Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi 25 (2):271-283, 2020
(*Mustafa Kemal University Journal of Agricultural Sciences* 25 (2):271-283, 2020)
e-ISSN: 2667-7733
http://dergipark.org.tr/mkutbd

ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Comparing hot air drying kinetics and color quality of organic and conventional sweet red peppers

Organik ve konvansiyonel tatlı kırmızı biberlerin sıcak hava kurutma kinetiği ve renk kalitesinin karşılaştırılması

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MAKALE BİLGİSİ / ARTICLE INFO

Makale tarihçesi / Article history:
DOI: 10.37908/mkutbd.747675
Geliş tarihi /Received:03.06.2020
Kabul tarihi/Accepted:30.06.2020

Keywords:
Organic red pepper, hot-air drying kinetics, modeling, moisture diffusivity, activation energy, color.

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ÖZET / ABSTRACT

Aims: This study was conducted to compare the hot air drying kinetics and color quality of organically and conventionally produced sweet red peppers.
Methods and Results: The pepper samples were dried at 60, 70 and 80°C using a hot air dryer. Drying kinetics, effective moisture diffusivity (D_{eff}), activation energy (E_a) and color quality were studied. The drying process for both organic (OSRP) and conventional sweet red peppers (CSRP) occurred mainly in falling rate period. Increasing the drying temperature reduced the drying time considerably. Except 60°C, significant difference was found between the drying times of OSRP and CSRP samples. The Midilli model gave the best fit for all data points for pepper types. A positive relationship was found between the drying temperature and D_{eff} values (OSRP: 39.62×10^{-10} – 58.58×10^{-10} m^2 s^{-1}; CSRP: 38.92×10^{-10} – 57.59×10^{-10} m^2 s^{-1}). Differences between the D_{eff} values of OSRP and CSRP samples were not significant.
Conclusions: Characteristic drying curve profiles, D_{eff} and E_a values followed the similar trajectory showing that the growing practice of the peppers did not significantly change the structural features related to heat transfer. The hot-air drying at 70°C and 80°C gave brighter and redder pepper powders; hence, these treatments are suggested as the suitable drying applications to produce high quality OSRP and CSRP powders in terms of color quality. By using 80°C instead of 60°C, about 25% and 32% savings in drying times could be obtainable for CSRP and OSRP samples, respectively.
Significance and Impact of the Study: Organic production has an increasing trend in the world; however, research on the evaluation of drying kinetics and color quality of organic products is very limited. Thus, this study aimed at studying appraisal of the drying kinetics and related parameters of CSRP and OSRP samples.

Atıf / Citation: Arslan A, Soysal Y, Keskin M (2020) Comparing hot air drying kinetics and color quality of organic and conventional sweet red peppers. *MKU. Tar. Bil. Derg.* 25(2) : 271-283. DOI: 10.37908/mkutbd.747675

INTRODUCTION

Organic farming offers pesticide residue-free, healthy, and tasty products and carried out in an environmentally-friendly and socially responsible manner (Bickel and Rossier, 2015). Since organic fruits and vegetables are not subjected to synthetic chemical pesticides and fertilizers, they utilize more metabolic energy to synthesize secondary plant metabolites (Winter and Davis, 2006). Organic products have higher antioxidant activity, higher concentrations (18–69%) of desirable antioxidants/(poly)phenolics and other plant secondary metabolites and also, lower concentrations of agrochemical residues (75%) and cadmium (48%) which all related to chronic and neurodegenerative diseases and certain cancers (Gomiero, 2018). Brandt et al. (2011) also stated that the content of secondary metabolites in organic produce was 12% higher than that of the conventional samples. Organic farming tends to increase both in the world (31.5 million ha in 2007 and 69.8 million ha in 2017) and in Turkey (0.17 million ha in 2007 and 0.54 million ha in 2017) that ranked 17 in the world in terms of organic farmland (TurkStat, 2018; Lernoud and Willer, 2019).

Peppers (*Capsicum annuum* L.) are grown in open arable farming areas or in greenhouses in almost every region of the world. Pepper fruit is an important source of food, medicinal and industrial products as it is an inexpensive source of vitamins, minerals and fiber (Moraes et al., 2013). It is consumed fresh or dried for the inclusion in spices, pastes, natural colorants, soups, sauces and oleoresin (Soysal et al., 2009). The total chillies and pepper production was about 36.8 million tonnes in the world in 2018 and Turkey ranked third after China and Mexico with 7.1% of the global production (FAOSTAT, 2020). Organic pepper is also produced in significant amounts in Turkey (5558 tonnes in 2018) (TMAF, 2020).

Moisture content of fresh agricultural products is reduced by using numerous drying techniques. Modern drying systems are employed to minimize crop losses for better preservation and improve the quality of the dried products as compared to the traditional sun and shade drying. Several factors including drying method, temperature, time and type of product have an impact on the operating costs and final product quality in drying process. High drying temperatures or energies shorten the drying time but they were an important factor resulting in lower quality dried product (Keskin et al., 2018; Keskin et al., 2019). Also, the loss of active ingredients in plants is affected by the drying methods, operating conditions and type of product (Chen and Mujumdar, 2007). Some researchers reported that organic production increased the concentration of phytochemicals in crops whereas some other studies did not demonstrate significant differences between organic and conventional production systems (Sablani et al., 2011). Moreover, the cultivation practices of the agricultural products may affect the phytochemical content, structure, taste, aroma, color and therefore the drying characteristics of the product.

Pepper fruits like many other agricultural products contain very high amount of moisture (up to 90%, wet basis). Therefore, various postharvest processing techniques like drying, freezing and cold storage techniques are used to lengthen the shelf life and preserve color, valuable vitamins, minerals and nutrients. In Turkey, pepper is dried commonly under open-sun-drying conditions as similar to many places in the world (Soysal et al., 2018). In this method, the drying period of pepper is about 7 to 20 days in summer months (Hwang et al., 2017). However, this method has some drawbacks such as inability to properly control the drying operation, longer drying times, inabilities to process large quantity of products, weather uncertainties, higher labor costs, large area requirement, insect infestation, contamination with dust and foreign materials, etc. (Nasiroglu and Kocabiyik, 2007; Soysal et al., 2009; Fadhel et al., 2014). On the other hand, even if various modern drying techniques like osmotic, microwave, infrared, fluidized-bed, refractance window, ultrasound and freeze drying have been developed, hot air drying is still the most commonly used method.

Asami et al. (2003) compared the impacts of freeze drying, air-drying and flash freezing on the total phenolic and ascorbic acid content of marionberry, strawberry and corn grown under organic, conventional and sustainable agricultural practices. Sablani et al. (2011) studied the effects of air and freeze drying on the phytochemical content and moisture diffusivity of conventional and organic berries. They concluded that air-drying resulted in considerable changes in phytochemicals in both conventionally and organically grown berries whereas freeze drying improved the retention of phytochemicals. Moreover, it is stated that conventional berries (Meeker1 and Duke) showed higher moisture diffusivity than organic fruits, whereas the trend was inverse for the other varieties (Meeker2 and Reka).

Although organic production has an increasing trend in the world, research on the evaluation of drying kinetics and color quality of organic and conventional products is very limited. To our best of knowledge, up to date, there has been no published study comparing the hot-air drying characteristics and color quality of organic and conventionally grown red peppers. Therefore, the aims of this study were to evaluate the impacts of hot-air drying on the drying kinetics and color qualities of organically and conventionally grown sweet red peppers and to model drying kinetic data mathematically.

MATERIALS and METHODS

Sweet Red Pepper Samples

Sweet red peppers (*Capsicum annuum* L., Kapiatype, Diyar F1 cultivar) grown in organic and conventional farming methods under greenhouse conditions near Erdemli, Mersin, Turkey (36.6115N, 34.2624E) were used in the study. This type of pepper is produced in Turkey. The peppers were hand harvested in the red stage. Pepper samples were stored at +4°C until drying experiments. The water contents of fresh peppers were evaluated by using standard oven method (drying at 103°C for 24 h). Before drying experiments, three samples were used for moisture content determination. The average initial wet based (w.b) moisture contents of the organic and conventional pepper samples were 91.80%±0.40 (w.b.) and 91.83%±0.39 (w.b.), respectively.

Hot Air Drying Procedure

Schematic view of the experimental hot-air dryer used in the drying experiments was shown in Figure 1 (Soysal et al., 2009). The dryer consisted of three main units; an air heater based on electric resistance, a radial fan and a drying cabin. A digital balance (Sartorius TE3102S, Germany, 3100, accuracy: 0.01 g) was placed under the rotating glass tray (diameter: 31 cm, mass: 1150 g) to continuously measure the mass of the material being dried without stopping the drying procedure. Mass of pepper samples and the air temperature inside the drying cabin were recorded at every minute during the drying process. Heated air with an airflow speed of about 1.25-1.50 m s^{-1} was forced to move around the sample and leave out of the drying cabin.

In each drying process, the pepper samples were washed with tap water and rinsed with distilled water and then, they were dripped and shredded with a thickness of about 1.43±0.07 mm. Shredded pepper samples were placed evenly and homogeneously in a layer of 7.6±0.07 mm on a glass tray. Seven drying processes at each drying temperature (60, 70 and 80°C) were carried out giving a total of 42 drying trials (organic pepper: 3x7= 21 trials, conventional pepper: 3x7=21 trials). All drying experiments were conducted in an acclimatized laboratory. Moisture loss of the samples with initial loads of about 150 g was recorded at one minute intervals. All drying experiments were terminated as the pepper samples reached to a moisture content of about 0.10 kg [H_2O] kg^{-1} [DM].

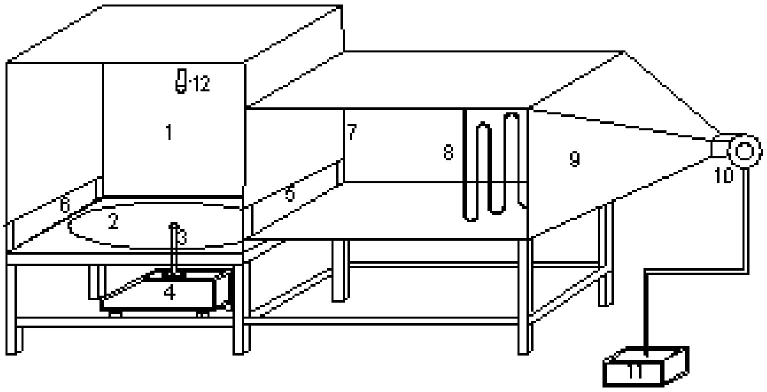

Figure 1. Experimental hot air drying system. 1: hot air drying chamber; 2: rotating glass tray; 3: tray rotating rod; 4: digital balance; 5: hot air entrance; 6: moist air outlet; 7: air heater cabin; 8: electric resistance heaters; 9: air duct; 10: fan; 11: fan speed adjuster; 12: temperature sensor.

Mathematical modeling

The experimental data were fitted to eleven different drying models to determine the most suitable drying equation (Table 1). The equilibrium moisture content (Me) was assumed to be zero an thus, the moisture ratio (MR) was simplified to M/M0 instead of (M-Me)/(M0-Me) (Doymaz and Pala, 2002).

Non-linear regression analyses for these eleven drying models were carried out by using SigmaPlot softaware (Version 12). The coefficient of determination (R^2), residual sum of squares (RSS) and standard error of estimate (SEE) were used as the primary criterions to select the best equation. These statistical values were calculated as follows:

$$RSS = \sum_{j=1}^{N} \left(MR_{\exp,i} - MR_{pre,i} \right)^2 \qquad \text{Eq. (1)}$$

$$SEE = \sqrt{\frac{\sum_{j=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N-2}} \quad \text{Eq. (2)}$$

where;
$MR_{\exp,i}$ is the i^{th} experimental moisture ratio,
$MR_{pre,i}$ is the i^{th} predicted moisture ratio and
N is the number of observations.

Table 1. Mathematical models applied to the drying curves of the organic and conventional red pepper samples

	Model name	Model equation*	References
1	Newton	$MR = \exp(-kt)$	Ertekin and Yaldiz (2004)
2	Page	$MR = \exp(-kt^n)$	Diamente and Munro (1993)
3	Henderson and Pabis	$MR = a\exp(-kt)$	Ertekin and Yaldiz (2004)
4	Logarithmic	$MR = a\exp(-kt) + b$	Yagcioglu et al. (1999)
5	Midilli et al.	$MR = a\exp(-kt^n) + bt$	Midilli et al. (2002)
6	Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)
7	Logistic	$MR = b/(1 + a\exp(kt))$	Jain and Pathare (2004)
8	Two term	$MR = a\exp(-kt) + b\exp(-k_1 t)$	Jain and Pathare (2004)
9	Verma et al.	$MR = a\exp(-kt) + (1-a)\exp(-bt)$	Verma et al. (1985)
10	Two term exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat)$	Soysal et al. (2006)
11	Diffusion approximation	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	Soysal et al. (2006)

Calculation of the Effective Moisture Diffusivity (D_{eff}) and Activation Energy (E_a)

The effective moisture diffusivity (D_{eff}) was interpreted by using the Fick's second diffusion equation. General equation for the moisture ratio (MR) for slab geometry with the assumptions of moisture migration by diffusion, negligible shrinkage, constant diffusion coefficients and temperature is given below (Crank, 1975):

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{i=0}^{\infty}\frac{1}{(2i+1)^2}\exp\left[\frac{(2i+1)^2\pi^2 D_{eff}t}{4L^2}\right] \quad \text{Eq. (3)}$$

where;
MR is the moisture ratio,
M is the moisture content,
M_0 is the initial moisture content,
M_e is the equilibrium moisture content,
D_{eff} is the effective moisture diffusivity ($m^2 s^{-1}$),
L is the half thickness of the samples (m),
i is a positive integer and
t is time (s).

For long drying periods, Eq. (3) can be further simplified as follows (Wang et al., 2007):

$$\ln(MR) = \frac{8}{\pi^2} - \frac{\pi^2 D_{eff}}{4L^2}t \quad \text{Eq. (4)}$$

The D_{eff} values were calculated by plotting the experimental ln(MR) data against drying time so the plot gives a straight line with a slope as $K = \pi^2 D_{eff}/4L^2$.

The temperature dependency of the effective moisture diffusivity was predicted by using an Arrhenius type equation (Doymaz and Ismail, 2011):

$$D_{eff} = D_0\exp(-E_a/RT) \quad \text{Eq. (5)}$$

The Eq. (5) can be converted to a linear form as follows:

$$\ln(D_{eff}) = \ln(D_0) - [(E_a/R)(1/T)] \quad \text{Eq. (6)}$$

where;
E_a is the energy of activation (kJ mol^{-1}),
R is the universal gas constant (8.3143×10^{-3} kJ mol^{-1}),
T is the absolute temperature (K) and
D_0 is the pre-exponential factor of the Arrhenius equation ($m^2 s^{-1}$).
Then, the E_a can be calculated from the slope of the Eq.(6) by plotting $ln(D_{eff})$ versus 1/T ($K_1 = E_a/R$).

Color analysis

Color of fresh and powdered sweet red pepper samples was measured with a chromameter (Minolta CR-400, Osaka, Japan). The CIE L*a*b* color model was used to define the color of the samples. The chromameter was utilized with illuminant C standard and calibrated using its white reflector plate. The color is expressed in three dimensions (L*a*b*) and the meaning of each parameter is as follows (Keskin et al., 2017): L*: Brightness of the color (0: black, 100: white), a*: Redness-greenness (–60: green, +60: red), b*: Yellowness-blueness (–60: blue, +60: yellow). Ground material measurement apparatus was utilized in measuring the color of the samples. Color change of the material was evaluated by using the redness to yellowness ratio (a*/b*), total color difference (ΔE*) and color difference values for each of the three color parameters (ΔL*, Δa*, Δb*) (Soysal et al., 2009):

$$\Delta L^* = L_d^* - L_f^* \quad \text{Eq. (7)}$$

$$\Delta a^* = a_d^* - a_f^* \quad \text{Eq. (8)}$$

$$\Delta b^* = b_d^* - b_f^* \quad \text{Eq. (9)}$$

$$\Delta E^* = \left[\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right]^{0.5} \quad \text{Eq. (10)}$$

where *d* and *f* refers to the dried and fresh products, respectively.

Statistical data analysis

The influence of drying temperatures on drying time and color of organic and conventional sweet red pepper samples were evaluated with a statistics software (SPPS, v.17, IBM, NY, USA) using one-way analysis of variance (ANOVA) and the means were compared with Duncan’s test (p <0.05).

RESULTS and DISCUSSION

Drying Kinetics

The drying time needed to reach to 0.10 kg [H_2O] kg^{-1} [DM] final moisture content of the samples decreased with the increasing temperature for both organic (OSRP) and conventional sweet red pepper (CSRP) samples (Figure 2, Table 2). As the drying temperature increased from 60 to 80°C, considerable savings in drying times of OSRP and CSRP samples were observed which reached to about 32% (114 min – 77 min) and 25% (119 min – 89 min), respectively (p <0.05). The drying times of the CSRP samples were 5 to 12 minutes longer as compared to the OSRP samples. Except 60°C, there was significant difference between the drying times of OSRP and CSRP samples (p <0.05).

It was observed that the drying process for both red pepper samples (OSRP and CSRP) took place mainly in the falling rate period after a short warming-up period (Figure 3). The drying rates descended as the moisture content decreased and the curves became steeper as the drying temperature increased.

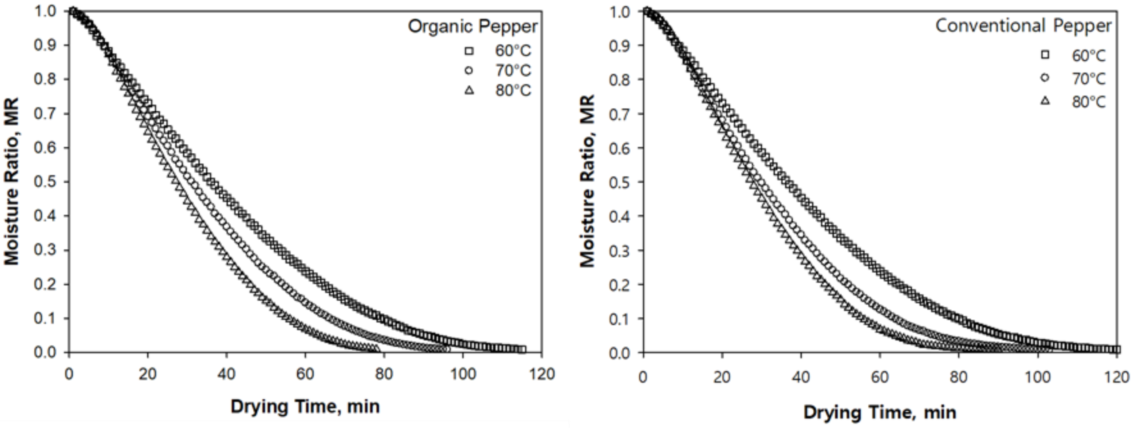

Figure 2. Moisture ratio as a function of drying time for the hot air drying of organic and conventional sweet red pepper samples

Table 2. Effect of hot air drying temperatures on the hot air drying time of organic and conventional sweet red pepper samples

Drying Temp. (°C)	Drying Time (min)	
	Organic Red Pepper	Conventional Red Pepper
60	114.00±5.66^d	119.00±8.93^d
70	95.00±4.58^b	102.00±5.03^c
80	77.00±6.71^a	89.00±4.36^b

Different letters indicate statistically significant differences (p <0.05)

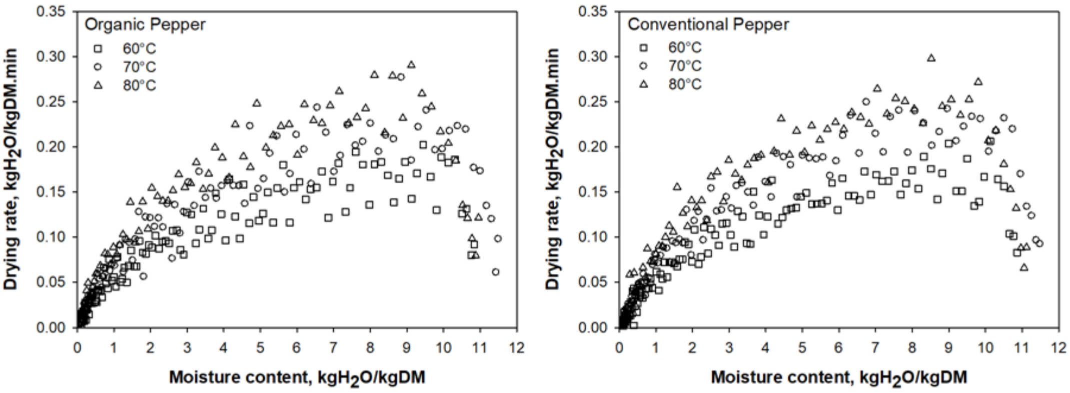

Figure 3. Moisture content versus drying rate curves for the hot air drying of organic and conventional sweet red peppers.

Mathematical modeling of drying curves

The experimental moisture ratios of the red pepper samples during the drying process were fitted against the drying time to compare the fitting ability of eleven different thin layer-drying models given in Table 1. The best descriptive model was determined using three parameters namely highest value for R^2 and lowest values for RSS and SEE. The best fitting model for both OSRP and CSRP samples was the Midilli model (Model 5) with the values for the R^2 greater than 0.9995, the SEE of lower than 0.0076 and the RSS of lower than 0.0058 (Table 3 and Figure 4). As expected, the value of the drying coefficient *k* increased with the increase in drying temperature. These results were in agreement with the drying rate data which followed the similar trends. Figure 5 shows the validation of Midilli model by comparing the predicted and experimental data from all drying experiments. The predicted data closely banded on and around the straight line of the 1:1 ratio.

Table 3. Statistical parameters and model constants for the Midilli model for hot air drying of organic and conventional sweet red pepper

Product	**Drying Temp. (°C)**	**Statistical parameters and model constants**					
		R^2	**SEE**	**RSS**	**k**	**a**	**b**
Organic red pepper	60	0.9995	0.0071	0.0056	0.0046	0.9817	-0.0003
	70	0.9997	0.0053	0.0026	0.0048	0.9929	-0.0003
	80	0.9998	0.0048	0.0016	0.0051	1.0013	-0.0005
Conventional red pepper	60	0.9995	0.0071	0.0058	0.0046	0.9841	-0.0003
	70	0.9997	0.0059	0.0035	0.0047	0.9906	-0.0001
	80	0.9995	0.0076	0.0050	0.0049	1.0630	-0.0002

Effective Moisture Diffusivity (D_{eff}) and Activation Energy (E_a)

The effective moisture diffusivity (D_{eff}) values increased notably with the increase in drying temperature (Table 4). Increasing drying temperatures accelerated the water molecules and led to faster decrease in the moisture content corresponding to the higher values of diffusivity (Thuwapanichayanan et al., 2011; Darvishi, et al., 2013; Soysal et al., 2018). The D_{eff} values of the OSRP and CSRP samples were found to be 39.62×10^{-10} – 58.58×10^{-10} m^2 s^{-1} and 38.92×10^{-10} – 57.59×10^{-10} m^2 s^{-1}, respectively (Table 4). The D_{eff} values obtained in this study lay within the range of 10^{-11} to 10^{-9} m^2 s^{-1} as previously reported for various biological materials (Saravacos, 1986; Rizvi, 1986; Madamba et al., 1996; Maskan et al., 2002; Wang et al., 2007; Kumar et al., 2011). Also, they were very similar (Kaleemullah and Kailappan, 2005; Kaleemullah and Kailappan, 2006; Vega et al., 2007; Taheri-Garavand et al., 2011), higher (Turhan et al., 1997; Kaymak-Ertekin, 2002; Sanjuán et al., 2003; Vega-Galvez et al., 2008; Scala and Crapiste, 2008; Arslan and Özcan, 2011; Cao et al., 2016; Deng et al., 2018) and lower (Doymaz and Pala, 2002) than that of the red peppers as compared to the findings of some other previous studies (Table 5). The differences could be attributed to differing drying conditions and physical and chemical properties of the dried materials such as cultivar, composition, slice thickness and stage of ripening (Deng et al., 2018).

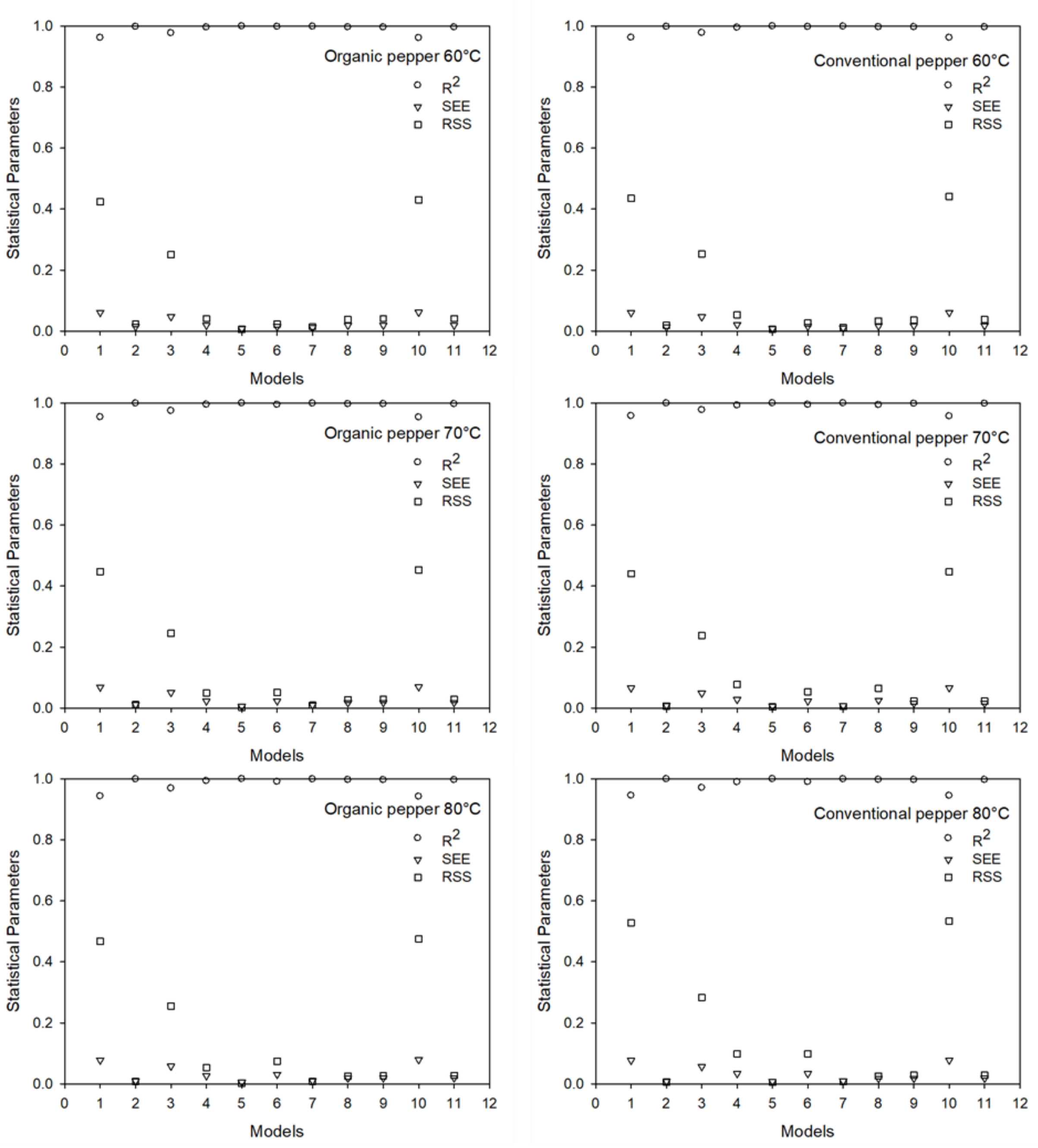

Figure 4. Statistical parameters (R2, SEE and RSS) specific to each of the eleven different models for hot air drying of organic and conventional sweet red peppers.

Effective moisture diffusivities of CSRP samples were found slightly lower than that of the OSRP samples. Meanwhile, such a trend in diffusivity values was also observed in the drying rate curves and the drying coefficients (*k*) of the Midilli model. Sablani et al. (2011) compared the effective moisture diffusivities of conventional and organic berries dried at 65°C by hot air drying and concluded that the conventional fruits (Meeker2 and Reka) had higher D_{eff} values than the organic fruits whereas the trend was reverse for other fruit varieties (Meeker1 and Duke). On the other hand, the pre-exponential factor of the Arrhenius equation (D_0) signifying moisture diffusivity when temperature goes to infinity (Turhan et al., 1997) was found as almost identical for both product types in the present study (Table 4). Moreover, same trend was observer in the activation energy (E_a) values which was also almost same for OSRP and CSRP samples (Table 5). Activation energy (E_a) was calculated from the slope of the Eq (6) by plotting $ln(D_{eff})$ against to 1/T ($slope=E_a/R$). The plots gave straight lines for the studied temperature range which indicating Arrhenius dependence (Figure 6).

Hence, the E_a values computed from the slope of these lines were 19.12 kJ mol^{-1} for the OSRP and 19.16 kJ mol^{-1} for the CSRP samples. This finding suggests that organic or conventional growing practice did not change much of the structural features related to the heat transfer properties of the pepper. The characteristic drying curve profiles and the extent of D_{eff} values discussed above strongly supports this statement.

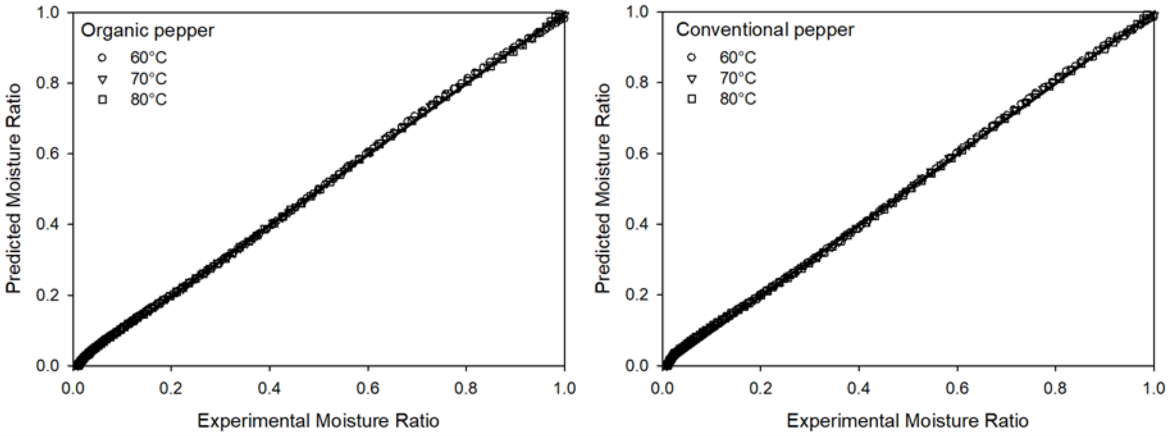

Figure 5. Comparison of the experimental and predicted moisture ratios at various hot air drying temperatures for organic and conventional sweet red peppers

The E_a values of the sweet red pepper samples obtained in this study were within the limits of 12.7-110.0 kJ mol^{-1} as previously reported for various agricultural products (Zogzas et al., 1996), slightly lower (Scala and Crapiste, 2008; Kaleemullah and Kailappan, 2005; Turhan et al., 1997 and Ramesh et al., 2001) and higher than the E_a values for red peppers reported by various authors (Table 5) (Kaymak-Ertekin, 2002; Doymaz and Pala, 2002; Sanjuán et al., 2003; Kaleemullah and Kailappan, 2006; Vega et al., 2007; Vega-Galvez et al., 2008; Taheri-Garavand et al., 2011; Cao et al., 2016 and Deng et al., 2018). These differences can be attributed to several factors such as cultivar, physical and chemical properties of the dried material (whole, sliced, shredded), composition, design features of drying equipment, slice thickness, growing conditions, ripening stage, etc.

Table 4. Effective moisture diffusion (D_{eff}) coefficients and activation energies (E_a) of organic and conventional red peppers at different hot air drying temperatures

Product	**Drying Temp. (°C)**	**D_0 ($\times 10^{-6}$ m^2 s^{-1})**	**D_{eff} ($\times 10^{-10}$ m^2 s^{-1})**	**Linear equation**	**R^2**
Organic red pepper	60	3.937	39.62	y=-0.0006770x+0.593315	0.948
	70		48.28	y= 0.0008250x+0.642557	0.946
	80		58.58	y=-0.0010009x+0.697119	0.938
Conventional red pepper	60	3.933	38.92	y=-0.0006650x+0.573831	0.958
	70		47.58	y=-0.0008130x+0.539205	0.971
	80		57.59	y=-0.0009840x+0.661887	0.966

Color Data Analysis Results

The color quality data are presented in Table 6 as the means of seven independent measurements from three subsamples with the values after the ± sign representing the standard deviation. The L*, a* and b* values of the fresh organic (OSRP) and conventional sweet red pepper (CSRP) samples which represent matte red color were almost same (p <0.05). However, the a*/b* ratio of the fresh OSRP and CSRP samples was significantly different (p <0.05) which means that the color of fresh CSRP samples was deeper in red as compared to the OSRP samples (Table 6).

Table 5. Published data for effective moisture diffusivities (D_{eff}) and activation energies (E_a) of red pepper dried by hot air drying

Product, Drying method	**Drying Temp. (°C)**	**D_{eff} ($x10^{-10}$ m^2 s^{-1})**	**E_a (kJ mol^{-1})**	**Reference**
Organic sweet red pepper-shredded, hot air	60-80	39.62-58.58	19.12	The current study
Conventional sweet red pepper-shredded, hot air	60-80	38.92-57.59	19.16	The current study
Red pepper-shredded, hot air	50-80	6.8-17.4	28.4	Turhan et al., 1997
Red pepper-whole, hot air	60	21.64	29.82	Ramesh et al., 2001
Red pepper-sliced, hot air	60	17.13	29.82	Ramesh et al., 2001
Red pepper-sliced, hot air	40-70	0.4-2.0	42.8	Kaymak-Ertekin, 2002
Red pepper-sliced, hot air	60	225	-	Doymaz and Pala, 2002
Red pepper-shredded, hot air	50-70	3.72-9.96	56-61	Sanjuán et al., 2003
Red pepper-whole, hot air	50-70	0.44-1.10	44.0	Sanjuán et al., 2003
Red pepper-whole, hot air	50-65	37.9-55.4	24.5	Kaleemullah and Kailappan, 2005
Red pepper-whole, hot air	50-65	37.8-71.0	37.8	Kaleemullah and Kailappan, 2006
Red-bell pepper-sliced, hot air	50-80	32.0-112.0	39.7	Vega et al., 2007
Red-bell pepper-sliced, hot air	50-90	0.7-3.8	40.8	Vega-Galvez et al., 2008
Red pepper-sliced, hot air	20-50	5.0-8.3	23.4	Scala and Crapiste, 2008
Red bell-sliced, hot air	40-80	17.0-119.0	44.5	Taheri-Garavand et al., 2011
Red-bell pepper, oven	50-70	4.0-13.1	-	Arslan and Özcan, 2011
Red pepper-whole, hot air	60-80	9.6-23.7	44.5	Cao et al., 2016
Red pepper-whole, hot air	50-80	1.4-6.9	48.9	Deng et al., 2018

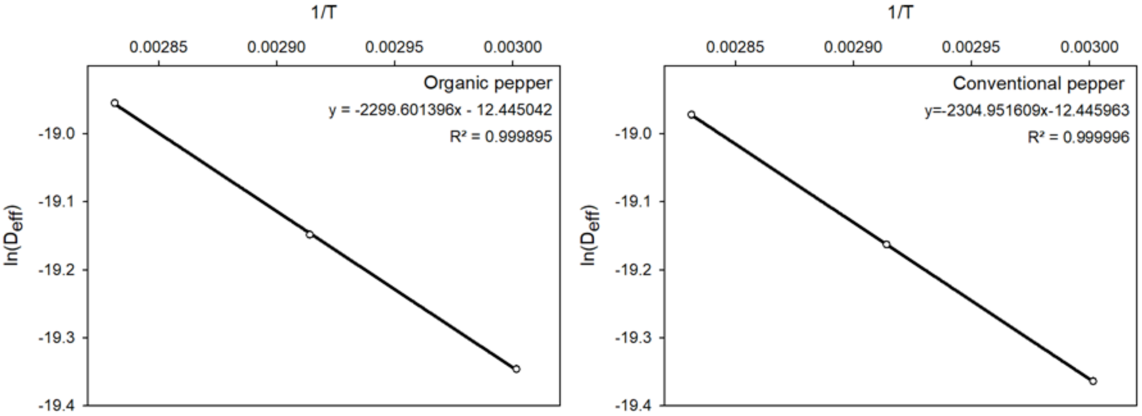

Figure 6. Arrhenius plot for the calculation of activation energy of organic and conventional red pepper samples

A major criterion used in the evaluation of the color quality of dried red peppers was reported as red color intensity (Kim et al., 2002; Topuz et al., 2011) which essentially originates from ketocarotenoids, capsanthin and capsorubin. In addition to this, red peppers with the color of higher brightness and redness and mild yellowness values were reported as more preferable products in view of color quality (Soysal et al., 2005; Ergunes and Tarhan, 2006). It was observed that the L* values of both organic and conventional fresh samples were notably enhanced after hot-air drying process (p <0.05). Beside this, except the a* values of the CSRP samples dried at 60 and 80°C, the a* and b* values of the dried samples were significantly higher than the values of the fresh samples (p <0.05). When compared to the values of fresh samples, the b* values of pepper powders increased about two-fold while the increase in a* values remained in very limited extent.

Regarding the changes in the color parameters of the powdered pepper samples, hot-air drying at 60°C resulted in the highest color difference values (ΔL*, Δb* and ΔE*) which signifies a brighter orangish-red product color (Table 7). On the other hand, hot-air dying at 70 and 80°C yielded the lowest ΔE* and the highest Δa* and a*/b* values for both OSRP and CSRP samples which means that these pepper powders had deeper red color (Table 6, Table 7). Hence, hot-air drying at 70 and 80°C can be evaluated as the most suitable drying applications for both OSRP and CSRP because these treatments gave brighter and redder red pepper powders.

Table 6. Color data of the fresh and dried-powdered organic and conventional sweet red pepper samples

Product Type	**Drying Temp. (°C)**	**Color Parameters**			
		L*	**a***	**b***	**a*/b***
Organic red pepper	Fresh	30.93 ± 0.02^{a}	24.10 ± 0.03^{a}	22.34 ± 0.06^{a}	1.08 ± 0.00^{d}
	60	61.42 ± 0.93^{c}	28.42 ± 0.97^{c}	41.36 ± 0.96^{e}	0.69 ± 0.02^{b}
	70	57.80 ± 0.94^{b}	30.67 ± 0.90^{e}	40.89 ± 0.97^{de}	0.75 ± 0.03^{c}
	80	58.24 ± 0.92^{b}	29.77 ± 0.94^{d}	40.42 ± 0.89^{cd}	0.74 ± 0.03^{c}
Conventional red pepper	Fresh	30.18 ± 0.02^{a}	25.29 ± 0.04^{b}	21.81 ± 0.06^{a}	1.16 ± 0.00^{e}
	60	65.04 ± 0.7^{e}	25.77 ± 0.97^{b}	39.78 ± 0.98^{c}	0.65 ± 0.02^{a}
	70	61.11 ± 0.91^{c}	28.89 ± 0.77^{c}	39.63 ± 0.87^{c}	0.73 ± 0.02^{c}
	80	62.55 ± 0.92^{d}	26.04 ± 0.24^{b}	37.26 ± 0.89^{b}	0.70 ± 0.02^{b}

Different letters in same column indicate statistically significant differences ($p < 0.05$)

Table 7. Effect of drying temperatures on the difference in color parameters of the powdered organic and conventional sweet red peppers

Product Type	**Drying Temp. (°C)**	**Differences in Color Parameters**			
		ΔL*	**Δa***	**Δb***	**ΔE***
Organic red pepper	60	30.48 ± 0.93^{b}	4.32 ± 0.97^{b}	19.02 ± 0.96^{c}	36.21 ± 0.77^{b}
	70	26.87 ± 0.94^{a}	6.57 ± 0.90^{c}	18.55 ± 0.97^{bc}	33.32 ± 1.06^{a}
	80	27.31 ± 0.92^{a}	5.67 ± 0.94^{c}	18.08 ± 0.89^{bc}	33.25 ± 1.21^{a}
Conventional red pepper	60	34.86 ± 0.73^{d}	0.47 ± 0.97^{a}	17.97 ± 0.98^{bc}	39.24 ± 0.64^{c}
	70	30.93 ± 0.91^{b}	3.59 ± 0.77^{b}	17.82 ± 0.87^{b}	35.89 ± 1.01^{b}
	80	32.37 ± 0.92^{c}	0.75 ± 0.24^{a}	15.45 ± 0.89^{a}	35.89 ± 0.85^{b}

Different letters in same column indicate statistically significant differences ($p < 0.05$)

CONCLUSIONS

The results of this research revealed that the entire hot air drying process for both organic (OSRP) and conventional pepper samples (CSRP) occurred mainly in falling rate period. Increasing the drying temperature decreased the drying time considerably. Except 60°C, significant difference was found between the drying times of OSRP and CSRP samples. Regarding the drying models, the Midilli model gave the best results for all data points for OSRP and CSRP samples. The value of the drying coefficient k increased with the increase in drying temperature.

A positive relationship was found between the drying temperature and effective moisture diffusivity (D_{eff}). The D_{eff} values of OSRP and CSRP samples were 39.62×10^{-10} – 58.58×10^{-10} m^2 s^{-1} and 38.92×10^{-10} – 57.59×10^{-10} m^2 s^{-1}, respectively. There was no remarkable difference between the D_{eff} values of OSRP and CSRP samples dried at 60, 70 and 80°C. Beside this, the pre-exponential factor of the Arrhenius equation (D_0) was found as almost identical for both OSRP and CSRP samples. Moreover, same trend was observer in the activation energy (E_a) values which were also almost same for the OSRP (19.12 kJ mol^{-1}) and CSRP (19.16 kJ mol^{-1}) samples. The trends in the characteristic drying curve profiles, D_{eff} and E_a values showed that the organic or conventional growing practice of the red pepper did not alter much of the structural features related to the heat transfer properties of the product.

Because the hot-air drying at 70 and 80°C gave brighter and redder pepper powders, these drying treatments can be suggested as the most suitable drying applications for both OSRP and CSRP samples. In addition, by using hot air drying at 80°C instead of 60°C, about 25% and 32% savings in drying times for CSRP and OSRP samples could be obtainable.

ÖZET

Amaç: Bu çalışma organik ve konvansiyonel olarak üretilen tatlı kırmızı biberlerin sıcak hava kurutma kinetiklerini ve renk kalitesini karşılaştırmak için yapılmıştır.

Yöntem ve Bulgular: Biber örnekleri, sıcak hava kurutucuda 60, 70 ve 80°C'de kurutuldu. Kurutma kinetiği, efektif nem difüzyonu (D_{eff}), aktivasyon enerjisi (E_a) ve renk kalitesi incelenmiştir. Hem organik (OTKB) hem de konvansiyonel tatlı kırmızı biberler (KTKB) için kurutma işlemi temel olarak azalan hızlı kurutma periyodunda gerçekleşmiştir. Kurutma sıcaklığının arttırılması, kuruma süresini önemli ölçüde azaltmıştır. 60°C haricinde, OTKB ve KTKB örneklerinin kuruma süreleri arasında önemli bir fark bulunmuştur. Midilli modelinin biber tipleri için tüm veri noktalarına en uygun verileri sağladığı tespit edilmiştir. Kurutma sıcaklığı ve D_{eff} değerleri arasında (OTKB için 39.62×10^{-10} - 58.58×10^{-10} m^2 s^{-1} ve KTKB için 38.92×10^{-10} - 57.59×10^{-10} m^2 s^{-1}) pozitif bir ilişki bulunmuştur. D_{eff} değerleri bakımından OTKB ve KTKB arasında dikkate değer bir fark bulunmamıştır.

Genel Yorum: Karakteristik sıcak hava kurutma eğrisi profilleri, D_{eff} ve E_a değerlerinin OTKB ve KTKB için benzer eğilimi izlediği ve kırmızı biberin yetiştirilme yönteminin ısı transferi ile ilgili yapısal özelliklerini önemli ölçüde değiştirmediği görülmüştür. 70°C ve 80°C'de sıcak hava ile kurutma, daha parlak ve daha kırmızı biber tozları sağladığından bu uygulamalar renk kalitesi açısından yüksek kaliteli OTKB ve KTKB tozları üretmek için uygun kurutma uygulamaları olarak önerilmektedir. 60°C yerine 80°C kullanılarak KTKB ve OTKB örnekleri için kurutma sürelerinde yaklaşık %25 ve %32 tasarruf sağlanabilmektedir.

Çalışmanın Önemi ve Etkisi: Organik üretim dünyada giderek artan bir eğilime sahiptir; ancak organik ürünlerin kurutma kinetikleri ve renk kalitesi ile ilgili araştırmalar çok sınırlıdır. Bu nedenle, bu çalışmada OTKB ve KTKB örneklerinin kurutma kinetiği ve ilgili parametreleri değerlendirilmiştir.

Anahtar Kelimeler: Organik kırmızı biber, sıcak hava kurutma kinetiği, modelleme, nem difüzyonu, aktivasyon enerjisi, renk.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Yunus Emre Sekerli for his assistance during the experiments.

CONFLICT OF INTEREST

The authors declare no conflict of interest for this study.

AUTHOR'S CONTRIBUTIONS

The contribution of the authors is equal.

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