CI&CEQ
Chemical Industry & Chemical Engineering Quarterly

Available online at
Association of the Chemical Engineers of Serbia AChE
www.ache.org.rs/CICEQ

Chem. Ind. Chem. Eng. Q. 28 (2) 151–159 (2022) CI&CEQ

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SCIENTIFIC PAPER

UDC 66.057:547.475.2:634.6

IMPACT OF AIR TEMPERATURE ON DRYING CHARACTERISTICS AND SOME BIOACTIVE PROPERTIES OF KIWI FRUIT SLICES

Article Highlights

- The drying rate of kiwifruits was highly influenced by drying temperature
- The parabolic model was determined to best predict the experimental moisture ratio
- Effective diffusion coefficient showed an increment with the increasing drying temperature
- AAC, TPC, and AC of fresh kiwifruits were determined higher than dried fruits
- L and b values of kiwifruits decreased during the drying process, unlike increased values

Abstract

Drying kinetics, ascorbic acid content (AAC), total phenolic content (TPC), and antioxidant capacity (AC) of kiwifruits at different temperatures (60 °C, 70 °C, and 80) were investigated. The drying rate and effective moisture diffusivity of kiwifruits were the highest at 80 °C. Additionally, the Parabolic model best predicts the experimental moisture ratio at 60 °C and 70 °C, while the Page model described the drying curve at 80 °C. On the other hand, the AAC, TPC, and AC of kiwifruits were significantly influenced by temperature. Degradation of AAC increased with the increment in temperature, while TPC and AC were higher at the higher temperature. The range of the AAC, TPC, and AC of fresh and dried fruits were 165.59±12.58-462.81±11.53 mg/100 g DW, 747.66±16.09-1846.87±15.52 mg/100 g GAE DW, and 0.283±0.15-1.903±0.15 mmol TE/100 g DW, respectively. The highest AAC, TPC, and AC losses were calculated as 64.22%, 59.43%, and 85.13%, respectively.

Keywords: ascorbic acid, antioxidant capacity, drying kinetics, kiwifruit.

The reduction of degenerative diseases, cardiovascular diseases, and cancer has been partially related to fruit and vegetable consumption. Several studies have shown that this relation results from antioxidant compounds, reducing oxidative stress caused by free radicals [1-3]. The antioxidant compounds have free radical scavenging ability by inhibiting initiation and preventing chain propagation, suppressing the free radical formation that makes bonds with metal ions, reducing hydrogen peroxide, and quenching superoxide and singlet oxygen. Thus, antioxidant compounds preserve the human body from oxidative stress. Antioxidants naturally found in fruits and vegetables, such as ascorbic acid and phenolic compounds [1-5]. Ascorbic acid, one of the most important food components in fruits and vegetables, is a strong antioxidant, but it is quite a thermo-sensitive compound [5, 6]. Generally, the assumption of well retained ascorbic acid in foods indicates higher retention of other nutritional compounds at the end of the process. Thus, ascorbic acid is frequently analyzed as an indicator to demonstrate the effect of the process [6].

Additionally, ascorbic acid prevents N-nitroso compounds derived from nitrates or nitrites and is responsible for cancer [5]. On the other hand, phenolic compounds, which are seconder metabolites of plants, are strong antioxidants [7]. Therefore, the phenolic compounds play an important role in human health with the anti-inflammatory and anti-oxidative effects that

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Paper received: 26 January, 2021.
Paper revised: 12 June, 2021.
Paper accepted: 16 July, 2021.

https://doi.org/10.2298/CICEQ210126026T

boost the immune system and prevent cancers and cardiovascular diseases [8, 9].

Kiwifruits originated in China have been recently cultivated in the Black Sea region of Turkey. Due to its health-promoting effect by high ascorbic acid and phenolic compounds, kiwifruit is considered a high nutritional fruit [10, 11]. Kiwifruits show antioxidant activity and have anti-inflammatory effects and prevention effects on cancer, hypolipidemia in vivo experiments, cure nephrotoxicity, and chemically-induced toxicity [12-16]. Due to these properties, kiwifruits, called 'healthy fruit,' are a promising fruit species with high commercial potential and increasing production worldwide [8,9]. On the other hand, following the fully ripening, kiwifruits have a very short shelf life because of being perishable [10,11,17]. Some preservation methods can be suggested to prevent short shelf life, such as drying.

Dehydration, one of the oldest preservation methods of foods, is an effective method to preserve fruits after harvest and reduce food quality losses [18-20]. Dehydration, also called drying, aims to reduce moisture content and water activity, to prevent deterioration based on microbiological spoilage, to stop or slow down enzymatic activity and chemical reaction, to extend shelf life and make lower costs of transportation and storage as well as new ways of consumption [19, 21-27]. On the other hand, the drying process for a long time may cause some quality losses such as degradation of vitamins, phenolic compounds, unfavorable flavor, and color changes, or losses of essential amino acids [27,28].

Hot-air drying is the most common drying technique due to its simplicity and easiness to control [29, 30]. However, hot-air drying has several issues such as long drying time and high energy consumption at a lower temperature, loss of product quality at higher temperatures, and reduction in rehydration ability [30, 31]. Some authors reported a reduction in the nutritional value of kiwifruits by hot-air drying. It was stated that the content of ascorbic acid and phenolic compounds of kiwifruits was considerably reduced by hot-air drying [6]. Likewise, Akar and Mazı [32] reported that total lower phenolic content of kiwifruits was remarkably found in hot-air dried kiwifruits compared to fresh samples. In another study, vitamin C, total phenolic content, and antioxidant activity of fresh kiwifruits significantly decreased during hot-air drying. Besides, a higher drying temperature causes a higher reduction ratio [5].

Most of the current literature focused on drying kinetics of kiwifruits with different methods. However, a few of them mention the degradation of nutritional components of kiwifruits during drying. In summary, degradation of these important compounds that provide 'being regarded as healthy fruit' needs further data besides drying kinetics. In the study, hot-air drying was selected as it is the most preferred drying method. In this context, the study aimed to determine the drying characteristics of kiwifruit slices at different air temperatures and the impact on the ascorbic acid content (AAC), total phenolic content (TPC), and antioxidant capacity (AC) of fresh and dried kiwifruit slices.

MATERIALS AND METHODS

Materials

Sample preparation

Fresh kiwifruits (*Actinidia delicosa* cv. Hayward) were provided from a local market in Denizli, a province in Turkey. Fresh kiwifruits were washed, removed from foreign materials, and cut into 5±0.5 mm slices. Determination of initial moisture content of samples was carried out in a drying oven at 105 °C till any sample weight changed. The initial moisture content of kiwifruits was 84.02±0.4%.

Methods

Drying experiment

A cabinet dryer (Yücebaş, Makine Ltd. Inc., Izmir, Turkey.) was used for drying experiments. Before drying, the cabinet dryer was turned on for approximately 30 min for stability. The samples (50 g) were weighed on a drying tray and placed in the cabinet dryer for each drying experiment. Drying processes were performed at 60 °C, 70 °C, and 80 °C. Besides, the air velocity and relative humidity were 2 m s^{-1} and 20%, respectively. Samples were taken out and weighed at intervals with a digital weight measure with 0.01 g precision during the drying process. The drying experiments were continued until the moisture content of samples achieved 7% on a wet basis (WB). All the drying experiments were performed in duplicate.

Thin-layer drying modeling of drying data

Thin-layer drying modeling of drying is a necessary procedure to design the best drying conditions. In the current study, thin-layer drying models, the most used mathematical equations in the drying process, were used. These equations provide important information about drying temperature and time [33].

Eq. (1) was used for calculation of moisture ratio (MR) of kiwifruit slices:

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

where M_i, M_t, and M_e are the initial moisture content, moisture content at any time, and equilibrium moisture content of samples, respectively. When compared to M_t and M_0, M_e was equal to zero and negligible according to the previous reports [34,35]. All moisture contents were indicated on dry matter (g g^{-1} dry matter).

Eq. (2) was used for the determination of drying rate (DR):

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

where $M_{t+\Delta t}$ represents moisture content at time difference Δt is the difference of time between two measuring points.

The determination coefficient (R^2), root mean square error (RMSE), and reduced chi-square (χ^2) were the statistical parameters that explain the relation between predicted and experimental data of kiwifruit slices dried at various air temperatures. The RMSE expresses the deviation between the predicted and experimental values. The lower values of χ^2 and RMSE and a higher value of R^2 are required to determine the best equation predicting experimental data. The R^2 (Eq. 3), RMSE (Eq. 4), and Chi-Square (χ^2) (Eq. 5) values were calculated as follows:

$$R^2 = 1 - \frac{\sum \left(MR_{\exp} - MR_{pre}\right)^2}{\sum \left(MR_{\exp} - MR_{\exp,avr}\right)^2} \quad (3)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=o}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right]^{1/2} \quad (4)$$

$$\chi^2 = \frac{\sum_{i=0}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2}{N - n} \quad (5)$$

$MR_{pre,i}$ is the predicted MR of mathematical models, $MR_{exp,i}$ is the experimental MR, $MR_{exp,avr}$ is the average of the experimental MR, N is the number of observation data, and n is the constants of the thin-layer drying models. [33,36,37]. The process modeling of kiwifruit slices drying was determined using MATLAB software (R2015a, version 8.5) non-linear curve fitting toolbox with the trust-region algorithm.

Determination of effective moisture diffusivity and activation energy in hot-air drying

Fick's second law was used to determine effective moisture diffusivity as suggested in the papers on drying foods [24, 33, 38]. Crank [39] proposed Fick's second law for infinite slab objects with constant moisture diffusivity as Eq. (6):

$$MR = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-(2n+1)^2\pi^2\frac{D_{eff}t}{4L^2}\right) \quad (6)$$

Effective moisture diffusivity (D_{eff}) was calculated with Eq. (6) as kiwifruit slices were assumed as infinite slab material. In Eq. (6), D_{eff} represents the effective moisture diffusivity ($m^2\ s^{-1}$ or $m^2\ min^{-1}$), and L is the half-thickness of the initial size of the sample before drying (m). For simplicity, Eq. (6) can be further simplified to only the first term of the series. Thus, Eq. (6) is written in a logarithmic form as follows [24,33]:

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2}{4L^2}D_{eff}t\right) \quad (7)$$

The plot of $ln(MR)$ versus time (Eq. 7) is a straight line with a slope as follows [33, 35]:

$$Slope = \frac{\pi^2}{4L^2}D_{eef} \quad (8)$$

Activation energy is calculated by the Arrhenius equation in the hot-air drying process as given by Eq. (9) [33]:

$$D_{eff} = D_0\exp\left(-\frac{E_a}{RT}\right) \quad (9)$$

where R is the universal gas constant (8.314 J $mol^{-1}K^{-1}$ or 1.987 cal $mo^{l-1}K^{-1}$), T represents absolute temperature, E_a is the activation energy (kJ mol^{-1} or kcal mol^{-1}) and D_0 is the pre-exponential constant ($m^2\ s^{-1}$) [33, 34]. After regulation of Eq. (9), a new equation is derived by transforming Eq. (9):

$$\ln D_{eff} = \ln D_0 - \frac{E_a}{RT} \quad (10)$$

Natural logarithm of effective moisture diffusivity versus $1/T$ gives a straight line with a slope representing activation energy:

$$Slope = \frac{E_a}{R} \quad (11)$$

Analysis of AAC

Extraction of AAC was performed according to Dönmez [40]. Each sample (5 g) was weighed and homogenized with distilled water with a ratio of 1:9 (w/v) using a laboratory-type blender. The homogenized samples were centrifugated at 4500 rpm for 10 min (Nüve NF800R), the supernatants were taken and filtrated through a 0.45 µm filter before the injection into the HPLC. Each AAC analysis was performed in duplicate.

A microsyringe was used to inject 20 µl of the last filtrate into the HPLC column. Mobil phase consisted of

0.01N H_2SO_4, which is HPLC purity. A HPLC device (SHIMADZU), column oven at 25 °C (SHIMADZU CTO-20A), Column Coregel 87H3 (7.8x300 mm), pump (SHIMADZU LC-20AD), degasser (SHIMADZU DGU-20A3), photo diode array (PDA) detector (SPD-M20A) at 254 nm were used for analysis. The mobile phase was isocratic with a 1 ml min^{-1} flow rate.

AAC was calculated using an equation obtained from a calibration curve consisting of different concentrations of stock solutions (50, 100, 250, 500, 750, and 1000 ppm) with a high R^2 (0.9999). Results were expressed mg/100g in dry weight (DW).

Analyzes of TPC and AC

Analyzes of TPC and AC were performed with methanolic extraction suggested by Otağ [41]. 5 g kiwifruit samples were homogenized with 45 ml of 90% methanol through a laboratory-type blender. After centrifugation at 4500 rpm for 10 min, the supernatants were collected and filtrated using filter paper.

The method of Singleton and Rossi [42] was used to analyze TPC with a slight modification. Firstly, 300 µl of extract and 1500 µl of Folin-Ciocalteu solution (%10 v/v) were mixed and kept in the dark for 3 min. After 3 min, 1200 µl of aqueous Na_2CO_3 was added to the mixture. Then, the mixture was incubated at room temperature in a dark place for 2 h. At the end of the 2 h, the absorbance of samples was measured at 760 nm using a spectrophotometer (T80, PG Ins. UK.). Each analysis was carried out in duplicate. TPC was calculated by an equation obtained from a calibration curve consisting of different concentrations of stock solutions (25, 50, 75, 100, and 250 mg/L) with a high R^2 (0.9997). The results were expressed as mg/100g gallic acid equivalent (GAE) in DW.

The antioxidant capacity analysis was performed according to Thaipong *et al.* [43] with a slight modification. 150 µL of extracts and 2850 µL of DPPH methanolic solution, whose absorbance is 1.1 at 515 nm, were mixed, and the mixture was incubated at room temperature in a dark place for 60 min. Following 60 min, the absorbance of samples was measured at 515 nm. Each sample was analyzed in duplicate, and AC was calculated using an equation obtained from a calibration curve consisting of different concentrations of stock solutions (10, 20, 30, 40, and 50 mg/L) with the high R^2 (0.9988). Results were expressed as mmol Trolox equivalent (mmol TE)/100g in DW.

Determination of color parameters

The reflectance color value of the kiwifruit slice was measured using a Hunter Lab Color Miniscan XE (45/0-L, USA). The samples were placed on a white background, and the measurement was performed at four different edge spots on the surface by covering a transparent glass. The measurements were repeated five times. ΔE indicates total color differences of the samples. High ΔE values represent the high color change compared to initial color values, meaning that the process causes high color loss in the samples. ΔE was calculated as follows [44]:

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad (12)$$

Statistical analysis

All statistical analysis was carried out using SPSS software (ver. 22 SPSS Inc., Chicago, IL, USA). One-way analysis of variance (ANOVA) and then Duncan post hoc test was used for comparing the means at the significance level $p<0.05$.

RESULTS AND DISCUSSION

Influence of temperature on drying time

Fig. 1 shows the variation of *MR* and *DR* of kiwifruits depending on time. It is a fact that drying temperature plays a significant role in drying time. A higher evaporation rate was observed at higher temperatures. In this context, *DR* increased with the increment in drying temperature as expected, and consequently, drying time decreased. The times required to reduce 7% (*WB*) water content were 330 min, 240 min, and 210 min for 60 °C, 70 °C, and 80 °C, respectively. A falling rate period was observed for drying kiwifruits, not clearly constant rate as has been already observed [10,11,45].

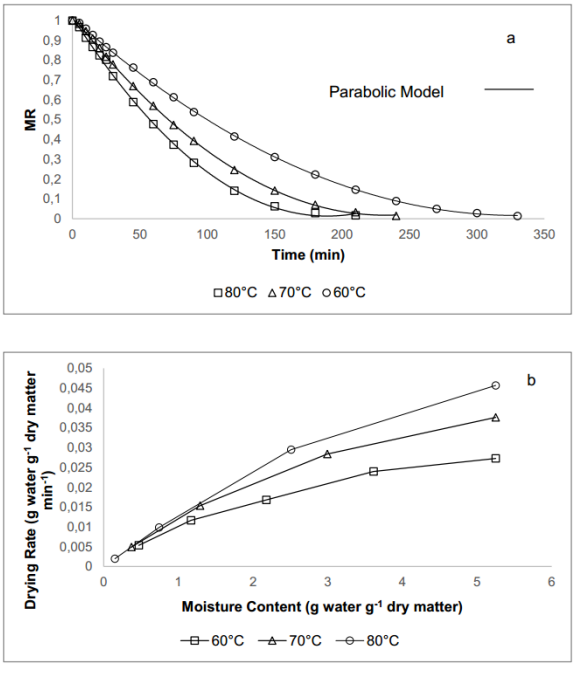

Figure 1. The variations of MR (a) and DR (b) of kiwifruits during the drying process at different temperature.

Mathematical modeling of convective drying curves

As shown in Fig. 1, the *MR* of kiwifruits at different temperatures fitted the mathematical models listed in Table 1. The statistical criteria were used to assess goodness to fit (Table 2). The R^2-values of the selected mathematical models were higher than the acceptable value of 0.90, as reported by Demiray *et al.* [33]. The lowest *RMSE*- and χ^2-values and the highest R^2-values for the drying curves at 60 °C and 70 °C were obtained from the Parabolic model, while the Page model was found to be suitable for the drying curve at 80 °C. The experimental and predicted *MR*-values obtained from the parabolic and Page models are compared in Fig. 2.

Table 1. Mathematical models of thin-layer drying curves

Model name	Model	Ref.
Logaritmic	$aexp(-kt) + c$	[33]
Lewis	$exp(-kt)$	[33]
Henderson and Pabis	$aexp(-kt)$	[33]
Page	$exp(-kt^n)$	[33]
Parabolic	$a + bt + ct^2$	[35]
Wang and Sing	$1 + at + bt^2$	[58]

Activation energy and effective moisture diffusivity

The values of effective moisture diffusivity and activation energy of kiwifruits are shown in Table 3. The effective moisture diffusivity of kiwifruits ranged from $3.01x10^{-8}$ to $4.99x10^{-8}$ m^2 min^{-1}. The effective moisture diffusivity of kiwifruits dried at 80 °C was the highest compared to those at other temperatures. It can be claimed that the effective moisture diffusivity increased with the increase in the drying air temperature. Thus, the moisture content of the samples could be more easily evaporated, and accordingly, *DR* increased. The effective moisture diffusivity is directly proportional to *DR* [33]. In the current study, effective moisture diffusivity of kiwifruits at 60 °C was found as $4.23x10^{-8}$ m^2 min^{-1}. At the same time, Chin *et al.* [45] and Kaya *et al.* [10] have notified that effective moisture diffusivities of kiwifruits at 60 °C and 65 °C were $1.57x10^{-8}$ m^2 min^{-1} and $5.81x10^{-10}$ m^2 s^{-1}. This difference could result from relative humidity, air velocity, and slice thickness.

The activation energy was calculated as a function of absolute temperature and given in Fig. 3. A slope obtained from the natural logarithm of effective moisture diffusivity versus T^{-1} was used to calculate activation energy. The activation energy was found to be 24.71 kJ mol^{-1} and 5.9 kcal mol^{-1}. Chin *et al.* [45] and Kaya *et al.* [10] have notified 37.70 kJ mol^{-1} and 27.707 kJ mol^{-1} activation energy for the 6 mm and 7 mm kiwifruit slices, respectively.

Effect of drying process on AAC, TPC, and AC

The effects of the temperature on AAC, TPC, and AC are shown in Table 4. The drying temperature con-

Table 2. Model constants and statistical parameters of thin-layer drying curves

Model	Temperature, °C	Model Constants			χ²	RMSE	R²
	60	k= 0.007714			0.002462495	0.04830	0.9828
Lewis	70	k= 0.010610			0.002830165	0.05151	0.9799
	80	k= 0.013110			0.002689296	0.05010	0.9809
	60	k= 0.001964	n= 1.285		0.000250131	0.01496	0.9984
Page	70	k= 0.002699	n= 1.310		0.000160754	0.01186	0.9990
	80	k= 0.003701	n= 1.302		0.000186690	0.01272	0.9989
	60	k= 0.008316	a= 1.056		0.001765952	0.03975	0.9890
Henderson and Pabis	70	k= 0.011630	a= 1.066		0.001846903	0.04020	0.9886
	80	k= 0.014300	a= 1.063		0.001922622	0.04082	0.9883
	60	k= 0.008549	a= 1.044	c= 0.0136	0.002185487	0.04290	0.9872
Logaritmic	70	k= 0.011970	a= 1.054	c= 0.0147	0.002335352	0.04356	0.9886
	80	k= 0.014800	a= 1.049	c= 0.0173	0.002509920	0.04481	0.9858
	60	a= -0.005866	b= 0.00008698		0.000083915	0.00867	0.9995
Wang and Singh	70	a= -0.008218	b= 0.00001706		0.000262311	0.01515	0.9984
	80	a= -0.010220	b= 0.00002643		0.000292806	0.01593	0.9982
	60	a= 1.013	b= -0.006050	c= 0.000009186	0.000027098	0.00478	0.9999
Parabolic	70	a= 1.023	b= -0.008671	c= 0.000018710	0.000086925	0.00840	0.9995
	80	a= 1.018	b= -0.010630	c= 0.000028130	0.000202566	0.01273	0.9989

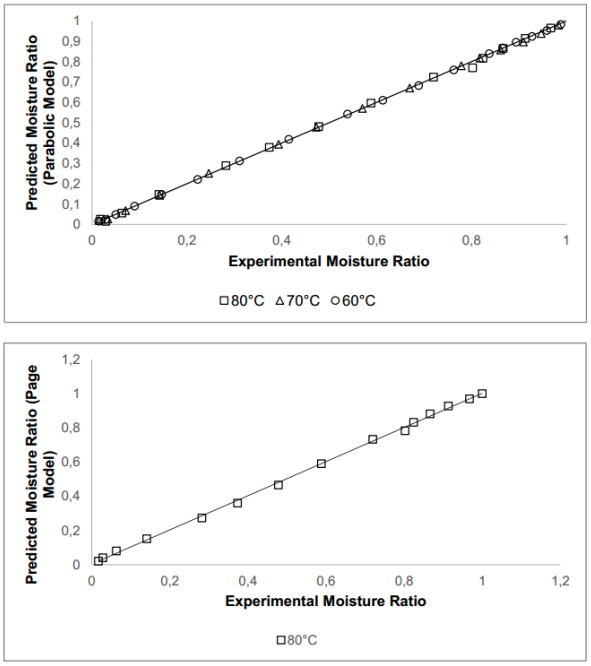

Figure 2. Comparison of the experimental and predicted MR values for the drying curves at 60 °C, 70 °C, and 80 °C (parabolic and Page model).

Table 3. Effective moisture diffusivity and activation energy of convective dried kiwifruits

Temperature	D_{eff}	E_a	E_a
°C	(m^2 min^{-1})	(kJ mol^{-1})	(kcal mol^{-1})
60	$3.01x10^{-8}$		
70	$4.23x10^{-8}$	24.71	5.9
80	$4.99x10^{-8}$		

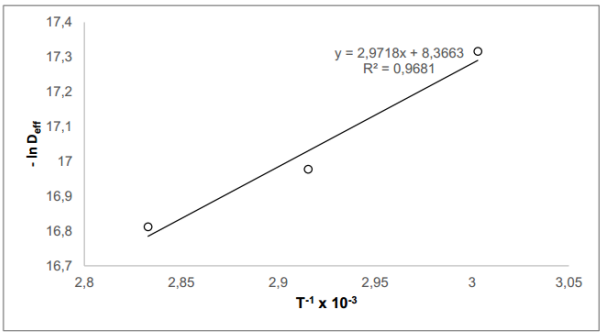

Figure 3. The Arrhenius-type relationship between the effective moisture diffusivity and absolute temperature.

siderably influenced the degradation of AAC and TPC. AAC and TPC were 462.81±11.53 mg 100 g^{-1} and 1846.87±15.52 mg GAE 100 g^{-1} in fresh kiwifruits. Correia *et al.* [5] reported higher values (535 mg 100 g^{-1} AAC and 3376 mg 100 g^{-1} TPC). but on the contrary, Leontowicz *et al.* [46] found a lower value of TPC (5.41-5.47 mg GAE 100 g^{-1}) than the present results. The highest AAC and TPC loss was 64.22% and 59.43% at 80 °C and 60 °C, respectively. AAC was highly affected by increasing drying temperature. This result was in good agreement with the previous reports [5,6,10,11,45,47,48]. The loss of AAC in kiwifruits was 57.27%, 59.90%, and 64.22% at 60 °C, 70 °C, and 80°C, respectively. Correia *et al.* [5] have reported the loss AAC in kiwifruits of 76%, 79%, and 82% at the end of the drying process carried out at 60 °C, 70 °C, and 80 °C, respectively, which are larger than the loss found in the present study. Higher AAC degradation at higher temperatures can be associated with its thermo-sensitivity character and easy degradable structure. It was notified that higher temperatures cause an increase in the rate of ascorbic acid oxidation (non-enzymatic or enzymatic) [11, 49]. TPC was also reduced by drying. Similarly, Akar and Barutçu Mazı [32] indicated lower phenolic compounds in hot-air dried kiwifruits when compared to fresh samples. However, the loss of TPC decreased with increasing drying temperature. Likewise, López *et al.* [4] have notified a higher TPC at higher drying temperatures of blueberries, although the TPC decreased with drying temperature. Izli *et al.* [50] have reported similar results for kiwifruits. It could be explained by the formation of phenolic compounds at higher temperatures because of the availability of precursors of phenolic molecules by the non-enzymatic interconversion between phenolic molecules [47]. The loss of TPC in kiwifruits was 59.43%, 54.72%, and 53.61% at 60 °C, 70 °C, and 80 °C, respectively. Correia *et al.* [5] have reported a decrease of 80%, 88%, and 93% in the TPC at kiwifruits dried at 60 °C, 70 °C, and 80 °C, respectively. A mean difference was found between the AAC and TPC of fresh and dried kiwifruits ($p<0.05$). The AC of fresh kiwifruits was 1.903±0.15 mmol TE 100 g^{-1} (DW). This value is lower than the value (6160 μmol TE 100 g^{-1}) notified by Correia *et al.* [5]. Drying temperature significantly affected the AC of kiwifruits ($p<0.05$), and the highest AC loss was in the samples dried at 60 °C. The exposure of the compounds with antioxidant activity to high temperatures causes degradation and decrement in the AC. However, the temperature is not the only factor affecting the degradation of the antioxidative compounds. Drying time is also an important factor, and the longer time, the higher degradation [5]. Similar to TPC, the loss of AC decreased with the increment in drying temperature. Long drying time may decrease antioxidant capacity [51]. Similar findings were reported by Horuz *et al.* [44]. On the contrary, Correia *et al.* [5] have notified that AC loss increased based on the increment in drying temperature. Decreasing AC has been proportionally

associated with the loss of AAC of the TPC [52,53]. Additionally, the correlation coefficients (r) between AAC and AC were 0.964, 0.934, and 0.964 at 60 °C, 70 °C, and 80 °C, respectively, while correlation coefficients between TPC-AC were calculated as 0.977, 0.958 and 0.974 at 60 °C, 70 °C, and 80 °C, respectively. According to these results, TPC contributed most to AC than AAC at each temperature.

Table 4 . AAC, TPC and AC of fresh and dried kiwifruits

Temperature	Time	AAC	Loss Percentage	TPC	Loss Percentage	AC	Loss Percentage
°C	h	mg 100 g^{-1} DW	%	mg 100 g^{-1} DW	%	mmol TE 100 g^{-1} DW	%
60	0	462.81±11.53^{a}	0	1846.87±15.52^{a}	0	1.903±0.15^{a}	0
	5.5	197.74±11.58^{b}	57.27	747.66±16.09^{b}	59.43	0.283±0.15^{b}	85.13
70	0	462.81±11.53^{a}	0	1846.97±15.52^{a}	0	1.903±0.15^{a}	0
	4	185.59±10.40$^{b\,c}$	59.90	837.35±17.01^{c}	54.72	0.480±0.01^{c}	74.78
80	0	462.81±11.53^{a}	0	1846.97±15.52^{a}	0	1.903±0.15^{a}	0
	3.5	165.59±12.58^{c}	64.22	857.47±16.50^{c}	53.61	0.475±0.005^{c}	75.03

*Different letters in the same column indicate significant differences with a confidence of 95%.

Color values of fresh and dried kiwifruit slices

The color values of fresh and dried kiwifruits are presented in Table 5. The *L*, *a*, and *b* values of fresh kiwifruits were 43.68±0.96, -3.73±0.06, and 16.64±0.45, respectively. The *L* value was significantly reduced by drying ($p<0.05$). The highest reduction in the *L* value was obtained from kiwifruits dried at 80 °C, meaning that the darkest dried kiwifruits were obtained at 80 °C. On the other hand, the *a* value remarkably increased during the drying, and the temperature greatly affected it ($p<0.05$). The *b* value of the fresh samples was higher than that of the dried kiwifruit slice samples ($p<0.05$). During drying, the redness of kiwifruits increased while the yellowness decreased. The degradation of some pigments, the oxidation of phenolic compounds, and the non-enzymatic browning directly affect the color of the dried fruit. Chlorophylls *a* and *b* are the major color pigments of kiwifruits [32]. The chemical structure of chlorophyll changes with heat treatment that causes magnesium replacement [54]. Accordingly, pheophytin and pheophorbide, darker pigments than chlorophylls, are derived [55]. A lower *L* value indicates higher darkness. Decrement in *L* values of the dried kiwifruits may be possibly explained by these alterations of chlorophyll's chemical structure because of the drying process and other factors affecting the color. Higher temperature leads to darker pigments formation, and thus, the *L* value of dried kiwifruits showed more decrement at higher temperatures. On the other hand, kiwifruits contain xanthophylls and β-carotene as chlorophylls [32]. Chlorophylls mask the yellow color of the carotenoids as the major color pigment and provide fresh green color [56]. Even though an increment in the *b* value is expected with removing the mask because of the change in chlorophylls, the b value decreased. This can be associated with the possible carotenoid degradation in kiwifruits. Akar and Barutçu Mazı [32] reported that the degradation of chlorophylls affects the *a* value of the foods. As the retention of the chlorophylls increased, the *a* value of kiwifruits decreased [32]. In the present study, increment in the *a* value may be proved with this statement. Likewise, Doymaz [57] notified a decrease in the *L* and *b* values of the infrared dried kiwifruits at the end of drying, and the *a* value increased compared to fresh kiwifruits. Moreover, the highest ΔE value was observed at 80 °C, meaning that the highest color change of kiwifruits occurred.

Table 5 . Color values of fresh and dried kiwifruits

	L	*a*	*b*	ΔE
Fresh	43.68± 0.96^{a}	-3.73± 0.06^{a}	16.64 ± 0.45^{a}	0
60 °C	35.45± 0.27^{b}	1.99 ± 0.01^{b}	15.18 ± 0.10^{b}	10.13
70 °C	34.17± 0.12^{b}	2.02 ± 0.03^{b}	14.66 ± 0.08^{b}	11.29
80 °C	32.51± 0.36^{c}	2.55 ± 0.03^{c}	13.61 ± 0.13^{c}	13.17

* Different letters in the same column indicate significant differences with a confidence of 95%.

CONCLUSION

Turkey's most common cultivated kiwifruits (*Actinidia delicosa* cv. Hayward) were investigated at different drying temperatures. The *DR* of kiwifruit slices was highly influenced by drying temperature. The longest drying time was 330 min at 60 °C, and the shortest was 210 min at 80 °C. The drying curves at 60 °C and 70 °C were suitably described with the Parabolic model, while the Page model gave a better fit for the drying curve at 80 °C. The effective moisture

diffusivity showed an increment with the increase in drying temperature. The highest effective moisture diffusivity was at 80 °C. The AAC, TPC, and AC were higher for fresh than dried kiwifruits. The highest reduction of AAC was observed at 80 °C because of the more rapid enzymatic and non-enzymatic degradation. On the contrary, the highest loss of TPC and AC occurred at 60 °C. The *L* and *b* values of kiwifruits decreased during the drying process, unlike the *a* value that increased. Higher temperature caused a higher color degradation. For preventing color degradation, lower drying temperatures should be preferred.

As a result, although higher temperatures provide a short drying time, a higher loss of AAC and color degradation were observed. In addition, relatively high retention of TPC and AC was determined at higher temperatures. In summary, while drying at 60 °C causes the highest loss of TPC and AC, the highest loss of AAC and color degradation drying at 80 °C. In light of these data, drying at 70 °C should be suggested for moderate nutritional loss and color degradation. On the other hand, hot-air drying was selected due to mostly being preferred for industrial production, easier to use, relatively cheaper. However, some promising methods should be evaluated. Therefore, kiwifruits should be dehydrated with other drying methods such as vacuum, microwave, combinations of vacuum-microwave, microwave-hot air in further studies as suggestions. Thus, the most suitable conditions and methods may be optimized by observing the loss of nutritional compounds and color properties during the process.

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NAUČNI RAD

UTICAJ TEMPERATURE VAZDUHA NA KARAKTERISTIKE SUŠENJA I NEKA BIOAKTIVNA SVOJSTVA KRIŠKI VOĆA KIVI

Istraživana je kinetika sušenja, sadržaj askorbinske kiseline (AAC), ukupni sadržaj fenola (TPC) i antioksidativni kapacitet (AC) plodova kivija na različitim temperaturama (60 °C, 70 °C i 80 °C). Brzina sušenja i efektivna difuzivnost vlage kivija bila je najveća na 80 °C. Parabolni model najbolje predviđa promenu sadržaja vlage na 60 °C i 70 °C, dok Pejdžov model bolje opisuje krivu sušenja na 80 °C. Sa druge strane, na AAC, TPC i AC kivija značajno je uticala temperatura. Degradacija AAC se povećavala sa povećanjem temperature, dok su TPC i AC bili viši na višoj temperaturi. Raspon AAC, TPC i AC svežeg i sušenog voća iznosio je 165,59±12,58-462,81±11,53 mg/100 g (računo na suvu masu), 747,66±16,09-1846,87±15,52 mg GAE/100 g i 0,283±0.15-1,903±0.15 mmol TE/100 g, redom. Najveći gubici AAC, TPC i AC iznose 64,22%, 59,43% i 85,13%, redom.

Ključne reči: askorbinska kiselina, antioksidativni kapacitet, kinetika sušenja, kivi.