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Assessment of pretreatments on drying kinetics and quality characteristics of thin-layer dried red pepper

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Abstract: In this study, the effect of pretreatments (hot water blanching, microwave blanching, and ohmic heating) on the drying kinetics and quality characteristics of red pepper, dried at 60 and 70 °C, was investigated. The drying times varied between 205–290 min, depending on the pretreatment and temperature applied. The drying rate also changed based on the pretreatment and the falling rate period was observed. Four mathematical models were fitted to experimental data and the logarithmic model was found to be the best for all of the samples. Effective moisture diffusivity values obtained from Fick's second law of diffusion ranged from 6.11×10^{-10} to 9.31×10^{-10} m^2 s^{-1}. The total phenolic contents, antioxidant capacities, and red pigment amounts of the dried peppers varied between 6.95 and 9.45 mg GAE g^{-1}dry matter (DM), 2610.43 and 4463.96 mmol AEAC 100 g^{-1}DM, and 184 and 443mg 100 g^{-1}DM, respectively. Rehydration ability of pretreated samples was similar to or slightly lower than that of the untreated samples. As a result, it can be suggested that ohmic heating before drying at a temperature of 70 °C could be a promising alternative pretreatment to decrease drying time and produce high-quality dried red pepper.

Keywords: Antioxidant capacity, drying kinetics, ohmic heating, red pepper, red pigment, total phenolics

1. Introduction

Red pepper (*Capsicum annuum* L.) is a rich source of bioactive compounds and is widely used as a food additive and food ingredient to provide spicy flavor and attractive color to food preparations and products (Won et al., 2015; Deng et al., 2018; Yang et al., 2018), such as sauces, soups, pizza, and pickles (Sharma et al., 2015). Fresh peppers are perishable and have a short shelf life due to their high moisture content. Drying is the most widely used method for red pepper processing (Yang et al., 2018). Although drying with conventional air is the most common method, the length of drying time, due to low rates of moisture removal from fruits and vegetables and thus, low energy efficiency (Jabeen et al., 2015; Deng et al., 2018), are the most important disadvantages of this method (Salengke and Sastry, 2005). At the same time, it can adversely affect the quality parameters of the final product, such as color, texture, and rehydration ability. Therefore, it is important to find alternatives to increase the rate of moisture removal during the drying process (Salengke and Sastry, 2005). Pretreatments play an important role in the acceleration of the drying rate in many fruits and vegetables (Srimagal et al., 2017). Some common treatments used prior to drying include hot water blanching (HWB) (Sharma et al., 2015), chemical dipping (Delfiya et al., 2017), microwave blanching (MWB) (Sabry et al., 2016; Srimagal et al., 2017) ohmic heating (OH) (Salengke and Sastry, 2005), ultrasound (US) (Mothibe et al., 2011), and pulsed electric field (PEF) (Won et al., 2015).

In recent years, to reduce both the drying time and the energy consumption of the drying process, and to improve product quality, a number of novel pretreatment technologies have been developed and studied (Sabry et al., 2016), in addition to conventional methods. MW-pretreated vegetables were found to have better nutritional quality in comparison with HWB-treated vegetables because of advantages such as shorter processing periods and improved heating efficiency (Nayak et al., 2018). Previous studies have shown that MWB increased the drying rate of carrot during the drying period and thus, reduced the drying time (Sabry et al., 2016; Delfiya et al., 2017). OH as an alternative processing method also has several advantages when compared to a conventional hot water process, including fast and uniform heating, less energy consumption, better product quality, less soluble nutrient loss, and less water usage (0.5 kg of water per kg of food product) (Bhat et al., 2017). It was reported that the drying rate of vegetable tissue was accelerated with

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OH pretreatment (Zhong and Lima, 2003), causing electroporation of the cell membranes by solubilizing the pectin substances, which resulted in migration of the moisture more easily (Deng et al., 2019).

According to the literature data, even though considerable work (Zhong and Lima, 2003; Salengke and Sastry, 2005; Won et al., 2015; Sabry et al., 2016) has been conducted on the impact of pretreatment and/or temperature on drying kinetics and some quality parameters of fruits and vegetables, no scientific work has been published related to the effects of novel pretreatments and temperatures on quality properties such as the polyphenol content, antioxidant capacity (AC), red pigment, and rehydration behavior of red pepper, as well as drying kinetics. Therefore, the present investigation was undertaken to evaluate the effect of conventional pretreatment (HWB), novel pretreatments (MWB and OH), and the drying temperature on the drying kinetics and quality properties of dried red pepper. One of the important points in drying technology is the modelling of the drying process. Appropriate drying kinetics are needed to estimate the drying rate and optimize the drying parameters (Cruz et al., 2015; Naderinezhad et al., 2016). Drying kinetics is also affected by the process conditions, such as air temperature and velocity (Song et al., 2009). For this reason, in this study, 2 drying temperatures (60 and 70 °C) were selected.

2. Materials and methods

2.1. Sample preparation

Fresh, high-quality Filkulağı variety red peppers of uniform color and size were purchased from a local store in Bursa, Turkey. They were kept at 4 °C before the experiments were conducted. Just before drying, the red peppers were washed well under running tap water and blotted with towel paper. Next, the stems were removed and the peppers were manually cut into halves along the pepper axis. After removing the seeds and placenta, each half was cut into squares with dimensions of 12.2 × 12.2 mm using a manual chopper, mixed well, and divided into 4 portions (about 30 g each). As a next step, 1 portion was retained as the control (untreated), while the others were subjected to 3 different treatments prior to drying in a convective dryer, in triplicate, as given below. Pretreatment conditions were determined with a preliminary experiment and peroxidase inactivation test. For all of the pretreatments, 0.25% table salt was used as a blanching medium with 220 s as the treatment time. After the pretreatments, all of the samples were drained off rapidly, rinsed gently, cooled under running water, and then blotted with towel paper to remove surface water.

2.2. Pretreatments

2.2.1. HWB

The peppers were blanched in the salt solution that had just reached the desired temperature (about 95 °C) in a stainless steel pot. The product to salt solution ratio (w/w) was approximately 1:10.

2.2.2. OH

Blanching of the peppers was performed in an OH chamber, which consisted of rectangular plexiglass (15 × 6.6 × 8 cm) and 2 planar AISI 304 stainless steel electrodes (14.5 × 8 cm). The chamber had a capacity of 500 mL. The temperature was measured with type-K thermocouples coated with Teflon to prevent interference from the electrical field, which were inserted into the center of the sample. The electrodes of the OH were connected to a variac (50 Hz, 0–600V, 25A) (Artsan Energy and Test Instruments, İstanbul, Turkey) (Figure 1). All of the the output data (current, voltage, temperature, etc.) were recorded at 1-s intervals on a data logger, with special software, and monitored on a computer. Pepper samples were placed between 2 stainless steel electrodes inside of the treatment chamber. The distance between the electrodes was adjustable and fixed at 14 cm to obtain the desired voltage in this study. The table salt solution was added to the chamber to insure better contact between the electrodes and the sample. The sample to liquid ratio in the treatment chamber was approximately 1:10 (w/w). Red pepper samples were treated with electric field strengths of E =16 V cm^{-1}.

2.2.3. MWB

Blanching was performed in a Bosch HMT812B/01(600 W, 2.45 GHz) microwave oven (Robert Bosch GmbH, Gerlingen, Germany). The product to salt solution ratio (w/w) was 1:5.

2.3. Drying process

The drying process was carried out at 60 and 70 °C in 20% relative humidity using a convective cabinet-type laboratory drier (Yücebaş Machine Analytical Equipment Industry Y35, İzmir, Turkey). The initial moisture content of the red pepper was measured using a Sartorius MA150 infrared moisture analyzer (Sartorius Stedim Biotech GmbH, Göttingen, Germany) at 105 °C. Prior to placing the sample in the drying cabinet, the system was run for at least 1 h to allow it to stabilize. About 20 g of peppers were distributed uniformly on greaseproof paper of a known weight as a thin layer. During the drying period, samples were weighed for a short time with a Mettler Toledo MS3002S digital weighing device (Mettler-Toledo Inc., Columbus, OH, USA) at an accuracy of ±0.01 g, at various time intervals ranging from 30 min at the beginning of the drying cycle to 5 min at the later stages of the drying process. Weighing of the samples was done manually outside of the dryer until their moisture content reached below 10%, which was considered a safe level for long-term storage (Wang et al., 2017) and acceptable for commercial dry product (Zhou et al., 2016). All of the drying experiments were performed in triplicate.

2.4. Moisture content

During drying of the pepper samples at different temperatures, the moisture content at any time of t was calculated as in Eq. (1):

$$Mt = \frac{m - DM}{DM}. \quad (1)$$

Here, Mt: is the moisture content at any time of t [g water per g dry matter (DM)] and m: is the mass (g).

2.5. Drying rate

To calculate the drying rate (g water g^{-1}DM min), an appropriate empirical equation was fitted to the experimental moisture removal data, and then differentiated with respect to time using Eq. (2):

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

Here,M_{t+dt}: is the moisture content at $t+dt$ (g water per g DM) and dt: is the time between 2 sample weighings (min).

2.6. Moisture ratio

The moisture ratio (MR) was calculated from the weight changes of the samples and these values were used in the modelling related to the drying kinetics, as in Eq. (3):

$$MR = \frac{M_t - M_e}{M_o - M_e}. \quad (3)$$

Here, MR: is the moisture ratio (dimensionless), M_t: is the moisture content at any time of t (g water per g DM), M_o: is the initial moisture content (g water per g DM), and M_e: is the equilibrium moisture content (g water per g DM).

2.7. Mathematical modelling

Four thin-layer drying models, commonly cited in the literature, were tested to describe the drying characteristics of the pepper samples (Table 1). The best model describing the thin-layer drying characteristics of pepper was chosen as the one with the lowest chisquare ($\chi 2$) and root mean square error (RMSE), and the highest (R^2). Constants k and n of the model equations below were evaluated through nonlinear regression analysis using MINITAB (16) software (Minitab Inc., State College, PA, USA) (Faustino et al., 2007).

Model validation was also performed to determine the suitable model. For this purpose, the averages of 2 data sets were used to build the model and the validation was achieved by applying the nonlinear regression method using the third data set. Model parameters were calculated using Eqs. (4) and (5) (Walther and Moore, 2005), as follows:

$$\mathrm{RMSE} = \left[\frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{MR}_{\mathrm{pred,i}} - \mathrm{MR}_{\mathrm{exp,i}}\right)^2\right]^{\frac{1}{2}}, \quad (4)$$

$$\chi^2 = \frac{\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{MR}_{\mathrm{pred,i}} - \mathrm{MR}_{\mathrm{exp,i}}\right)^2}{\mathrm{N} - \mathrm{z}}. \quad (5)$$

Here, N is the number of observations, z is the number of drying constants, $MR_{exp,i}$ is the experimental MR of the ith data, and $MR_{predi,i}$: is the predicted MR of the ith data.

2.8. Effective moisture diffusivity

The Ficks second diffusion equation has been widely applied to describe the mass transfer by diffusion during the falling rate drying period. For calculation of effective diffusivity, red pepper was considered as a homogeneous infinite slab and the thickness of the slab was regarded as the distance of moisture migration in the drying process (Deng et al., 2018). The relationship between the MR and effective moisture diffusivity (D_{eff}) can be expressed as in Eq. (6) (Rayaguru and Routray, 2012):

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (6)$$

Where D_{eff} is the effective moisture diffusivity in m^2s^{-1}, t is the time of drying in s, and L is half of the thickness of red pepper in m (average of 2.4×10^{-3} m in this study).

By plotting the logarithm of the experimental MR values (lnMR) versus the drying time, a straight line was obtained and the D_{eff} was calculated as in Eq. (7) (Cruz et al., 2015; Beigi, 2016):

$$D_{eff} = -k\frac{4L^2}{\pi^2} \quad (7)$$

where k is the slope of the line.

2.9. Extraction of the total polyphenols and antioxidants

Dried (0.2 g) and fresh (1.0 g) samples were extracted with 80% aqueous methanol (4.5 mL) on a mechanical shaker for 2 h. The mixture was centrifuged (Sigma 3K30, Sigma-Aldrich Corp., St. Louis, MO, USA) at 10,000 rpm for 15 min and the supernatant was decanted into polypropylene tubes. The pellets were extracted under identical conditions. Supernatants were combined and filtered through Whatman No.1 filter paper. The clear extracts were analyzed for both determination of the total phenolic content (TPC) and AC.

The TPC was determined using the Folin-Ciocalteu method (Obanda and Owuor, 1997) from a calibration curve of gallic acid (R^2 = 0.99) as mg of gallic acid equivalents per g of DM. The AC was determined using the 2,2,diphenyl-2-picryl-hydrazyl (DPPH) method of Turkmen et al. (2005) and standard curve of reference antioxidant ascorbic acid (0–20 µg mL^{-1}) was assayed under identical conditions for its affinity to scavenge

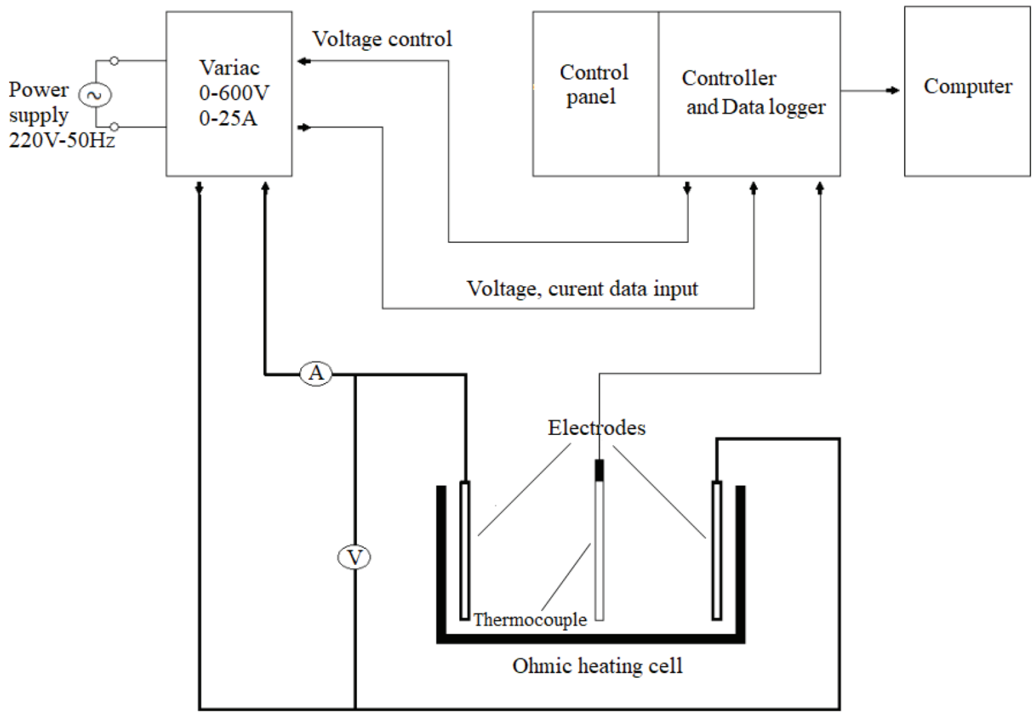

Figure 1. Schematic diagram of the OH system.

Table 1. Thin-layer drying models fitted to the experimental data.

Model name	Equation	Reference
Newton	$MR = \exp(-kt)$	Ayensu (1997); Roberts et al. (2008)
Page	$MR = \exp(-kt^n)$	Sobukola and Dairo (2007); Hassan-Beygi et al. (2009)
Logarithmic	$MR = a\exp(-kt) + c$	Yagcioglu (1999)
Henderson and Pabis	$MR = a\exp(-kt)$	Diamante et al. (2010)

k: (min^{-1}): drying rate constant; t: drying time (min), a, n, c: constant in the model.

DPPH. The AC of the samples was converted to the ascorbic acid equivalent (AEAC), defined as mmol of ascorbic acid equivalents per 100 g of DM.

2.10. Red pigment

Red pigment was determined by the methods described previously by Yang et al. (2018) and Wang et al. (2017) with some modifications. The amount of red pigment was calculated using Eq. (8) (Delfiya et al., 2017):

$$X = (A \times V \times 1000) / (A_{1\,cm}^{1\%} \times 100). \quad (8)$$

Here, X is the red pigment content in mg, A is the absorbance of the extract, V is the volume of the solution in mL, and $A_{1\,cm}^{1\%}$: is the specific absorption coefficient (2250 for paprika red pigment).

2.11.Rehydration capacity and rehydration ratio

The rehydration test was performed according to the methods of Vega-Gálvezet al. (2009) and Delfiya et al. (2017). To determine the rehydration capacity (RC) of the dried peppers, the sample was placed in a beaker containing distilled water at a ratio of 1:50 (w/w) at 25 °C, mixed thoroughly, and allowed to rehydrate for 6h. At the end of the rehydration period, the samples were drained, blotted with tissue paper to remove surface water, and weighed. The RC, which is the absorbed water (rehydration), was determined using Eq. (9) (Singh et al., 2000):

$$RC = (\textit{regained moisture,g}) / (\textit{initial moisture,g - residual moisture,g}) \quad (9)$$

The rehydration ratio (RR) was determined using Eq. (10) (Mothibe et al., 2014; Delfiya et al., 2017):

$$RR = Wr/Wd. \quad (10)$$

Here, Wr is the weight of rehydrated samples (g) and Wd is the weight of the dried samples (g).

2.12. Statistical analysis

All data were expressed as the mean ± standard deviation of triplicate measurements and analyzed using IBM

SPSS Statistics 23.0 (IBM Corp., Armonk, NY, USA). Experimental data were analyzed using ANOVA to evaluate the effect of the pretreatment and drying temperature on the quality characteristics of red pepper. Statistical analyses were performed using the general linear model procedure. Means were compared using the Duncan multiple comparison test. Values of $P < 0.05$ were considered as significantly different ($\alpha = 0.05$).

3. Results and discussion

3.1. Drying kinetics

3.1.1.Moisture ratio

Effects of the pretreatment and temperature on the drying time of the red pepper samples are presented in Table 2. The results showed that the pretreatment and air temperature had an effect on the drying time. Initial moisture contents of the untreated, HWB-, MWB-, and OH-treated peppers were 8.17, 9.00, 8.91, and 9.11 g water g^{-1} DM, respectively. Red peppers were thin-layer dried at 60 and 70 °C in a hot-air drier to a final average moisture content of 0.057 g water g^{-1} DM. In comparison with the pretreatments, the control samples required a longer drying time (315 min). Among all of the pretreatments applied, while the longest drying time (290 min) was observed in the OH-treated pepper dried at 60 °C, the shortest drying time (205 min) was determined in the MWB-treated sample dried at 70 °C. The increase in drying temperature for the control and pretreated pepper samples resulted in a reduction in the drying time, which was in agreement with the results of a previous study (Zhou et al., 2016). By increasing the temperature from 60 to 70 °C, reductions in the drying time of the control, HWB-, MWB-, and OH-treated peppers were 11.11%, 21.82%, 24.07%, and 27.59%, respectively. The results indicated that the shortest drying time for both temperatures, when compared to the control group, was observed in the MW-treated samples.The result was in agreement with that of Sabry et al. (2016), who reported that MW pretreatment considerably reduced the drying time of carrot slices. Similarly, Srimagal et al. (2017) reported that HWB and MWB reduced the drying time due to their ability to alter the cell wall structure and form pores in the tissues, enabling increased water diffusion from interior to surface during drying. This possible reason was also reported by Delfia et al. (2017).

Table 2. Drying time of the red pepper samples dried at different temperatures.

Temperature (°C)	Samples	Drying time (min)
60	Control	315
	HWB	275
	MWB	270
	OH	290
70	Control	280
	HWB	215
	MWB	205
	OH	210

The changes in the MR of the pretreated and untreated pepper samples dried at different temperatures as a function of time are presented in Figure 2. For all of the samples, the MR decreased with an increase in the drying temperature, as expected. In addition, at the beginning of drying, the MR was very high and decreased as the time increased. Similar results were observed by Mothibe et al. (2014) and Won et al. (2015). This could be explained by increasing resistance to moisture diffusion inside of the material due to toughening of the outer layers of the product (Nadi and Tzempelikos, 2018).

3.1.2. Drying rate

The drying rate was calculated according to the logarithmic model and plotted against the moisture

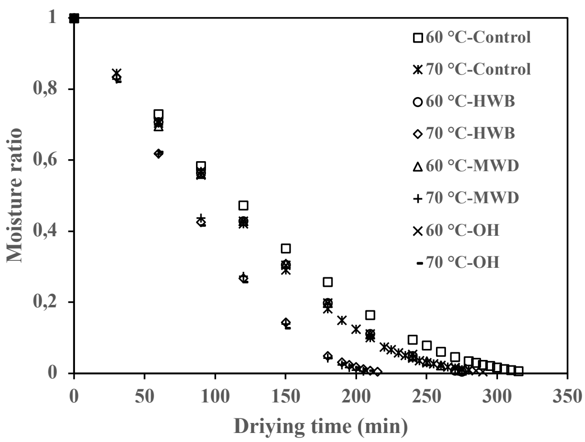

Figure 2. MR of the red pepper samples dried at different temperatures.

content (on a dry basis) in order to investigate the effects of the pretreatment and temperature on the drying rate of red pepper (Figure 3). It was decreased continuously due to decrease in moisture content, which caused a decrease in the moisture migration and evaporation rate from the surface of the product (Kaur et al., 2018). For the pepper samples, a constant rate period was not observed in the drying experiments. Therefore, the entire drying process occurred only in the falling rate period. This reason could be that the diffusion was a dominant physical mechanism governing moisture movement in the samples (Falade and Abbo, 2007). Therefore, reducing the moisture content and increasing the surface shrinkage of products during the drying process could cause decreasing heat penetration through the dried layer and thus, the decline in the drying rate (Cruz et al., 2015).

For all of the samples, as the temperature increased from 60 to 70 °C, the drying rate increased (Figure 3). This can be explained by increased heat transfer between the red peppers and their environment, resulting in an increased acceleration of water migration from the core to the surface of the peppers (Nadi and Tzempelikos, 2018). Moreover, it is known that decreased air relative humidity, as a result of increasing temperature, has a high drying potential (Doymaz and Aktas, 2018). Consequently, increased temperature accelerated the drying process, resulting in a decrease in the time required to draw out the moisture from the sample (Jabeen et al., 2015).

During the initial phase of drying, the highest drying rate (0.08001 g water g^{-1} DM min) was observed in the OH-treated peppers, dried at 70 °C, followed by the HWB-(0.07803 g water g^{-1}DM min) and MWB- (0.07283 g water g^{-1}DM min) treated peppers, and the control (0.05687 g water g^{-1}DM min), respectively (Figure 3). This showed that when compared with the control at the same temperatures, all of the pretreatments increased the drying rate of the pepper samples during hot-air drying. The result were in agreement with those of Salengke and Sastry (2005), who reported that the drying rates of OH-pretreated grapes were significantly higher than those of the untreated samples, due to the breakup of the grape skin during the ohmic pretreatment. Similarly, Mothibe et al. (2014) reported that cell structures were affected during different pretreatments, due to the fact that cell wall breakdown caused an increase in intercellular spaces.

3.2. Mathematical modelling

The model parameters and the statistics used to evaluate the suitability of the models are presented in Table 3. The

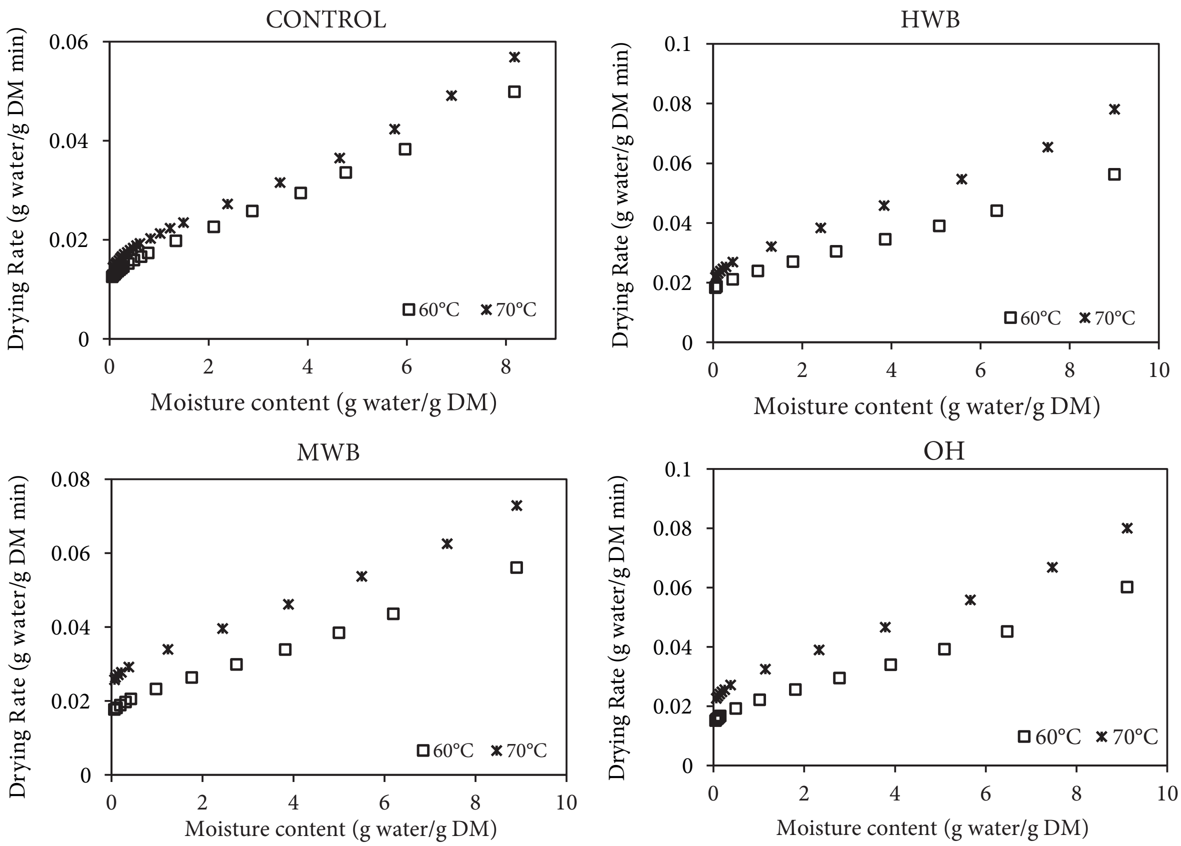

Figure 3. Drying rate of red pepper samples dried at different temperatures.

Table 3. Statistical results obtained from the modelling of the dried red peppers.

Temperature (°C)	Samples	Model	Coefficient	R^2	RMSE	χ^2
60	Control	Newton	k: 0.008354	0.9667	0.06974	0.00513
		Page	k: 0.000424, n: 1.57256	0.9962	0.02031	0.00046
		Logarithmic	a: 1.38307, k: 0.004392, c: 0.361583	0.9962	0.01806	0.00039
		Henderson and Pabis	a: 1.09605, k: 0.008865	0.9591	0.05020	0.002817
	HWB	Newton	k: 0.008377	0.9676	0.07101	0.00560
		Page	k: 0.000454, n: 1.58428	0.9960	0.02063	0.00053
		Logarithmic	a: 1.53967, k: 0.004044, c: 0.524115	0.9968	0.01800	0.00046
		Henderson and Pabis	a: 1.06943, k: 0.008841	0.9613	0.06677	0.00557
	MWB	Newton	k: 0.008749	0.9653	0.07148	0.00557
		Page	k: 0.000437, n: 1.59537	0.9942	0.02400	0.00069
		Logarithmic	a: 1.50303, k: 0.004190, c: 0.489035	0.9977	0.01505	0.00030
		Henderson and Pabis	a: 1.07582, k: 0.009228	0.9587	0.06743	0.00546
	OH	Newton	k: 0.008780	0.9648	0.07420	0.00596
		Page	k: 0.000441, n: 1.59283	0.9964	0.01935	0.00044
		Logarithmic	a: 1.37785, k: 0.004816, c: 0.35727	0.9952	0.02199	0.00063
		Henderson and Pabis	a: 1.07933, k: 0.009270	0.9578	0.06938	0.00569
70	Control	Newton	k: 0.009550	0.9706	0.06545	0.00448
		Page	k: 0.000369, n: 1.63498	0.9949	0.02408	0.00063
		Logarithmic	a: 1.42799, k: 0.004865, c: 0.39107	0.9955	0.01991	0.00046
		Henderson and Pabis	a: 1.11634, k: 0.010262	0.9629	0.04552	0.00227

Table 3. (Continued).

70	HWB	Newton	k: 0.011987	0.9689	0.07687	0.00640
		Page	k: 0.000538, n: 1.64962	0.9980	0.01503	0.00027
		Logarithmic	a: 1.47421, k: 0.005857, c: 0.443724	0.9948	0.02498	0.00081
		Henderson and Pabis	a: 1.09878, k: 0.012820	0.9616	0.06955	0.00571
	MWB	Newton	k: 0.011538	0.9701	0.08076	0.00717
		Page	k: 0.000506, n: 1.65802	0.9960	0.02620	0.00084
		Logarithmic	a: 1.63569, k: 0.004940, c: 0.610574	0.9969	0.02026	0.00056
		Henderson and Pabis	a: 1.0938, k: 0.012360	0.9630	0.07436	0.00676
	OH	Newton	k: 0.012047	0.9662	0.08119	0.00719
		Page	k: 0.000613, n: 1.62802	0.9964	0.02115	0.00054
		Logarithmic	a: 1.44607, k: 0.006134, c: 0.417064	0.9949	0.02474	0.00082
		Henderson and Pabis	a: 1.09181, k: 0.0128531	0.9590	0.07774	0.00739

logarithmic model mostly provided the highest R^2 values and the lowest $\chi 2$ and RMSE values; hence, it was found to be the best for describing the drying characteristics of the red pepper samples according to these values. On the other hand, the page model values were close to those of the logarithmic model. The drying rate constant k, which increased with an increase in the drying temperature, indicated that the drying kinetics were dependent on the temperature. Similar observations have been reported by other researchers (Kaur et al., 2018).

Validation of the selected model was confirmed by comparing the predicted moisture contents with the measured values for the different drying temperatures and pretreatments. The plot of the experimental versus predicted MR by the logarithmic model isshown in Figure 4. The data points were closely banding around the 1:1 line, which indicated very good agreement between the calculated and experimental data ($R^2 > 0.99$). Therefore, the logarithmic model could adequately describe the drying behavior of the red pepper and thus, the change in the moisture content of the product could be estimated to be close to the experimental data using this model.

3.3.Effective moisture diffusivity

The values of the D_{eff} coefficients were calculated using Eq.(7) and are presented in Table 4. The D_{eff} values varied from 6.11×10^{-10} m² s⁻¹ for the untreated red pepper dried at 60 °C to 9.31×10^{-10} m^2 $s^{-1}$for the HWB-treated sample dried at 70 °C. The obtained values were comparable with the reported values of 1.33×10^{-10} to 8.97×10^{-10} m^2 $s^{-1}$and 5.01×10^{-10} to 8.32×10^{-10} m^2 s^{-1} for red pepper by Deng et al. (2018) and Di Scala and Crapiste (2008), respectively. On the other hand, Darvishi et al. (2014) determined D_{eff} values in the range of 8.32×10^{-8} to 2.36×10^{-7} m^2 s^{-1} for microwave drying of green pepper. Faustino et al. (2007) also reported that the D_{eff}values ranged between 9.0×10^{-10} and 8.0×10^{-9} m^2 s^{-1} for hot-air-dried green bell pepper at different temperatures.The differences between the results can be explained by the effect of some factors, such as the type and composition of the materials and the drying methods.

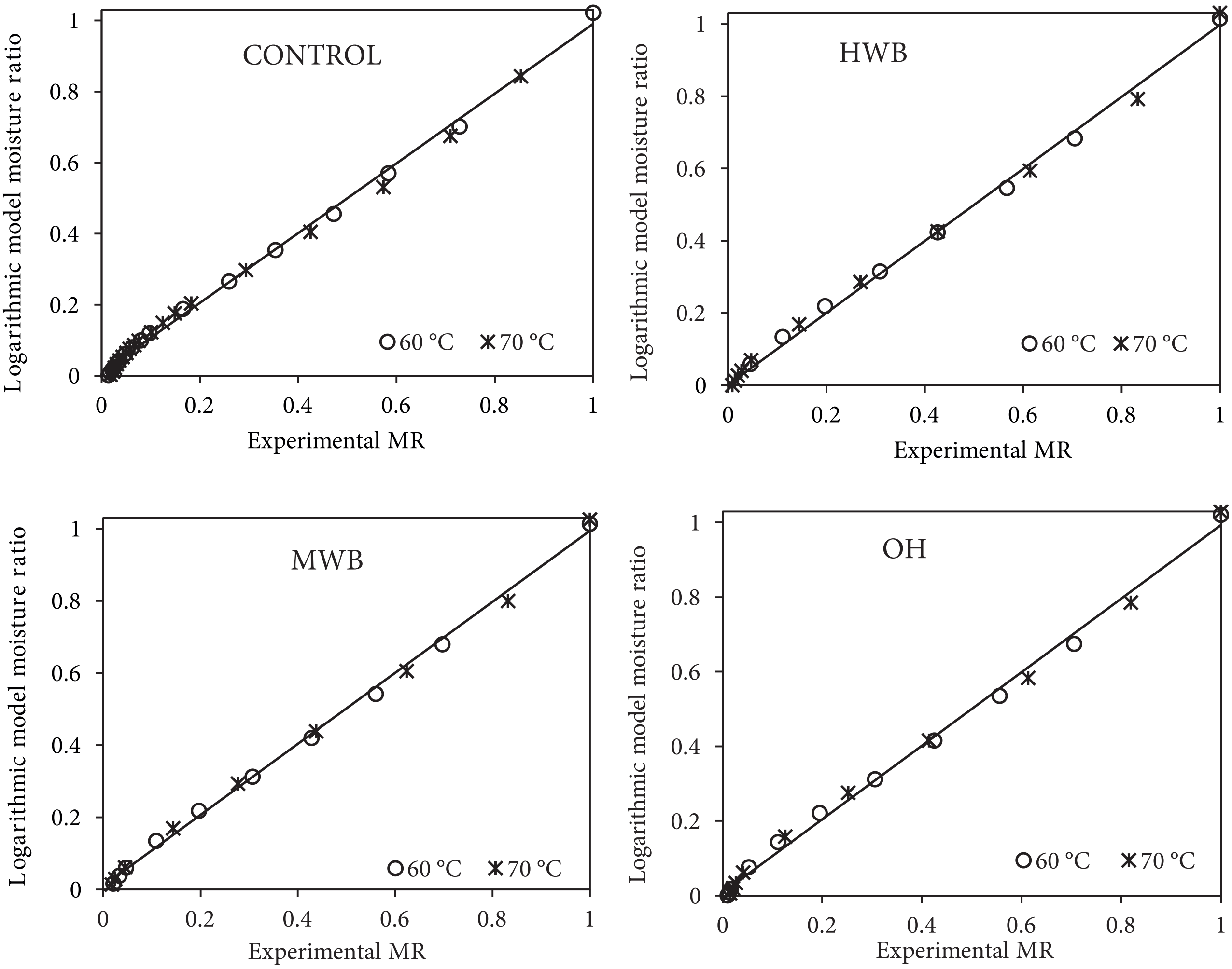

Figure 4. Experimental and predicted (from the logarithmic model) MR values for the different temperatures and pretreatments.

Table 4. D_{eff} values of the red pepper samples dried at different temperatures.

Temperature (°C)	Samples	D_{eff} ($\times 10^{-10} m^2 s^{-1}$)
60	Control	6.11
	HWB	7.05
	MWB	6.70
	OH	7.21
70	Control	6.54
	HWB	9.31
	MWB	9.27
	OH	9.19

It can be concluded that an increment in the drying temperature caused an increase in the D_{eff} values, which was in agreement with the findings of previous studies (Cruz et al., 2015; Deng et al., 2018). This could have been due to the fact that the movement of water molecules is accelerated when the temperature increases,resulting in higher moisture diffusivity (Deng et al., 2018).

As seen in Table 4, the D_{eff} values for the pretreated samples were higher in comparison with the untreated samples. Similarly, Won et al. (2015) found that PEF pretreatment for red pepper increased the D_{eff} values when compared to the untreated control, owing to higher cell membrane disruption.

3.4. Total polyphenol content and antioxidant capacity

The TPC of the dried pepper samples is shown in Table 5. The initial TPC of the fresh red pepper was 18.13 mg gallic acid equivalents (GAE) g^{-1} DM. This was in agreement with the results of Shaimaa et al. (2016), who found that the TPC of some red peppers were in the range of 13.96 to 28.43 mg GAE g^{-1} DW. However, this result differed from the findings of Zhou et al. (2016), who found that the initial TPC in fresh red pepper was 7.06 mg GAE

g^{-1}DM, which was markedly lower than those obtained from the present study. There are many factors influencing the concentration of TPC in foods, such as the growing conditions, variety, and ripening stage (Chavez-Mendoza et al., 2015).

The results revealed that after drying, the TPC of the red pepper samples decreased considerably when compared to the fresh samples, as also observed by Reis et al. (2013) for red pepper, which could have been due to the chemical degradation of phenolic compounds during drying (Vega-Gálvez et al., 2008; Reyes et al., 2011; Önal et al., 2019). Additionally, polyphenols are affected by hydrolysis and oxidation reactions. Polyphenol oxidases (PPO) catalyze the oxidation of phenolic compounds in fruits (Sturm et al., 2012). Damage to the cell membrane releases the enzyme and therefore, activates it (Reis et al., 2013). For this reason, under the experimental conditions herein (at drying temperatures of 60 and 70 °C), the PPO activity could have remained high for longer periods depending on the pretreatments, due to the fact that higher temperatures, such as 75–80 °C, are needed to inactivate the enzyme (Madrau et al., 2009). On the contrary, Ruttarattanamongkol et al. (2016) and Lutz et al. (2015), respectively, reported an increase in the TPC after drying in sweet potatoes and apples. This was attributed to the release of phenolic compounds from the food matrix during the drying process (Multari et al., 2018) or the formation of Maillard reaction products, which could cause new phenolic compounds to form from precursors (Önal et al., 2019).

As seen in Table 6, the pretreatment and temperature significantly affected the TPC of the dried red peppers. After drying at 70 °C, there were no significant differences between the TPC of the control and any of the pretreated red peppers. There are limited studies about the effects of pretreatments on the TPC of various fruits and vegetables; however, there are no studies about the effects of pretreatments on the TPC of dried red pepper. According to Sharma et al. (2015), there was no difference between the TPC of red bell pepper streated with blanching and those with chemical pretreatments. These pretreatments retained the TPC of the pepper samples significantly. Guida et al. (2013) reported that the blanching of artichoke heads by ohmic treatment resulted in an increase of about 29%

Table 5. TPC, AC, and red pigment values of the dried red pepper samples.

Temperature (°C)	Samples	TPC (mg GAE g^{-1}DM)	AC (mmol AEAC 100 g^{-1}DM)	Red pigment (mg 100 g^{-1}DM)
60	Control	8.62 ± 0.23^b	4368.60 ± 198.38^b	215.97 ± 8.99^a
	HWB	6.95 ± 0.63^a	2836.91 ± 124.45^a	422.14 ± 9.85^c
	MWB	8.23 ± 0.06^b	2610.43 ± 77.94^a	314.95 ± 9.60^b
	OH	8.48 ± 0.36^b	3939.49 ± 122.29^b	443.07 ± 14.82^c
70	Control	9.45 ± 0.54^a	4463.96 ± 156.33^b	184.00 ± 8.57^a
	HWB	8.44 ± 0.24^a	3140.86 ± 239.96^a	287.78 ± 14.58^b
	MWB	8.68 ± 0.24^a	2675.99 ± 131.12^a	283.78 ± 13.45^b
	OH	8.92 ± 0.26^a	4148.08 ± 274.87^b	320.55 ± 6.96^b

Values in the same column with the same letter for each parameter were not significantly different at a confidence level of 95%.

Table 6. Variance analysis results for the effect of drying temperature, pretreatment, and their interactions on the TPC, AC, and red pigment of the dried peppers.

Sources of variation		TPC		AC		Red pigment	
	DF[a]	MS[b]	F	MS	F	MS	F
Temperature	1	3.871	9.204*	170,084.538	1.810	38,510.392	102.173*
Pretreatment	3	1.948	4.633*	4,256,944.205	45.293*	38,742.266	102.788*
Temperature× pretreatment	3	0.361	0.859	17,951.074	0.191	4751.608	12.607*

a: Degree of freedom; b: mean squares; *: significance at P < 0.05.

in the TPC, while conventional blanching of the samples caused a decrease of about 27% in the TPC.

The AC of the dried pepper samples varied from 2610.43 to 4463.96 mmol AEAC 100 g^{-1}DM, as seen in Table 5. The initial value of the fresh red pepper was 9595.37 mmol AEAC 100 g^{-1} DM. The AC of the dried samples showed a similar trend to that of the TPC and decreased markedly when compared to fresh sample. This was in accordance with Blanco-Rios et al. (2017), who reported a decrease in the antioxidant activity of red pepper after hot-air drying due to the result of the oxidation of phenolic compounds. A similar result was observed by Reyes et al. (2011) in apple. Blanco-Rios et al. (2017) also found significant correlations between the TPC and antioxidant activity in red peppers. As seen in Table 6, pretreatment, but not temperature, significantly affected the AC of the dried red peppers. After drying at both 60 and 70 °C, while the AC of the HWB- and MWB-treated peppers was significantly lower thanthat of the control samples, the AC of the OH-treated peppers was similar tothat of the control samples ($P > 0.05$). The decrease in AC, which was caused by the pretreatments,could have been related to increased membrane permeabilization,which increases the moisture migration rate and also facilitates the reaction of polyphenol oxidase during drying.

3.5. Red pigment

The red pigment content of the peppers under different pretreatments and temperatures is presented in Table 5. The content in the fresh samples was 333.56 mg 100 g^{-1} DM.Among all of the pepper samples, only the OH- and HWB-treated samples dried at 60 °C had higher red pigment contents than the fresh sample. It was obvious that the red pigment content of the pepper was dependent on the pretreatmentand temperature(Table 6). In the case of drying at 70 °C, regardless of the pretreatment applied, the red pigment content of all of the dried peppers was lower than that of the fresh ones. This result was agreement with the results of Yang et al. (2018),who reported that natural pigment degradation was accelerated at high temperatures.

Pretreatment, temperature, and their interactions together significantly affected the red pigment content ($P < 0.05$). Atboth drying temperatures, the pretreatments resulted in higher red pigment contents when compared to the control group (Table 5, Figure 5), which was in agreement with findings of earlier studies (Won et al., 2015; Deng et al., 2018).This might have been due to the shorter drying time of the pretreated peppers; thus, reducing exposure to oxygen and heat. The reason was probably that pretreatment can damage the cell wall of the products where pigments accumulate; hence, this enhances pigment extraction (Deng et al., 2019). The red pigment contents of the peppers treated with OH and HWB were higher than those treated with MWB for 60 °C ($P < 0.05$). Nevertheless, there was no significant difference between any of the pretreated samples at 70 °C. In Table 5, it can also be seen that the increase in temperature from 60 to 70 °C resulted in a reduction in the red pigment contents of all of the samples. The reason may have been deterioration in the carotenoids as a result of the high drying temperatures (Vega-Galvez et al., 2009; Tunde-Akintunde et al., 2014).

3.6. Rehydration capacity and rehydration ratio

The RC and RR values of the dried peppers were in the range of 0.49–0.61 and 4.77–5.66, respectively (Table 7). Similarly, Singh et al. (2000) reported that the highest RC for green bell pepper was 0.47. The maximum RRs for red pepper were reported as 4.48 and 4.9 by Deng et al. (2018) and Delfiya et al. (2017), respectively, which was in agreement with the results of the current study. Pretreatment significantly affected the RC and RR values of the red pepper (Table 8). At 60 °C, while the lowest RC and RR values were obtained in the HWB-treated samples, there were no significant differencesbetween the values of the other samples ($P < 0.05$). However, at 70 °C, no significant differences were observed between RC and RR values of any of the samples (Table 7). These results contradicted those of Tunde-Akintunde et al. (2014), who observed that the rehydration indices for pretreatments were generally higher than that of untreated pepper samples.The low RC

(a) (b) (c) (d)

Figure 5. Color of the dried red peppers (a: MWB, b: control, c: OH, d: HWB).

Table 7. RC and RR values of the dried pepper samples.

Samples	RC		RR	
	60 °C	70 °C	60 °C	70 °C
Control	0.61 ± 0.01[b]	0.56 ± 0.01[a]	5.66 ± 0.11[b]	5.26 ± 0.09[a]
HWB	0.49 ± 0.02[a]	0.56 ± 0.02[a]	4.77 ± 0.13[a]	5.31 ± 0.01[a]
MWB	0.59 ± 0.02[b]	0.55 ± 0.01[a]	5.43 ± 0.22[b]	5.16 ± 0.10[a]
OH	0.55 ± 0.02[ab]	0.57 ± 0.02[a]	5.18 ± 0.11[ab]	5.45 ± 0.12[a]

Values in the same column with the same letter for each temperature were not significantly different at a confidence level of 95%.

Table 8. Variance analysis results for the effect of drying temperature, pretreatment, and their interactions on the RC and RR of the dried peppers.

Sources of variation		RC		RR	
	DF[a]	MS	F	MS	F
Temperature	1	0.00002807	0.033	0.006	0.150
Pretreatment	3	0.004	4.852*	0.183	4.222*
Temperature× pretreatment	3	0.004	5.013*	0.296	6.812*

a: Degree of freedom; b: mean squares; *: significance at $P < 0.05$.

observed in the HWB-treated samples could have been due to the fact that the pretreatments resulted in different structural changes and greater shrinkage and thus, slow moisture transfer during rehydration.

The drying temperature had no significant influence on the RC and RR values of the red pepper, as seen in Table 8. On the contrary, Vega-Gálvez et al. (2009) reported that at a drying temperature of 90 °C, which was higher than the temperatures studied in the current study, the RR was affected, since the absorbed water decreased with temperaturedue to cellular structure damage.

4. Conclusion

In this study, the influence of pretreatment on the dying kinetics and other properties of red pepper dried at different temperatures was investigated. The results showed that the drying kinetics of red pepper were significantly affected by pretreatment and temperature. The OH pretreatment and 70 °C drying temperature had a positive effect on the drying rate. Thin-layer drying of red pepper took place in the falling drying rate period. The logarithmic model was found the best to describe the drying behavior of the peppers for thin-layer drying conditions. The highest TPC, AC, red pigment, and rehydration ability were determined in the OH-pretreated samples. While all of the variation sources affected only the red pigment levels, the temperature and pretreatments had an impact on the TPC. The drying temperatures exhibited no significant difference on theAC of the red peppers. These results demonstrated the importance of pretreatments and process parameters on the drying and quality characteristics of vegetables. Consequently, OH as a pretreatment and drying at 70 °C can potentially be used to reduce the drying time of red pepper, as well as to retain quality.

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