Mehmet Başlar*, Salih Karasu, Mahmut Kiliçli, Ahmet Abdullah Us and Osman Sağdiç

Degradation Kinetics of Bioactive Compounds and Antioxidant Activity of Pomegranate Arils during the Drying Process

Abstract: In this study, the drying kinetics of pomegranate arils, the degradation kinetics of some bioactive compounds, and changes in color values during the drying process were investigated. The drying process was performed by a forced air circulating oven at 55, 65, and 75°C. Drying times were calculated to be 1,020, 520, and 330 min, respectively. Effective moisture diffusivity values ranged from 5.39×10^{-11} to 1.70×10^{-10} m^2 s^{-1} and increased with increases in temperature. Six different thin-layer drying models were applied to evaluate the goodness of the model. The degradation rate of bioactive compounds increased at higher temperatures; however, remaining amounts of phenolic, anthocyanin, and flavonoid compounds after drying were higher in samples dried at 75°C. The highest antioxidant capacity value was observed in the pomegranate arils dried at 75°C. While the L^* values of pomegranate arils decreased after the drying process, the a^* values increased.

Keywords: pomegranate, phenolic compounds, antioxidant, drying kinetics, moisture diffusivity

***Corresponding author: Mehmet Başlar,** Department of Food Engineering, Chemical and Metallurgical Faculty, Yıldız Technical University, Esenler, Istanbul 34210, Turkey, E-mail: mbaslar@yildiz.edu.tr
Salih Karasu: E-mail: egelislh@hotmail.com, **Mahmut Kiliçli:** E-mail: mahmut_1031@hotmail.com, **Ahmet Abdullah Us:** E-mail: ahmetaus@gmail.com, **Osman Sağdiç:** E-mail: osagdic@yildiz.edu.tr, Department of Food Engineering, Chemical and Metallurgical Faculty, Yıldız Technical University, Esenler, Istanbul 34210, Turkey

1 Introduction

Pomegranate is a subtropical and tropical fruit mainly cultivated in Mesopotamia, India, the US, and Mediterranean countries. Turkey is one of the most important countries in terms of pomegranate production and exportation. Pomegranates contain certain valuable substances, such as phenolic acids, tannins, anthocyanins, vitamins, and organic acids, with antioxidant properties [1, 2]. Antioxidants inhibit free radical activity and have beneficial effects on cancer, cardiovascular, and other diseases. The antioxidant properties of pomegranates are mainly due to their high phenolic content. Red fruits are rich in bioactive phenolic compounds [1]. The consumption demand for pomegranates has increased significantly in recent years because of the fruit's functional properties.

Pomegranate fruit is generally consumed fresh and is also processed into juice, concentrate, or jam. Because fresh pomegranates are perishable and vulnerable to microorganisms, oxygen, and other factors, they have a short shelf life and seasonal consumptions [3]. Therefore, food preservation methods are necessary in order to increase shelf life and allow year-round consumption.

There are particular methods applied in fruit preservation, such as freezing, drying, and controlled and modified atmospheric packaging. Drying is one of the most widely used methods in food processing to eliminate or reduce microorganism and enzymatic activity [4]. Dried products have a longer shelf life than fresh ones due to their low moisture content. In addition, the drying process provides an advantage compared to other preservation methods in terms of lower transportation, handling, and storage costs [5, 6]. Therefore, drying offers a good alternative to increase consumption of fresh fruit all year round [7].

Since drying is a complex process including simultaneous heat and moisture transfer, mathematical models are necessary to determine the drying kinetics of fruit [8]. Some qualitative properties of fruit, such as nutritional value, color, and functional properties, may be reduced during the drying process as a result of heat treatment. As previously mentioned, functional and therapeutic properties and color quality of pomegranate fruits are related to their phenolic and flavonoid content, especially anthocyanins. These valuable nutrients are not heat stable and may degrade during the drying process, particularly at high temperatures [9]. Degradation of these compounds should be taken into consideration to optimize process parameters.

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There are numerous researches on determining drying behaviors for several fruits and vegetables, including apricots [10], grapes [11], kiwi fruit [12], gooseberries [13], sour cherries [14], tomato [15, 16], mushroom [17], and mandarin [18]. Doymaz [5, 19], Kingsly and Singh [20], and AbdulHak et al. [21] studied the drying properties of pomegranate arils. These studies were related to understanding drying kinetics and determining suitable models to describe them. Limited research has been conducted attempting to describe the degradation kinetics of the bioactive compounds of pomegranate arils during the drying process [22]. Thus, there is little information available in the literature describing the effect of the drying treatment on phenolic compounds, anthocyanins, and the antioxidant capacity of pomegranate arils. Therefore, the degradation kinetics of these bioactive compounds during the drying process should be studied to determine suitable drying conditions and to reduce degradation.

The present study focuses on the degradation kinetics of bioactive compounds in pomegranate arils, as well as drying kinetics behavior. The objective of this study is to investigate the effect of drying temperature on the antioxidant capacity, total phenolic (TP) content, total flavonoid (TF) content, total anthocyanin (TA) content, color value, and drying characteristics of pomegranate arils.

2 Materials and methods

2.1 Materials

Pomegranate fruits (*Punica granatum*) were collected from a retail market and immediately transferred to the laboratory. The fruits were kept at 4°C until analysis. Chemicals used in the study were obtained from Merck (Darmstadt, Germany).

2.2 Drying conditions

Arils were manually separated from the pomegranate fruits. Uniform size arils were used. The arils' shape was considered as spherical, their radius measured about 0.6 ± 0.2 cm, and initial moisture content was recorded as $79.1 \pm 0.2\%$, wet basis (w.b.). The arils (100 g) were dried with a forced air circulation oven (Memmert-UF110, Germany). The drying process was conducted at 55, 65, and 75°C at 1.3 m/s constant air velocity. Moisture loss during the drying process was recorded at equal intervals, and the weight of the arils was measured using an analytical balance (Shimadzu TW-423, Japan) with an accuracy of 0.001 g.

2.3 Mathematical modeling of drying curve

In the present study, the obtained data were modeled by six thin-layer drying models, as illustrated in Table 1. According to this model, the moisture ratio was simplified to M/M_0 instead of $(M - M_e)/(M_0 - M_e)$ as the value of M_e is relatively small compared to M or M_0 [19], where M is the moisture content at time t, M_0 is the initial moisture content, and M_e is the equilibrium moisture content. Model acceptability was determined based on R^2, reduced chi-square (χ^2), and root mean square error values. Higher R^2 and lower RMSE and χ^2 values indicate good fitness of the established model. These parameters were calculated using the following equations:

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

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

$\mathrm{MR}_{\mathrm{exp},i}$ and $\mathrm{MR}_{\mathrm{pre},i}$ are experimental and predicted moisture ratio values of the ith observation, N is the number of observations, and z is the number of constants in the models.

Table 1 Drying models applied to the pomegranate arils drying curves

Number	Model	Equation	References
1	Lewis (Newton)	$\exp(-kt)$	[23]
2	Henderson and Pabis	$a\exp(-kt)$	[24]
3	Logarithmic	$a\exp(-kt) + c$	[25]
4	Page	$\exp(-kt^n)$	[26]
5	Two-term exponential	$a\exp(-kt) + (1-a)\exp(-k_0ct)$	[27]
6	Mod. Henderson and Pabis	$a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	[28]

2.4 Determination of effective moisture diffusivity and activation energy

Fick's second law equation was used to explain the drying process in the present study insofar as the drying of

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food materials occurred in a falling rate period. Fick's law can be shown by the following equation:

$$\frac{M}{t} = \nabla[D_{\text{eff}}(\nabla M)] \tag{3}$$

The following equation was obtained from Fick's second law by adapting it to spherical shapes and unstable diffusion conditions [29]:

$$\text{MR} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n}\exp\left(n^2\pi^2\frac{D_{\text{eff}}t}{r^2}\right) \tag{4}$$

Equation (4) can be simplified to the following equation for long drying periods:

$$\ln(\text{MR}) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{\text{eff}}t}{r^2}\right) \tag{5}$$

D_{eff} values can be calculated by plotting the ln (MR) value as a function of time, and a straight line with a slope of (K) can be obtained from this plot. This can be written as

$$K = \frac{\pi^2 D_{\text{eff}}}{R^2} \tag{6}$$

Temperature dependencies of the diffusion parameters were calculated using the Arrhenius equation. Activation energy was calculated by plotting D_{eff} values against the reciprocal of the absolute temperature, and the following equation was used to determine E_a values:

$$D_{\text{eff}} = D_0\exp\left(-\frac{E_a}{RT}\right) \tag{7}$$

where D_0 is the pre-exponential factor of the Arrhenius equation (m^2/s), E_a is activation energy (kJ/mol), R is the ideal gas constant (kJ/mol K), and T is the drying temperature in degree Kelvin.

2.5 Extraction procedure

The dried sample was rehydrated by adding the water removed during the drying process. A total of 50 g of pomegranate was weighed and inserted into a screw bottle, followed by the addition of 200 mL of ethanol: water (75:25). The mixture was homogenized with an ultra-turrax (Daihan, HG-15D) at 10,000 rpm for 2 min and then mixed by shaking for 2 h at room temperature. Next, the mixture was centrifuged (Hettich, Universal 320R, Germany) at 4,000 rpm for 10 min, and the supernatants were filtered using a 0.45 μm filter.

2.6 Total phenolic content

The TP content of pomegranate arils was determined according to the modified method described by Singleton and Rossi [30]. A 0.5 mL extract was mixed with 2.5 mL of 0.2 N Folin-Ciocelteu's phenol reagent and 2 mL of 7.5% Na_2CO_3. The mixture was incubated for 30 min at room temperature in a dark place. At the end of the incubation, the absorbance was measured at 760 nm using a UV-VIS spectrophotometer (Shimadzu, UV-1800, Japan). TP was calculated as gallic acid equivalent [31].

2.7 Total flavonoid content

The TF content of pomegranate arils was determined according to Zhishen et al. [32]. Pomegranate extract of 1 mL was placed into 10 mL volumetric glass. Then, pure water was added until a total of 5 and 0.3 mL $NaNO_2$ (5%) was put in the volumetric glass. After 5 min, 0.3 mL $AlCl_3$ (10%) was added. After 6 minutes, 2 mL NaOH (1 M) was added, and the total volume of the solution was finalized to 10 mL by the addition of pure water. The obtained solution was thoroughly mixed, and the absorbance was measured at 510 nm with a UV-VIS spectrophotometer (Shimadzu, UV-1800, Japan). TF was calculated as catechin equivalent.

2.8 Total anthocyanin content

TA content was estimated according to the pH differential method [33]. The extracts were separately mixed with buffers of pH 1 and pH 4.5 and incubated at room temperature in a dark place for 30 min. The absorbance of the samples was measured at 510 and 700 nm using a UV-VIS spectrophotometer (Shimadzu, UV-1800). The TA content was expressed in mg of cyanidin-3-glucoside per kg of fresh pomegranate sample.

2.9 Antioxidant capacity

The antioxidant capacity analysis was carried out according to the DPPH method reported by Singh et al. [34]. First, 0.1 mL of pomegranate arils extract was mixed with 4.9 mL of DPPH solution (0.1 mM in ethanol). After 30 min of holding about 25°C, the absorbance at 517 nm was recorded. Antioxidant capacity was described as the percentage of scavenging effect according to the following equation:

$$\text{DPPH Scavenging Effect}\,(\%) = \left(\frac{Ac - As}{Ac}\right)\times 100 \tag{8}$$

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2.10 Color measurements

The surface color of the pomegranate arils was tested with a chroma meter (CR-400, Konica Minolta, Japan) before and after the drying treatment. The mean values of the obtained data are defined as the color values in this study. The color values were expressed as L^* (whiteness/darkness), a^* (redness/greenness), and b^* (yellowness/blueness). The total color change (ΔE) was calculated according to the following equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (9)$$

2.11 Thermal degradation kinetics

A first-order kinetic model was used in the study to predict the thermal degradation of bioactive compounds. Equation (10) was shown as

$$C_t = C_0 \exp(-k_0 t) \quad (10)$$

where C_t represents the TP, TF, and TA contents at drying time t and $t = 0$ min, respectively, and k_0 is the degradation kinetics constant. Logarithms of the ratios of C_t and C_0 versus time were plotted, and its slopes were used to calculate half-life ($t_{1/2}$) values, as expressed in the following equation:

$$t_{1_2} = \frac{\ln 2}{k} \quad (11)$$

The effect of temperature on the degradation of bioactive compounds was predicted by the Arrhenius equation:

$$k = A_0 \exp\left(\frac{E_a}{RT}\right) \quad (12)$$

where k is the degradation rate, E_a is the activation energy (J/mol), R is the ideal gas constant (J/mol K), and T is the temperature in degree Kelvin.

2.12 Energy consumption

An energy meter (PeakTech-9035, Germany) was directly used in plugging to determine the total energy consumption [35].

3 Statistical analysis

The nonlinear regression analysis was carried out using the Statistica computer program and was based on the Levenberg–Marquardt algorithm. The coefficient of determination (R^2) was the main criterion for determining the best model to describe the drying curves of pomegranate arils.

4 Results and discussion

4.1 Drying kinetics of pomegranate arils

The pomegranate arils were dried until they attained 25% (w/w) moisture content, as shown in Figure 1. The figure clearly demonstrates that the drying rate increased significantly with increasing temperature. The drying times of pomegranate arils were 1,020, 529, and 330 min for drying processes carried out at 55, 65, and 75°C, respectively. The decrease in drying time or increased drying rate might have resulted from an increase in water vapor pressure as a result of the increased heat transfer rate at higher temperatures, which affects the migration of moisture from arils to the outside [20]. According to Figure 1, the drying rate was very rapid during the first stage and decelerated in the last stage of the drying process. In other words, a linear variation was not observed in the drying rate of pomegranate arils. These results were in conformity with other studies on the drying kinetics of pomegranate arils [19, 22] and other fruit samples [8, 36].

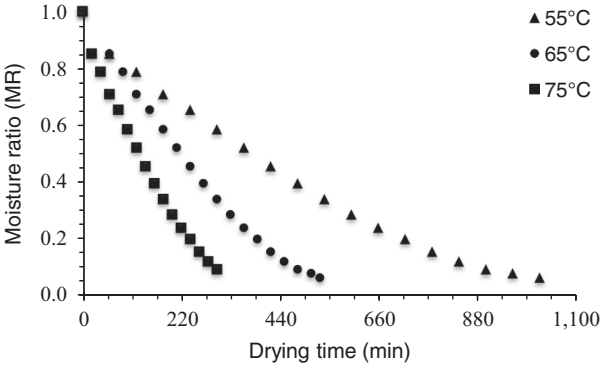


Figure 1 Drying curves of dried pomegranate arils: variation of moisture content with drying time of pomegranate arils at different temperatures

Total energy consumption values spent during the drying of pomegranate arils were determined to be 1.5, 1.8, and 2.8 kW h for 75, 65, and 55°C, respectively. The results indicate that a higher drying temperature condition might decrease the loss of energy. This is in conformity with the

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study by Motevali et al. [37], which reported that increased temperature and air velocity decreased energy consumption as well as drying time.

4.2 Evaluation of the models

In order to determine the best model for describing the drying kinetics of arils, the experimental data were fitted to six thin-layer drying models that were carried out at the different temperatures illustrated in Table 1. The R^2 values (>0.96) showed that the selected models could be satisfactorily applied to describing the drying kinetics of pomegranate arils. The logarithmic model was determined to be the best model based on its R^2 value (0.9989–0.9999). On the other hand, experimental data obtained from 75°C could not be fitted to the Page model. Apart from this, the Page model described the drying kinetics of other experimental data well ($R^2 = 0.9989$). Other authors have suggested the Page [20, 22] and Midilli et al. models [19]. The corresponding model constants and coefficients are tabulated in Table 2. In addition, the *k*-values (drying constant of models) increased with increases in drying temperature; therefore, *k*-values could be used to determine temperature effects on the drying kinetics of arils due to the correlation between the values and drying temperature.

4.3 Effective moisture diffusivity

Effective moisture diffusivity is an important concept for designing and modeling mass-transfer processes such as dehydration, adsorption, and desorption of moisture during storage [38]. The effective moisture diffusivity (D_{eff}) of pomegranate arils was determined to understand the drying kinetics of the falling rate period. Moisture diffusivity values were calculated to be 5.39×10^{-11}, 1.12×10^{-10}, and 1.70×10^{-10} m^2 s^{-1} at 55, 65, and 75°C, respectively, from Fick's second law by means of eq. (11). As seen from the results, D_{eff} values increased with higher drying temperatures. This might have resulted from the freer evaporation of water from pomegranate arils as a result of an increase in heat transfer potential between the pomegranate arils and the drying atmosphere [19]. D_{eff} values were close to those reported by Doymaz [19], between 9.373×10^{-11} and 3.429×10^{-10} m^2 s^{-1}. Karaaslan et al. [22] reported D_{eff} values ranging from 1.43×10^{-9} to 6.03×10^{-9} m^2 s^{-1} in a vacuum dryer. Minaei et al. [39] reported D_{eff} values of 0.74×10^{-10} to 5.25×10^{-10} m^2 s^{-1} in vacuum conditions, which varied from 3.43×10^{-10} to 3.05×10^{-10} in a microwave dryer. The results obtained from the present study were comparable with the results of Akpinar and Bicer [40] for strawberries (60–85°C) and Mirzaee et al. [41] for apricots (40–80°C).

Table 2 Statistical constants of the six drying models ($p < 0.05$)

Models	Parameters	Temperature (°C)		
		55°C	65°C	75°C
Lewis (Newton)	k	0.0986	0.2221	0.3249
	R^2	0.9787	0.9796	0.9782
	RMSE	0.0393	0.0569	0.0601
	χ^2	0.0018	0.0039	0.0044
Henderson Pabis	k	0.1049	0.2428	0.3575
	a	1.053	1.091	1.083
	R^2	0.9834	0.9852	0.9782
	RMSE	0.0341	0.0484	0.0501
	χ^2	0.0014	0.0028	0.0031
Logarithmic	k	0.0487	0.0941	0.1117
	a	1.597	1.547	2.201
	R^2	0.9999	0.9989	0.9997
	RMSE	0.0054	0.0142	0.099
	χ^2	0.0000	0.0002	0.0001
Page	k	0.0534	0.0826	
	n	1.272	1.605	
	R^2	0.9984	0.9996	*nf*
	RMSE	0.0065	0.083	0.0161
	χ^2	0.0000	0.0001	0.0003
Two-term exponential	k	0.0030	0.2125	0.3249
	k_0	0.0550	0.4607	0.5700
	a	0.3244	0.4003	0.4579
	c	0.0550	0.4607	0.5700
	RMSE	0.0391	0.0201	0.0501
	χ^2	0.0018	0.0004	0.0032
Mod. Henderson and Pabis	k	0.1049	0.5894	0.3573
	a	0.3643	29.29	0.4106
	b	0.3472	40.58	0.2793
	c	0.3421	−68.87	0.3937
	g	0.1049	0.5704	0.3575
	h	0.1049	0.6366	0.3576
	R^2	0.9998	0.9993	0.9782
	RMSE	0.0341	0.0484	0.0121
	χ^2	0.0014	0.0028	0.0002

Note: a, b, c and n are drying coefficients and g, h, k and k_0 are drying constants (1/min). nf: not fitted.

In the present study, the following equation was obtained by fitting experimental data to the Arrhenius equation, expressing the effect of temperature on D_{eff} values in eq. (7):

$$D_{\text{eff}} = 8.9 \times 10^{-4} \exp\left(-\frac{5388}{(T + 273\text{K})}\right) (R^2 = 0.9872) \quad (13)$$

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Using this formula, an E_a value of 44.798 kJ/mol was found in our study. The E_a value was reported to be 60.34 kJ mol^{-1} [19] and ranged from 24.26 to 31.54 kJ mol^{-1} for pomegranate arils [22]. The lower E_a values obtained by Karaaslan et al. [22] might have been due to the vacuum drying and pretreatment process, which facilitates the migration of moisture from arils. The experimental results were also in agreement with other studies investigating the temperature dependency of the drying process for various fruit groups [41, 42].

4.4 Degradation kinetics of bioactive compounds

Degradation of TP, TF, and TA is an important issue due to their functional and therapeutic effects and should be taken into account in the drying process. Initial values of TP, TF, and TA were found to be 1,165.13, 397.84, and 46.479 mg kg^{-1}, respectively. Figure 2 represents the degradation kinetics of TP, TF, and TA in the pomegranate arils. As shown in the figure, remaining TP, TA, and TF values were reduced with increased drying time, and the degradation rate accelerated with increasing temperature, meaning that the loss of bioactive compounds increased as a function of time. Table 3 demonstrates the variations of k and $t_{1/2}$ (min) values at different temperatures. While k-values increased with increasing drying temperature, $t_{1/2}$ (min) values decreased, indicating that bioactive compounds degrade rapidly at higher temperature levels, that is, a slight augmentation in temperature may accelerate the loss of bioactive compounds. Karaaslan et al. [22] observed the same trend between changes in k and $t_{1/2}$ and temperature. There were significant differences between the remaining total bioactive compounds (TP, TA, and TF) concentration in the pomegranate arils dried at different temperatures ($p < 0.05$).

The remaining percentage values (C/C_0) of the TP value of pomegranate arils dropped to 78.61, 81.82, and 84.11% at 55, 65, and 75°C, respectively. Although the degradation rate was very rapid at high temperatures, the C/C_0 value for TP content at 75°C at the end of the drying process was higher than it was at 55 and 65°C. This result can be explained by long-term heat treatment at lower temperature and other detrimental factors, such as oxidation during long drying process, which might

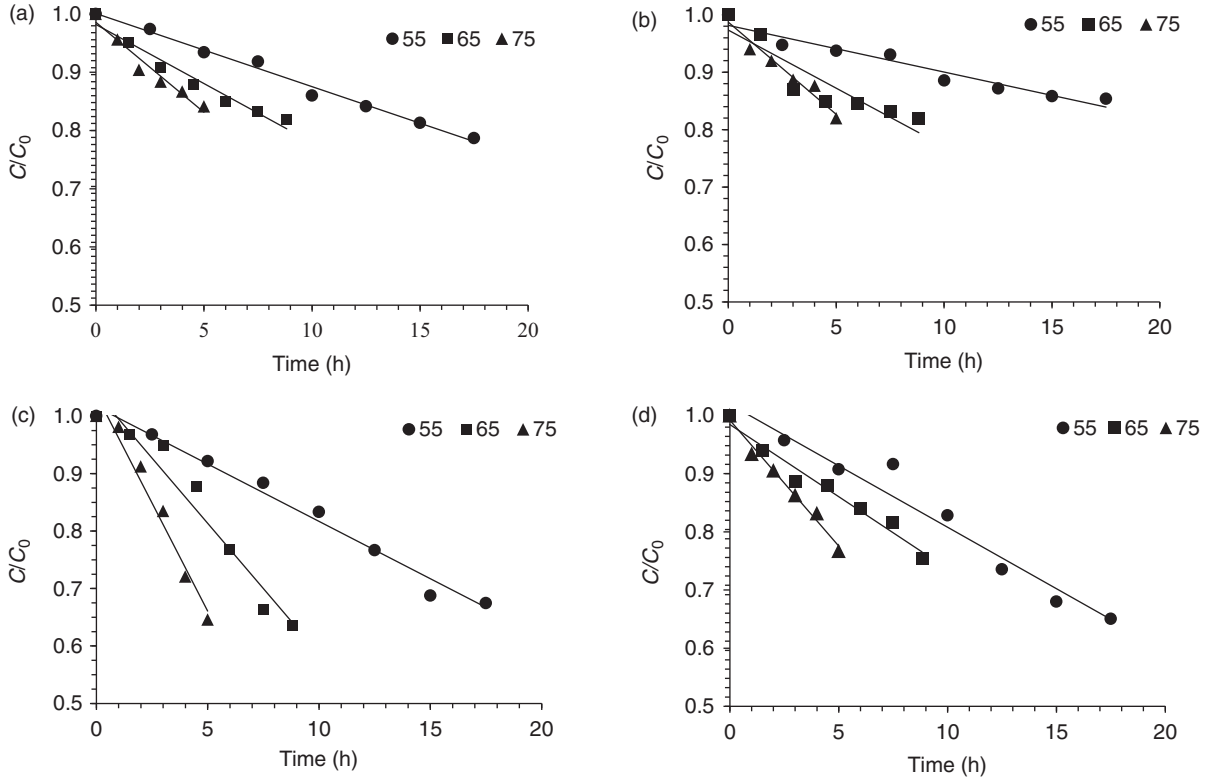


Figure 2 Degradation kinetics of bioactive compounds of pomegranate aril samples (a) TP, (b) DPPH, (c) TA, (d) flavonoids

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Table 3 Degradation kinetic parameters of pomegranate arils during drying process

	Temp. (°C)	R^2	k ($\times$ 1,000)	$t_{1/2}$ (h)	E_a (kJ/mol)
Total phenolic content(mg/kg)	55	0.989	13.696 ± 0.333	50.6	
	65	0.957	18.358 ± 1.158	27.3	31.76
	75	0.949	27.653 ± 2.108	18.4	
Total anthocyanin content (mg/kg)	55	0.908	18.630 ± 1.685	34.3	
	65	0.893	44.998 ± 4.707	15.4	39.10
	75	0.913	74.368 ± 7.669	9.3	
DPPH (%ARA)	55	0.913	10.351 ± 0.593	67.0	34.236
	65	0.906	25.291 ± 1.710	27.4	
	75	0.950	38.550 ± 2.168	18.0	
Total flavonoid (mg/kg)	55	0.931	22.632 ± 1.594	28.2	
	65	0.961	30.295 ± 1.294	21.1	37.85
	75	0.982	50.338 ± 1.827	12.7	

lead to the loss of bioactive compounds in the pomegranate arils. Similarly, Madrau et al. [43] reported that the degradation of polyphenol content and loss of antioxidant activity was higher at 55°C than at 75°C drying temperature. The authors stated that a longer drying time caused a greater loss of phenolic compounds at a lower drying temperature in the presence of air. These results are not in agreement with those of Karaaslan et al. [22] and Bchir et al. [44], who observed that TP and TA values were higher during the drying process of pomegranate arils at lower drying temperatures. In fact, Karaaslan et al. [22] reported that the TP values of pomegranate arils reduced to 64.0, 67.0, and 73.0% at 75, 65, and 55°C, respectively, employing a vacuum drying and hot water pretreatment process. The differences between these results and those from our study might have resulted from the fact that they applied a vacuum drying and pretreatment process. One explanation is that, by limiting oxygen with a vacuum process, they might have reduced the loss of bioactive compounds in their study. Bchir et al. [44] reported that TP values dropped to about 46, 43, and 41% at 40, 50, and 60°C, respectively. This significant loss of TP values might have resulted from the osmotic pretreatment process applied in their study. C/C_0 values of TF decreased to 0.65, 0.75, and 0.77 at 55, 65, and 75°C, respectively, at the last stage of the drying process. This loss of TF values was higher than that of TP values, indicating that flavonoids were more affected by drying conditions and are thus more sensitive to temperature than other phenolic compounds. Karaaslan et al. [22] observed the same trend in their study.

Experimental data were fitted to the Arrhenius model to predict bioactive compound degradations depending on temperature. The Arrhenius model was successfully applied to describe the effect of temperature on the degradation of bioactive compounds in pomegranate arils ($R^2 > 0.97$), as shown Figure 3. As can be seen, the degradation rate of TP, TF, and TA and the decrease in antioxidant activity increased as a function of temperature. Table 3 shows the Arrhenius model parameters. E_a values ranged from 31.75 to 39.10 kJ mol^{-1} for the bioactive compounds' degradation, with respect to temperature. The E_a values calculated for TP were lower than those for TF, indicating that flavonoids are more sensitive to heat treatment than TP. Karaaslan et al. [22] found an E_a value of 21.93–36.23 kJ mol^{-1} for TP and values ranging from 52.39 to 54.50 kJ mol^{-1} for TA when vacuum drying pomegranate arils. The fact that the E_a values were higher for TA than for TP indicates that the heat stability of TA is lower than that of TP.

4.5 Antioxidant activity

As mentioned above, pomegranates have antioxidant activity and can be classified as a functional food. This antioxidant activity is associated with their anthocyanin, phenolic, and flavonoid content and their collective free radical scavenging activity. For all the reasons above, antioxidant compounds can be seen as a quality indicator in the processing of pomegranate fruit. In the present study, antioxidant activity was determined by measuring the DPPH radicals scavenging capacity, which was found

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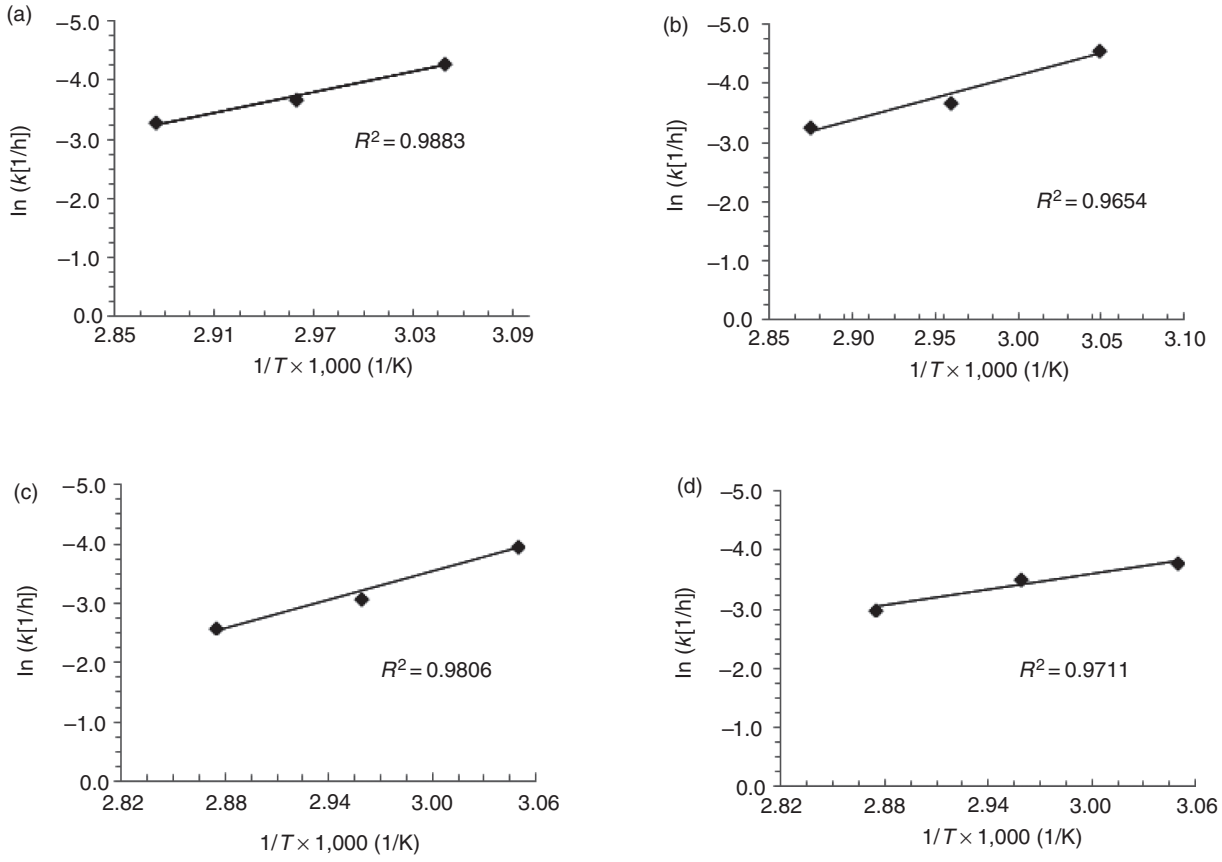


Figure 3 The Arrhenius plots for degradation of TP, TA, DPPH, and flavonoids in samples of (a) TP, (b) TA, (c) DPPH, and (d) flavonoids

to be 67.38%. Figure 2 shows that antioxidant activity changes as a function of time. Moreover, Figure 2(b and c) demonstrates that antioxidant activity is highly related to bioactive content. The C/C_0 values for the DPPH scavenging capacity during the last stage of the drying process were found to be 0.82, 0.83, and 0.85 at 55, 65, and 75°C, respectively, indicating that antioxidant activity also decreased as a function of drying time, regardless of temperature. These results were in agreement with those of other studies [44, 45] and might have resulted from the degradation of phenolic and flavonoid compounds. For these reasons, drying time and drying temperature should be adjusted in order to decrease the loss of bioactive components and antioxidant capacity in dried pomegranate arils [46]. The present study suggested that there were slight differences between drying temperature conditions in terms of antioxidant capacity change. These results were not in agreement with those of some other studies [22, 42, 47], which recommended low drying temperatures for reducing bioactive compound loss and decreases in antioxidant activity. These differences might have resulted from the pretreatment process applied in the studies of Bchir et al. [44] and Karaaslan et al. [22].

4.6 Color change

Color is an important parameter affecting customer preference and product quality. L^*, a^*, and b^* values were measured both before and after the drying process to determine the effect of drying conditions (especially temperature) on the color values of pomegranate arils. Table 4 shows the L^*, a^* and b^* values of untreated and dried arils at different drying temperatures. As can be seen, the L^* value reduced with increased drying temperature. This can be explained by the degradation of TF and TA content, non-enzymatic browning reactions, and a decrease in solubility and moisture content related to the drying process [46]. Table 4 also indicates that the a^* values increased as a function of drying time regardless of drying temperature. Anthocyanin is mainly responsible for the bright red color formation of pomegranate arils. The increasing a^* values of pomegranate arils in spite of the

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degradation of anthocyanin during the drying process can be explained by browning reactions. In fact, Mandala et al. [47] suggested that the decrease of "L^*" values and the increase of "a^*" values might result from the increase of fruit browning. ΔE values were obtained to understand the total color change at different drying conditions. As can be seen from Table 4, ΔE values were determined as 8.43, 7.64, and 6.46 at 55, 65, and 75°C, respectively. Statistical analysis showed a significant difference between the color values of dried and undried pomegranate arils ($p < 0.05$), indicating that enzymatic and, especially, non-enzymatic browning occurred during the drying process. Table 4 further demonstrates that b^* values of the samples were affected significantly by the application of different drying temperatures, whereas the L^* and a^* values were not significantly affected ($p < 0.05$). A similar trend was observed in studies conducted by Bchir et al. [44] and Vega-Galvez et al. [48]. The present study showed that the optimization of drying parameters is critical to maintaining the color value of pomegranate arils during the drying process.

Table 4 Color change of pomegranate arils after drying process

Parameters	Untreated arils	Dried arils		
		55°C	65°C	75°C
L	26.88 ± 1.07^{b}	20.67 ± 0.15^{a}	21.08 ± 1.90^{a}	22.21 ± 1.10^{a}
a	13.42 ± 1.34^{b}	18.84 ± 1.26^{a}	18.29 ± 1.33^{a}	17.84 ± 1.21^{a}
b	3.07 ± 0.29^{a}	4.95 ± 0.68^{bc}	4.13 ± 0.31^{b}	3.78 ± 0.47^{ab}
ΔE		8.43 ± 1.12	7.64 ± 0.63	6.46 ± 0.74

Note: Values in the same line with different lowercase letters (a, b, c) are significantly different as per the Duncan test ($P < 0.05$)

5 Conclusion

In this study, dehydration kinetics of pomegranate aril was determined and Logarithmic model showed a better fit to the experimental data ($R^2 > 0.998$ and RMSE < 0.1). The drying rate and bioactive compound degradation of the pomegranate arils were significantly affected by drying temperature, and the drying rate increased with increasing temperatures. The degradation rate of TPC, TFC and TA increased at higher temperature levels (between 55 and 75° C). However, bioactive component decreased due to a shorter drying process. Also, the study revealed that drying temperature levels did not significantly ($p < 0.05$) change the color parameters of pomegranate arils. The results of study suggest that high temperature short time drying conditions could assist preserving of valuable food biocomponents in pomegranate arils.

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