relies on the degree of ripeness [87,88]. For fresh apricots, other writers noted that the Red Carlet variety's ascorbic acid value was 2.8 (0.3) mg/100 [89], and research suggests that other apricot types also contain low levels of this acid (2–10 mg/100 g) [90].

3.2.5. Energy Consumption for Drying Apricots

The lowest specific energy value of 3.48 kWh/kg necessary to implement the drying process is obtained at parameters of the drying agent $T = 50\text{ }^{\circ}\text{C}$ and $v = 2.0\text{ m/s}$. The process duration is $dt = 600\text{ min}$. The minimum duration of the drying process $dt = 420\text{ min}$ is obtained at parameters of the drying agent $T = 80\text{ }^{\circ}\text{C}$ and $v = 2\text{ m/s}$. The energy necessary to implement the process is 1.91 kWh/kg.

4. Conclusions

In this study, apricot halves and apple slices were dried under various circumstances. The following conclusions were reached after looking into the drying kinetics, vitamin C retention, and color change. To determine the benefits and drawbacks of the convective drying process, the impact of the drying agent parameters on these quality factors was examined. Regardless of the drying air temperature and for a relative humidity of the drying air lower than 100%, fruits dry at a decreasing rate over time. The drying kinetics of the apple slices and apricot halves were clearly influenced by the air temperature programs. The expected result of rising temperature was a reduction in overall drying time. Due to greater convective heat and mass transfer coefficients between the drying air and the fruit, drying periods decreased as the speed of the drying air increased. The amount of ascorbic acid and the color of the items that are dried directly depend on the temperature of the drying agent and the drying period. Product quality is strongly affected by thermal effects, and a browning process has been observed in all drying conditions and fruit shapes. Parameters for the drying process of apples and apricots was chosen as optimal, taking into account the duration of the drying process and the physicochemical characteristics of the products (moisture content, ascorbic acid content, color changes), respectively. The optimal method for obtaining high quality dried apples and apricots is to dry them at $T = 60\text{ }^{\circ}\text{C}$ and $v = 1.5\text{ m/s}$ while taking into account drying effectiveness and product attributes overall. A range of fruits and vegetables with similar physicochemical characteristics and that have not received any prior treatment before drying can be dried using the drying installation or the technique of drying apples and apricots that was previously supplied.

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