DRYING CHARACTERISTICS AND QUALITY OF RED PEPPER SLICES UNDER HOT AIR FOLLOWED BY MICROWAVE FINISH DRYING

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***Abstract*— Red pepper slices were subjected to hot air, microwave and hot air followed by microwave finish drying. The hot air-drying experiments were conducted at temperatures of 45, 55 and 65°C. Microwave experiments were carried out at 780 W microwave power level. Hot air followed by microwave finish drying decreased the drying time required when compared to drying with hot air drying. Among the five thin layer drying models that were used to fit the experimental data, Page and Modified Page models gave the highest correlation coefficient, lowest root mean square error, and reduced chi-square, thus indicating that Page and Modified Page models best described the hot air drying of red pepper slices. In this study, ascorbic acid degradation and color changes during drying were also investigated. In the drying process at 65ºC for 9 hours, ascorbic acid content decreased to 330.94±1.45 mg/100g dry matter after 8 hours. After 8 hours, no ascorbic acid was found. Moreover, the kinetics of ascorbic acid and color changes of red pepper slices, due to drying by hot air drying were studied. It was confirmed that ascorbic acid degradation followed first order kinetics. The results indicate that hot air followed by microwave finish drying may be an alternative method for the drying of red pepper slices since it provides good quality product in shorter time.**

***Keywords*— red pepper, drying, ascorbic acid, color, degradation**

I. INTRODUCTION

The Capsicum genus, which is a member of the Solanaceae family, represents a diverse plant group, from the well-known sweet green bell pepper to the fiery hot, recently exploited habanero. Red pepper is an excellent product in terms of nutritional value. The color of red pepper comes from carotenoids like capsanthin, carotene, capsorubin, kryptoxantin, capsaisinoid, zeaxantine and lutein. Furthermore, red pepper is an excellent source of vitamin C. Fresh peppers are perishable and have a short shelf life due to high moisture content. Drying is the most widely used primary method of food preservation. Dried red pepper is an important spice or ingredient for industrial and culinary purposes, it provides intense colour and strong flavor (Montoya-Ballesteros *et al.*, 2014; Deng *et al.*, 2018).

Drying of the red peppers can be accomplished using various techniques including hot air, vacuum, freeze, microwave drying, etc. and drying techniques offer different advantages depending on the drying method. Conventional hot air drying is the most frequently used dehydration method, meanwhile, fruits and vegetables undergo physical and chemical changes which influence the quality attributes like sensorial and nutritional values (Scala and Crapiste, 2008; Deng *et al.*, 2018). In vacuum drying, removal of moisture from food products takes place under low pressure. The lower pressure allows drying temperature to be reduced and higher quality to be obtained than with classical air conventional process at atmospheric pressure. Freeze-drying is a process whereby water is removed by dehydration, through sublimation of ice in the materials. Microwave drying has many unique features related to its selective and volumetric heating compared to traditional drying techniques (Song *et al.*, 2016). The advantages of the previously mentioned dying techniques can be brought together by combining them with microwave finish drying which provides an alternative way to improve the quality of the dehydrated products by increasing the evaporation rate and decreasing the drying time and energy consumption (Alibas, 2006; Demiray *et al.*, 2017).

This study aimed to investigate the effects of different drying processes [hot air, microwave, and also the microwave finish drying method (hot air + microwave)], microwave output power and drying temperatures on the moisture content, color values, and ascorbic acid contents of red pepper slices. Moreover, the kinetics of ascorbic acid and color degradation of dried red pepper slices using convective hot air dryer also investigated.

II. METHODS

A. Sample Preparation

Red peppers (*Capsicum annuum* L.) were purchased from a local market. The whole samples were stored at 4 ± 0.5°C before they were used in experiments. The initial moisture content of red peppers was found to be 9.58 kg water/kg dry matter. Prior to drying, samples were taken out of refrigerator, sliced into 4 cm wide, 7.0 ± 2.0 cm length and 0.6 ± 0.1 cm thickness using a stainless-steel knife.

B. Drying Equipment

The hot air-drying experiments were performed in a cabinet laboratory type dryer (Yücebaş Makine Ltd. Inc., İzmir, Turkey) in the Food Engineering Department of Pamukkale University, Turkey. It consists of a centrifugal fan to supply the air flow, an electric heater and an electronic proportional controller. The dryer included four removable trays of 40 × 60 cm, which are made of stainless-steel gauze formed into a fine sieve. A programmable domestic microwave oven (Vestel, MD-23, Turkey) with maximum output of 900 W at 2450 MHz was used for the drying experiments. The dimensions of the microwave cavity were 330 mm × 350 mm × 215 mm. The oven consisted of a glass plate with 314 mm diameter at the base of the oven.

C. Drying Procedure

a) Hot air drying: The hot air-drying experiments were conducted at temperatures of 45, 55 and 65°C. At all drying experiments, a constant airflow of 0.2 m/s and a constant 20% relative humidity was used. The cabinet dryer was started at about 1 h before the drying experiments to stabilize both temperature and relative humidity. About 1500 g of red pepper slices were weighed and placed on trays as a single layer. During hot air drying, weight of the sample was recorded regularly. In addition, samples were taken from the trays on regular basis for further analyses. The hot air drying was applied until the weight of sample reduced to a level corresponding to moisture content of about 0.10 kg water / kg dry matter. The reason for choosing 0.10 kg water / kg dry matter as the final moisture content value is that the water activity value at this moment was determined below 0.55 in all drying experiments. As it is known, decreasing the water activity value below 0.65 in dried products prevents many enzymatic and non-enzymatic changes, especially microbiological degradation (Rahman and Labuza, 2007). In addition, the percentage moisture content of the dried red pepper samples was determined between 10-12%. Similar problems were encountered when studies in the literature were examined. As a matter of fact, Doymaz and Pala (2002), in their study, dried red peppers with an initial moisture content of 81.90% by using hot air-drying method after applying some pre-treatments to a moisture content of 11%. Akpinar *et al.* (2003) dried red peppers using hot air drying at three different temperatures. The initial moisture content of the red peppers used in drying was determined as 87.25% and they were dried until they contain 10% moisture. Three replicates for each of the experiment were done.

b) Microwave drying: Drying experiments were carried out at 780 W microwave power level. The microwave power output from the generator was calibrated following the 2L method recommended by the International Microwave Power Institute (Anonymous, 1989). The power absorbed by the samples during drying was calculated as the difference between the power absorption by the water load and the total magnetron power output. 1250 g of samples were placed in a single layer on a rotating glass plate in the oven. The on-off timing used in the intermittent microwave drying treatment was 10 s ON – 15 s OFF. The rotating glass plate was removed from the oven every 25 s during the drying period and moisture loss determined by weighing the plate using a digital balance (Denver Instruments, TP-3002, Germany) with a 0.01 g precision. The microwave power was applied until the mass of the sample reduced to a level corresponding to a moisture content of about 0.10 kg water/kg dry matter. Attention was paid to ensure that the sample was not charred. All experiments were carried out in triplicate.

c) Air followed by a microwave finish drying: Drying was carried out by a combination of hot air-microwave techniques. Red pepper sample was dried at 45, 55 and 65°C initially for 720, 420 and 360 min respectively, then, dried by microwave (at 780 W). This point corresponds to a moisture content of about 1.4 kg water/kg dry matter. It is a critical point where drying slows down.

D. Quality Evaluation

For quality evaluation, similar drying experiments were conducted separately under the same microwave, hot air and microwave finish drying conditions. After the drying experiments, dried samples were wrapped in aluminum foil in polyethylene packages and stored at –20°C for further ascorbic acid and color analyses. Similarly, Rufian-Henares *et al.* (2013) after drying the red peppers, they were stored at -20°C until the ascorbic acid and antioxidant activity analyzes were made.

E. Ascorbic Acid Analysis

The ascorbic acid content was determined in both fresh and dried red pepper samples following the HPLC analytical procedure outlined by Demiray *et al.* (2013). Fresh or dried red pepper samples were mixed with metaphosporic acid solution (1%, v/v) at the ratio of 1:10 (w/v), and the mixture was blended in a Waring blender. Samples were transferred into polypropylene centrifuge tubes and centrifuged at 11000 × g for 20 min at 4 °C. Supernatants of the extracted samples were filtered through a 0.45 µm PVDF syringe filters (Minisart, Sartorius, Gottingen, Germany) before injection.

The analysis was carried out using a Shimadzu LC-20AD, LC-20A quaternary pump, DGU-20A Degasser, equipped with a SPD-M20A photodiode array detector. The ascorbic acid fraction was separated on an ACE 5 C18 column (250 × 4.6 mm, ID, 5 µm) isocratically at 35 ˚C using the mobile phase of ultra-pure water at pH 3 (adjusted with H_3PO_4). The flow rate was 0.5 mL min^{-1}; injection volume was 20 µL, and the applied wavelength was 254 nm. The retention time of ascorbic acid peak was archived at 5.2 min. A 5-point standard curve was established to calculate the ascorbic content of samples. All samples were tested in triplicate.

F. Color Measurements

In this study, which examines the effects of drying process on color change of red pepper slices, the color values of the samples taken at predetermined time period during drying were measured with a color measuring device (Hunter Associates Laboratory, Model: MiniScan XE, USA). Hunter L, a, and b values obtained as a result of color measurements are not color concepts perceived directly by the consumer in the market. For that reason, of these values, total color criteria such as Hue angle, which appeal to people's color perception, Chroma, and total color change (ΔE), were calculated with the help of Eqs. 1, 2, and 3, respectively (Korkmaz *et al.*, 2021). The hue angle is defined as a color circle, and violet-red colors are at 270°-0° angle values, yellow at 60° angle, and colors between green and blue at 120°-240° angle values. The chroma value indicates the saturation of the color. While chroma values decrease in dull colors, they increase in vivid colors.

$$Hue\ Angle = \tan^{-1}\left(\frac{b}{a}\right) \quad (1)$$

$$Chroma = (a^2 + b^2)^{1/2} \quad (2)$$

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad (3)$$

Before performing color measurements, the Hunterlab MiniScan XE colorimeter was calibrated with white and black standard calibration plates. Color measurements were made from 3 different points and evaluated by taking the average of the obtained values.

G. Mathematical Modeling

The moisture content of the samples used in the drying experiments was calculated based on dry weight with the help of Eq. 4.

$$M = \frac{m_w}{m_d}. \quad (4)$$

In the equation, M value indicates moisture content (kg water/kg dry matter), m_w value indicates water amount (kg), and m_d value indicates dry matter amount (kg).

The drying rate was calculated with the help of Eq. 5.

$$DR = \frac{M_{t+dt} - M_t}{d_t}. \quad (5)$$

In the equation, DR drying rate (kg water/(kg dry matter×h)), M_t value moisture content at t (kg water/kg dry matter), M_{t+dt} value moisture content at $t + dt$ (kg water/kg dry matter)) and t value is expressed as time (h).

Moisture ratio (MR) was calculated by using Eq. 6.

$$MR = \frac{M_t - M_e}{M_0 - M_e}. \quad (6)$$

In the equation, M_t value indicates amount of water at any one time (kg water/kg dry matter), M_0 value indicates the water content of the product (kg water/kg dry matter) before starting to dry, M_e value indicates the amount of water (kg water/kg dry matter) contained in the drying air (Menges and Ertekin, 2006; Sitorus *et al*., 2021). In order to understand how the moisture content changes over time, using the test results obtained in the hot air-drying process, five semi-experimental models that are indicated in Table 1, namely Logarithmic, Lewis, Henderson & Pabis, Page, and Modified Page were tested and made comparison among these models statistically.

Table 1. Mathematical models applied to hot air drying curves of red pepper slices

Model Name	Model	Reference
Logaritmic	MR = *a*exp(-*kt*) + c	Ertekin and Yaldiz, 2004
Lewis	MR = exp(-*kt*)	Ergün *et al.*, 2016
Henderson and Pabis	MR = *a*exp(-*kt*)	Malaikritsanachalee *et al.*, 2018
Page	MR = exp(-*kt*^{n})	Chuwattanakul and Eiamsa-Ard, 2019
Modified Page	MR = exp[-*(kt)*^{n}]	Erbay and Icier, 2009

By calculating the model constants, the model that best describes the hot air-drying process of the red pepper slices was detected with the data obtained from the result of the experiment that used the non-linear regression method.

Regression analysis was performed for statistical validation. The regression coefficient (R^2) was chosen as the criterion to select the curve that was created with the help of mathematical models and gave the most accurate information about the drying kinetics of the samples. In addition, statistical evaluation criteria such as chi-square (χ^2) and root-mean-square error ($RMSE$) were also considered auxiliary elements in verifying the Eqs. 7 and 8.

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - z}. \quad (7)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]^{1/2}. \quad (8)$$

In these equations, the value of $MR_{exp,i}$ indicates the experimental dimensionless moisture content, while the value of $MR_{pre,i}$ indicates the estimated dimensionless moisture content calculated with the help of models. In the same way, the N value in the equation indicates the number of observations made and the z value indicates the number of constants. Root-mean-square error ($RMSE$) value indicates the deviation between the values calculated with the help of experimental values and models, and it is desirable that this value would be as close to zero as possible. Furthermore, the value of chi-square (χ^2) is rather small, indicating that the values calculated with the experimental data and models are compatible with each other.

H. Degradation Kinetics of Ascorbic Acid and Total Color Change

A significant increase or decrease in ascorbic acid content and ΔE values was determined only during hot air drying processes. Therefore, kinetic calculations could only be made for these quality characteristics. Degradation of ascorbic acid and total color change (ΔE) in red pepper slices during hot air drying were calculated by using the standard equation for zero, first and second-order reactions and degradation rate constants were determined by fitting Eqs. (9), (10) and (11) to experimental data.

$$C = C_0 - k_0 t. \quad (9)$$

$$C = C_0 \exp(-k_1 t). \quad (10)$$

$$\frac{1}{C} = \frac{1}{C_0} - k_2 t. \quad (11)$$

where C is the studied parameter (ascorbic acid content and ΔE) at any given drying time, C_0 are initial values of untreated samples and k_0, k_1, k_2 are rate constants.

The Arrhenius equation is the most widely accepted method of accounting for the temperature dependence of the rate constant in food systems. The temperature and the rate constant are related according to the Arrhenius equation

$$k = k_a \exp\left(-\frac{E_a}{RT}\right) \quad (12)$$

where k is the rate constant at temperature T (K), k_a is the frequency factor, E_a is the activation energy (kJ/mol), and R is the universal gas constant (8.314 J/molK).

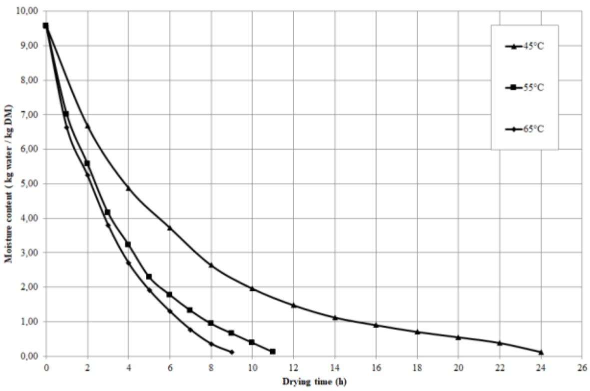

Figure 1. Hot air drying of red pepper slices at different air temperatures.

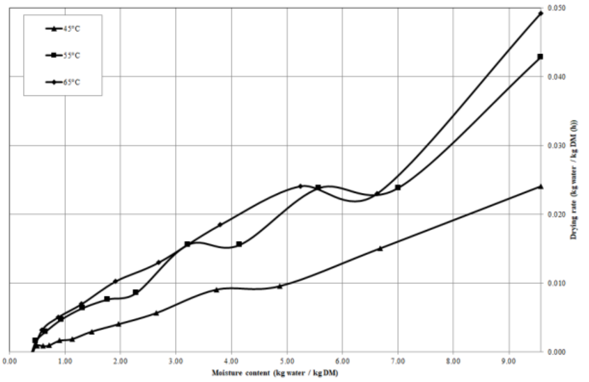

Figure 2. Drying rate versus moisture content of red pepper slices at different air temperatures.

The coefficient Q_{10} is another way to characterize the effect of the temperature on the rate of a reaction and it was calculated by the Eq. (13).

$$Q_{10} = \left({k_2}/{k_1}\right)^{10/(T_2-T_1)} \quad (13)$$

where k_1 and k_2 are reaction rate constants at temperatures T_1 and T_2, respectively (h^{-1}).

The experimental results are expressed as mean ± standard deviation of triplicate measurements and results were processed using Microsoft Excel.

I. Statistical Analysis

The means and standard deviations of experimental results were calculated from three replicates. One-way analysis of variance (ANOVA) to evaluate differences and Tukey's test to control the experiment wise error rate were used. Differences at $p<0.05$ were considered significant and were indicated with different letters.

III. RESULTS

A. Hot Air Drying

The red pepper samples were collected at different drying temperatures and time during hot air-drying process. The moisture contents were measured, and the average dry matter content of the fresh red peppers was 9.58 kg water/kg dry matter. The moisture content of the red pepper samples as a function of hot air drying time is shown in Fig. 1. In practical basis, to drying of vegetables to an intermediate moisture food product, the final moisture content should be dried to a low value (0.1 kg water / kg dry matter) to maintain a stable and low water activity state (Maskan, 2000). As seen in Fig. 1, a reduction in drying time occurred with the increasing drying temperature. The time required for the lowering of moisture content of red pepper levels to 0.1 level, from 9.58 on dry basis varied between 9 and 24 h depending on the drying temperature. These results were in agreement with previous literature studies (Yang *et al.*, 2018; Deng *et al.*, 2018). The drying rate was calculated at different times and plotted against average moisture content as shown in Fig. 2. Depending on the drying conditions, average drying rates of red pepper ranged from 0.3828 to 1.021 kg water / kg ((dry matter) × h) for the drying temperature between 45 and 65°C, respectively.

B. Microwave Drying

The time taken to reach a moisture content of 0.1 kg water/kg dry matter for the microwave drying at 780 W was 2100 s. Red pepper like other vegetables are very responsive to microwave application and will absorb the microwave energy quickly and efficiently as long as there is residual moisture. The microwave applications for drying therefore offer a distinct advantage, i.e. energy absorption proportional to the residual moisture content (Feng *et al.*, 2002; Arslan and Özcan, 2010). Even though much less time is necessary for drying, one disadvantage of this method is the lack of temperature control (Waldea *et al.*, 2006).

C. Microwave Finish Drying

The microwave method was used alone in red pepper samples, as well as in combination with the hot air-drying method. From the moment the drying process became difficult, the drying process continued until the targeted moisture content value was reached using the microwave oven. The moisture content-drying time graph of the red pepper samples taken to the microwave oven after drying with hot air for a while is indicated in Figure 3. In Figure 3, it is seen that drying continues at a constant rate in all drying processes in which the microwave process is applied. The drying process with hot air at 65ºC lasted for 9 hours, the drying process with microwave finish drying lasted for 6 hours and 400 seconds (approximately 6.1 hours). The result of the study bears a resemblance to a study in the literature. Maskan (2000) sliced the banana samples in a cylindrical shape with a thickness of 4.3 mm and then dried them using microwave-assisted hot air. He stated that the hot air-drying process takes longer (8.03 hours), but microwave-assisted hot air drying takes a shorter time (2.87 hours).

D. Modelling of Drying Curves

During the drying process performed at three different temperatures, the modeling of the drying process at three different temperatures was made using the data obtained from the red pepper slices dried up to 10-15% moisture content. Five different models were used in the study. Moisture ratio (MR) values were calculated using the moisture content values, and these parameters were used to detect the appropriate drying model. In Table 2, the

Table 2. Statistical results obtained from the selected models for hot air drying of red pepper slices

Model	Temperature (ºC)	Constants and coefficients			χ^2	RMSE	R^2
Lewis	45	k= 0.0024			0.002830	0.051116	0.9846
	55	k = 0.0049			0.000690	0.025115	0.9978
	65	k = 0.0057			0.001296	0.034153	0.9942
Page	45	k = 0.0046	n= 0.896		0.000001	0.001054	0.9943
	55	k = 0.0049	n = 1.005		0.000050	0.006351	0.9969
	65	k = 0.0052	n =1.011		0.000140	0.010752	0.9908
Modified Page	45	k = 0.0026	n = 0.896		0.000001	0.000777	0.9943
	55	k = 0.0047	n = 1.005		0.000040	0.005774	0.9969
	65	k = 0.0055	n =1.011		0.000120	0.009803	0.9908
Henderson and Pabis	45	k = 0.0022	a= 0.869		0.000790	0.025821	0.9871
	55	k = 0.0050	a = 1.043		0.000030	0.004619	0.9853
	65	k= 0.0059	a = 1.077		0.000480	0.019606	0.9858
Logarithmic	45	k = 0.0033	a = 1.089	c= 0.041	0.001640	0.035556	0.9920
	55	k = 0.0070	a = 1.300	c = 0.040	0.013460	0.100459	0.9506
	65	k = 0.0076	a = 1.209	c = 0.041	0.007557	0.072732	0.9632

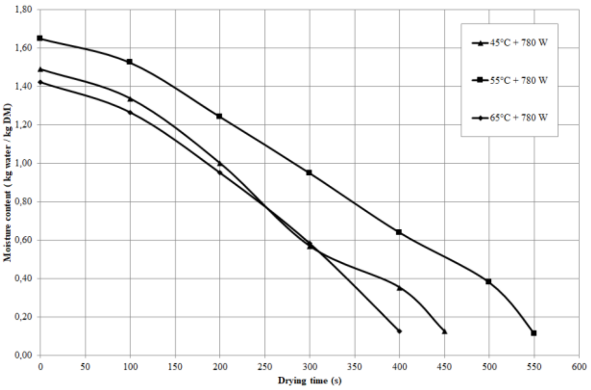

Figure 3. Drying curves of red pepper slices dried by microwave finish drying method.

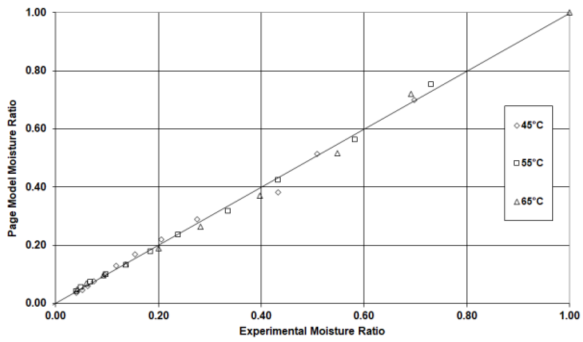

Figure 4. Comparison of experimental and Page models moisture ratio.

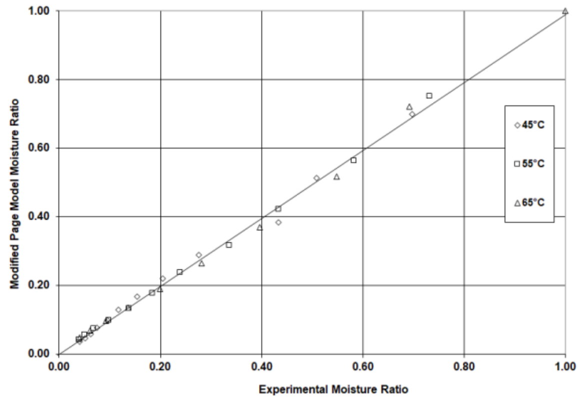

Figure 5. Comparison of experimental and Modified Page models moisture ratio.

constants and coefficients of the theoretical models used in the study, as well as RMSE (root-mean-square error), χ^2 and R^2 values are given.

In Table 2, Page and Modified Page models with high R^2 value and low RMSE value were found to be the best models describing the drying kinetics of the red pepper sample. Graphical representation, which includes the comparison of the experimental values obtained for the variation of the humidity values with the drying time at each temperature value at which drying takes place, with the values obtained from the Page and Modified Page models used, were given in Fig. 4 and Fig. 5. When the literature on drying kinetics is examined, it is seen that similar results are obtained. Arslan and Özcan (2011) sliced the red pepper samples with a thickness of 10±0.1 mm and then dried them in a drying oven at 50°C and 70°C. At the end of the modeling works, it was detected that the Page and Modified Page models, as well as the "Midilli and Küçük" model, were models expressing the drying kinetics. In another study (Vega *et al.*, 2007), they sliced red pepper samples into cubes with a volume of 1cm^3. The sliced samples were dried in a convective dryer at 50°C, 60°C, 70°C, and 80°C and air velocity of 2.5 m/s. According to the obtained drying data, kinetic modellings were made, and it was concluded that the most appropriate model was the Modified Page model.

E. Changes in Ascorbic Acid Content during Drying

Compared to other food components, ascorbic acid is generally chosen as an indicator of food quality because it changes rapidly in the direction of degradation due to the effects of the conditions under the influence of the food. Degradation of ascorbic acid depends on various

Table 3. Ascorbic acid contents of red pepper slices

Conditions	Drying time	Ascorbic acid content*(mg/100 g DM)
Fresh	---	1507.75±18.88[a]
45°C	24 h	307.44±0.89[b]
55°C	11 h	284.69±0.07[bc]
65°C	9 h	---
780W	2100 s	---
45°C + 780W	12 h + 450 s	242.03±0.96[bc]
55°C + 780W	7 h + 550 s	230.13±1.58[c]
65°C + 780W	6 h + 400 s	---

factors such as oxygen, light, temperature and moisture content (Rojas and Gerschenson, 2001). Erenturk *et al.* (2005) stated that temperature rise increased the loss of ascorbic acid in cut fruits, especially at the beginning of drying. As the surface area's contact with air increases, ascorbic acid losses also increase. Zanoni *et al.* (1999) also stated that the loss of ascorbic acid was due to the effect of significantly higher temperature.

In the analysis made before starting the drying process, the content of ascorbic acid was determined as 1507.75 mg/100g dry matter in fresh red peppers. In a similar study, it is reported that fresh red peppers contain ascorbic acid at the level of 932 mg/100g dry matter (Rufian-Henares *et al.*, 2013). In another study, on the other hand, it is reported that fresh red peppers contain ascorbic acid at the level of 1780 mg/100g dry matter (Hallmann and Rembialkowska, 2012). In red pepper slices dried with hot air, the content of ascorbic acid decreased from 1507.75±18.88 mg/100g dry matter to 307.44±0.89 mg/100g dry matter during the drying process at 45ºC for 24 hours. In the drying process at 65ºC for 9 hours, ascorbic acid content decreased to 330.94±1.45 mg/100g dry matter after 8 hours. After 9 hours, no ascorbic acid was found in the samples (Table 3). It shows that ascorbic acid was influenced by high temperatures more, and important losses happened.

In Table 3 results of the ascorbic acid analysis performed on the red pepper samples dried with microwave finish drying are shown. When the results were examined, a loss of 83.95% in ascorbic acid was detected after 450 seconds of microwave drying at 780W, which was applied after 12 hours of drying at 45°C with hot air. On the other hand, at the end of the microwave finish drying at 55 °C, it was detected that 84.74% loss occurred in ascorbic acid content. After drying with hot air at 65°C for 6 hours, it was observed that ascorbic acid completely disintegrated and disappeared in the red pepper samples after 400 seconds of processing at 780W microwave power.

As a result of the study, it can be argued that a certain amount of ascorbic acid loss occurs in dried samples compared to fresh samples, regardless of the drying method. Statistically, the difference between the amount of ascorbic acid in the fresh samples and the amount of ascorbic acid detected in the samples at the end of the drying process was found to be significant ($p<0.05$). On the other hand, no significant difference emerged between the amount of ascorbic acid in the samples microwave finish drying at 45°C and 55°C ($p>0.05$).

In the study, microwave application time was shorter in the microwave finish drying process compared to the microwave drying process. When the ascorbic acid contents of red peppers are examined, indicated in Table 3, it is observable that no ascorbic acid is found in the samples dried in the microwave drying. This situation is thought to be caused by long-term microwave application. When the studies were examined in the literature, similar results were found. Alibas-Ozkan *et al.* (2007) dried the spinach samples at different powers by the microwave drying and determined their ascorbic acid content. The researchers stated that the loss of ascorbic acid was greater due to the prolongation of the microwave drying process. In another similar study, Zhang and Hamauzu (2004) cooked the broccoli samples by microwave. They stated that the loss of ascorbic acid in the end product was greater due to the prolongation of the microwave cooking process.

Samples were taken every two hours as a basis for the kinetic calculations made to detect the losses in ascorbic acid content during hot air drying. As can be understood from Table 4, the change of ascorbic acid during drying in red pepper slices occurred in accordance with the first-order kinetic model (Fig. 6). Kinetic parameters belonging to ascorbic acid were given in Table 5.

As it is expected, the rate of degradation of ascorbic acid increases with increasing temperature. For example, while the half-life ($t_{1/2}$) was 9.96 hours in the drying process at 45ºC, this value decreased to 3.74 at 65ºC. The decrease in the $t_{1/2}$ value indicates that the stability of ascorbic acid decreases depending on the temperature.

Table 4. The kinetic parameters* of zero, first and second order models for *Ascorbic acid* and *ΔE* during hot air drying

Drying Temperature (°C)	Quality Parameter	Zero-order Model			First-order Model			Second-order Model		
		k_0	C_0	R^2	k_1	C_0	R^2	k_2	C_0	R^2
45	*Ascorbic acid*	51.027	1342.7	0.8767	0.0696	1487.8	0.9911	0.0001	1438.4	0.9702
	ΔE	0.3138	0	0.9978	0.0938	0	0.9454	0.0353	0	0.7814
55	*Ascorbic acid*	111.47	1400.9	0.9671	0.1492	1485.6	0.9903	0.0002	1327.5	0.8596
	ΔE	0.7798	0	0.9882	0.1882	0	0.8824	0.0582	0	0.7134
65	*Ascorbic acid*	142.62	1398.7	0.9632	0.1851	1498.7	0.9953	0.0003	1385.6	0.9231
	ΔE	1.1902	0	0.9970	0.2024	0	0.9816	0.0699	0	0.8973

*k_0, k_1, k_2 and C_0: reaction rate constant zero, first, second order model, and initial value of quality parameters, respectively.

Table 5. Kinetic parameters of ascorbic acid degradation and ΔE value of red pepper samples when dried at different temperatures[a]

Quality Parameter	Temperature (ºC)	Reaction Order	Q_{10} Value	k	$t_{1/2}$ (h)	E_a ($kJmol^{-1}$)
Ascorbic acid	45	1	2.14	0.0696	9.96	43.98
	55	1		0.1492	4.64	
	65	1	1.24	0.1851	3.74	
ΔE	45	0		0.3138	---	59.82
	55	0	2.49	0.7798	---	
	65	0	1.53	1.1902	---	

[a]Q_{10}, k and E_a: temperature coefficient, reaction rate constant and activation energy, respectively.

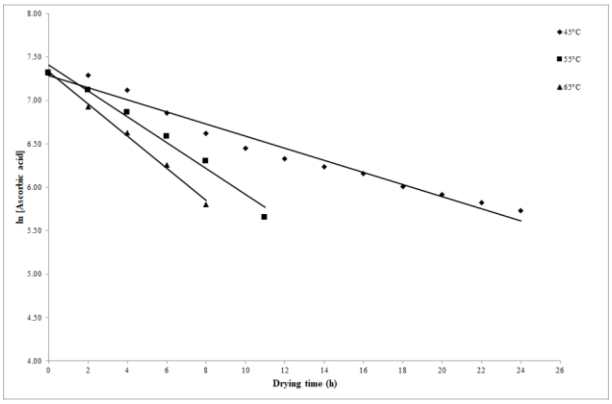

Figure 6. The degradation kinetics of ascorbic acid in red pepper slices dried at different air temperatures.

The findings obtained from the study are compatible with the literature data. Indeed, Rufian-Henares *et al.* (2013) stated that the degradation of ascorbic acid is compatible with the first-order kinetic model in red pepper. In another study, the researchers dried the red peppers at 50-70ºC after slicing (Scala and Crapiste, 2008). They determined the ascorbic acid content of the samples during the drying process. As a result of the kinetic models, they stated that the degradation kinetics of ascorbic acid during the drying of red peppers are compatible with the first-order reaction model. In addition, they calculated the activation energy value of this change as 26.90 kJ/mol. In this study, the activation energy value of thermal degradation of ascorbic acid as a result of the drying process was calculated as 43.98 kJ/mol (Table 5). When Q_{10} values were examined, it was detected that the effect of increasing the temperature from 45ºC to 55ºC was greater than the increase from 55ºC to 65ºC.

E. Changes in Color Values during Drying

In all drying processes, the color values of the red pepper samples taken before, during, and after drying were determined by using a color detector device. Color values of fresh and dried red pepper samples are given in Table 6. When the *L* values of the dried and fresh samples were examined, it was detected that there was a statistically significant difference between the values ($p<0.05$). It was observed that there was no significant difference ($p>0.05$) between the *L* values of the samples in drying at 45°C in the microwave and microwave-finish drying. There was no significant difference between the *L* value of the red pepper sample dried with microwave finish drying at 55°C and the *L* values of the samples dried at 65°C and 45°C with microwave finish drying ($p>0.05$). However, *L* values measured at 45°C and 65°C in microwave finish drying processes were found to be statistically different from each other ($p<0.05$). There was no significant difference between *a* values of the samples dried at 55°C and 65°C with microwave finish drying ($p>0.05$). It was detected that the *a* value of the samples dried at 45°C with microwave finish drying was different from the value of the samples dried at 55°C and 65°C with microwave finish drying ($p<0.05$). There was no significant difference between the *a* value of the samples dried by the microwave drying and the *a* values of the samples dried at 55°C and 65°C with microwave finish drying ($p>0.05$). The *b* value of fresh red pepper was measured as 9.89±0.32. The *b* values of red peppers dried at 45, 55 and 65°C with hot air were determined as 7.23±0.28, 6.94±0.35 and 5.50±0.48, respectively. It was determined that the *b* values decreased as the drying temperature increased. It was determined that there was no statistical difference between the *b* value of fresh red pepper and the color values of the samples dried at 45°C +780W ($p>0.05$).

In drying red pepper samples with microwave finish drying, *ΔE* values expressing the total color change were also calculated, and the results are given in Table 6. There was no significant difference between the *ΔE* values of the samples dried with microwave finish drying 45°C and 55°C ($p>0.05$). However, the *ΔE* value of the sample dried at 65°C with microwave finish drying is statistically different from the *ΔE* value of the samples dried under the other two conditions ($p<0.05$).

The chroma values of red pepper samples dried at three different temperatures by microwave finish drying were significantly different from the chroma values of fresh samples ($p<0.05$). When the Hue angle values indicated in Table 6 are examined, the situation is different from the chroma value. No significant difference ($p>0.05$) observed between the Hue angle values of the fresh samples and the Hue angle values of the microwave finish dried samples. When similar studies in the literature were examined, it was found that they were similar to the results obtained in this study. Alibas (2007) cut the

Table 6. Color parameters of red pepper slices

Conditions	Color Parameters*					
	L	a	b	ΔE	Croma	Hue Angle
Fresh	26.93±0.87[a]	29.76±0.65[a]	9.89±0.32[a]	0.00	31.36±0.45[a]	18.38±0.28[b]
45°C	23.85±0.48[d]	23.57±0.64[c]	7.23±0.28[b]	7.32±0.68[c]	24.65±0.28[c]	17.05±0.29[b]
55°C	22.22±0.43[e]	22.47±0.32[cd]	6.94±0.35[b]	9.07±0.14[b]	23.52±0.26[cd]	17.16±0.34[b]
65°C	21.65±0.87[e]	21.09±0.51[d]	5.50±0.48[c]	10.95±0.24[a]	21.80±0.39[d]	14.62±0.49[c]
780W	25.46±0.18[b]	21.94±0.37[cd]	8.25±0.26[ab]	7.24±0.43[c]	23.44±0.37[cd]	20.61±0.23[a]
45°C + 780W	24.83±0.12[bc]	26.72±0.24[b]	8.65±0.18[a]	3.90±0.41[d]	28.09±0.14[b]	17.94±0.28[b]
55°C + 780W	24.28±0.32[cd]	23.62±0.28[c]	7.12±0.14[b]	4.27±0.10[d]	24.67±0.26[c]	16.78±0.39[b]
65°C + 780W	23.79±0.45[d]	23.46±0.29[c]	7.05±0.21[b]	7.65±0.19[c]	24.50±0.42[c]	16.73±0.14[bh]

*Different letters in the same column indicate the significant differences in the drying conditions ($p < 0.05$).

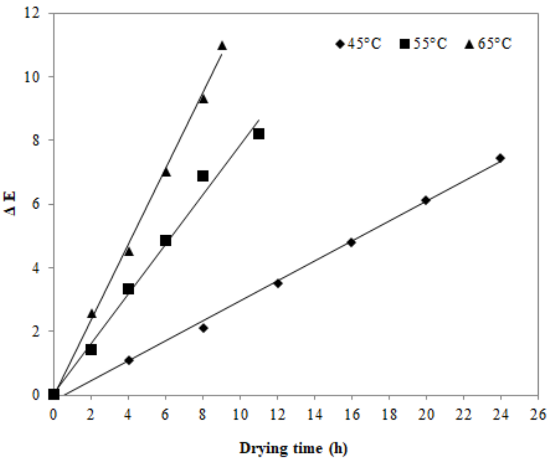

Figure 7. Kinetics of the ΔE values change at red pepper slices as a function of drying time at different air temperatures.

pumpkin samples at 5 mm thickness, 40 mm length and 20 mm width and dried them with three different methods as microwave, hot air and microwave assisted hot air. The researcher measured *L*, *a* and *b* values in fresh and dried samples and calculated the chroma and Hue angle values by using these values. According to the results, the *L* value of the samples dried with microwave assisted hot air was statistically different from the *L* value of the fresh samples. No significant difference observed between the Hue angle values of fresh pumpkin and microwave-assisted hot air-dried pumpkin samples. As a result, the researcher stated that the best drying method for drying pumpkin is microwave-assisted hot air drying in terms of color quality. In another study, banana samples were sliced with a thickness of 4.3±0.177 mm and dried by microwave, hot air and microwave-assisted hot air methods. Comparing the color values of the fresh and dried samples, the researcher found that the *L* and *b* values of the samples dried with microwave-assisted hot air were closer to the *L* and *b* values of the fresh banana samples (Maskan, 2000).

No obvious increase or decrease in color values other than *ΔE* values was detected during hot air-drying processes. Since a net trend increase in ΔE values was detected, kinetic calculations could only be made for this color value. When the kinetic data of the ΔE value in Table 4 is examined, it would be seen that the ΔE value fit the zero-order kinetic model. A graph which indicates that the ΔE values obtained from the drying processes of red pepper slices with hot air at different ambient temperatures fit the zero-order kinetic model is given in Fig. 7.

The findings obtained in the study are compatible with the literature data. Indeed, Aguerre and Suarez (1987) dried corn kernels at 57, 81 and 100°C with hot air and measured the color values of the samples during the drying process. As a result of the calculations, they stated that the change in ΔE value fits the zero-order kinetic model. Similarly, Rhim *et al.* (1989) applied the heat treatment of grape juice from 60°C to 95°C. The researchers measured the color values of the grape juice at certain periods throughout the process. As a result of the kinetic calculations, it was stated that the change in *ΔE* value fits to the zero-order kinetic model. When the zero-order kinetic model data of the *ΔE* value in Table 5 are examined, it is seen that the activation energy value is 59.82 kJ/mol. Similar results were obtained from the study of Barreiro *et al.* (1997) that examine the effect of heat treatment on color during the concentration of tomato pulp. As a result of the study, the researchers stated that the total color change of the tomato samples fits to the zero-order kinetic model and the activation energy was calculated as 42.64 kJ/mol. When Q_{10} values were examined, it was detected that the effect of increasing the drying temperature from 45°C to 55°C on the *ΔE* value was greater than the increase in temperature from 55°C to 65°C.

V. CONCLUSIONS

This study focused on the effect of hot air, microwave and microwave finish drying on the physical and chemical properties of the red pepper slices. Hot air followed by microwave finish drying increased the drying rate and reduced the drying time. The content of ascorbic acid was determined as 1507.75 mg/100g dry matter in fresh red peppers. On the other hand, ascorbic acid was not determined in red pepper samples after microwave drying, microwave finish drying at 65°C, and hot air drying at 65°C. In this respect, it is thought that lower temperatures (45°C-55°C) should be preferred for drying red peppers. The reason why ascorbic acid was not detected in red pepper samples dried by microwave drying method is thought to be high microwave power (780 W). In this respect, it may be recommended to carry out drying studies with lower power values for microwave drying. It had little effect on the color of finished products as compared to the hot air and microwave drying methods.

In this study, the degradation kinetics of ascorbic acid in red pepper slices during hot air drying was also investigated. The first-order reaction was best fitted to the degradation of ascorbic acid. The reaction rate was greatly influenced by the temperature during hot air drying. The Page and Modified Page models, which gave higher the correlation coefficient and lower reduced Chi square and RMSE, were considered the best for explaining the hot air drying of red pepper slices.

The findings of this study are to give an idea to the producers about the design of the red pepper drying process, the advantages and disadvantages of microwave finish drying, the optimization of the process parameters. Moreover, as a result of the study, it is thought that 45°C+ 780 W drying process will be suitable for drying red peppers in terms of both time and quality parameters.

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