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# CONVECTIVE DRYING OF CHOKEBERRY CV. "VIKING" AND MODELING OF DRYING KINETICS

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## ABSTRACT
In this study, the effects of drying air temperatures (50, 60, 70, and 80°C) and velocities (0.5, 0.8, and 1.2 m/s) on chokeberry quality during convective drying were evaluated. The drying time decreased significantly with increasing drying air temperatures and velocities, from 2265 minutes at 50°C to 195 minutes at 80°C, and from 360 minutes at 0.5 m/s to 240 minutes at 1.2 m/s at 70°C. Higher drying air temperatures and velocities also enhanced the fruit color quality. The best antioxidant activity, anthocyanin, and phenolic content were achieved at 70°C with dryin air velocities between 0.5 m/s and 1.2 m/s. The Midilli et al. model provided the best fit for the drying kinetics, with high accuracy ($R^2 \geq 0.9978$, $\chi^2 \leq 0.0003$, RMSE≤0.0161).
**Keywords***:* Antioxidants, capacity, black chokeberries, drying, modeling, *Rosaceae*

# ARONYANIN KONVEKTİF KURUTULMASI VE KURUTMA KİNETİĞİNİN MODELLEMESİ

## ÖZ
Bu çalışmada, konvektif kurutma sırasında farklı kurutma havası sıcaklıklarının (50, 60, 70 ve 80°C) ve hızlarının (0.5, 0.8 ve 1.2 m/s) aronya meyvesi kalitesi üzerindeki etkileri incelenmiştir. Artan

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sıcaklık ve hava hızı ile kuruma süresi önemli ölçüde azalmış; 50°C'de 2265 dakika olan süre, 80°C'de 195 dakikaya düşmüştür. 70°C'de ise 0.5 m/s'de 360 dakika olan süre, 1.2 m/s'de 240 dakikaya düşmüştür. Daha yüksek sıcaklık ve artan hava hızları meyve rengi kalitesini iyileştirmiştir. En yüksek antioksidan aktivitesi, toplam antosiyanin ve toplam fenolik içerik 70°C'de, 0.5 m/s ile 1.2 m/s hava hızları arasında elde edilmiştir. Kuruma kinetiklerinin tanımlanmasında ise Midilli ve ark. modeli yüksek doğrulukla uyum sağlamıştır ($R^2 \geq 0.9978$, $\chi^2 \leq 0.0003$, RMSE≤0.0161).
**Anahtar Kelimeler:** Antioksidanlar, kapasite, aronya, kurutma, modelleme, *Rosaceae*

**INTRODUCTION**

Chokeberry [*Aronia melanocarpa* (Michx.) Elliott] belongs to the family *Rosaceae* and is a berry fruit crop. Initially grown in north and northeastern Türkiye in 2012 (Boz and Poyraz Engin, 2019), its cultivation has expanded to the highlands of Central Anatolia and the Mediterranean regions in recent years. The primary reason for its growing popularity is its exceptionally high antioxidant capacity and anthocyanin content compared to other berry types (Oszmianski and Sapis, 1988; Wu et al., 2006; Kulling and Rawel, 2008). Chokeberry fruits are rich in polyphenols (Jeppsson and Johansson, 2000; Krawiec, 2008) and contain high levels of cyanidin-3-arabinoside and cyanidin-3-galactoside (Borowska and Brzoska, 2016). Among more than 100 types of fruits, chokeberry ranks first in antioxidant capacity (Wu et al., 2006). One kilogram of fresh chokeberry fruit contains 2147 mg/100 g total anthocyanin content, significantly higher than blueberries (529-705 mg/100 g), raspberries (116-845 mg/100 g), and blackberries (353-433 mg/100 g FW) (Wu et al., 2006).

Chokeberry fruits also contain 14-28 mg/100 g vitamin C, 1.8-2.5 mg/100 g carotene, 0.05-0.1 mg/100 g vitamin B9, 0.5-0.8 mg/100 g vitamin E, 12-20% total soluble solids, 560-1050 mg/100 g FW total anthocyanin content, a pH of 3.3-3.7, and 0.7-1.2% titratable acidity (Jeppsson and Johansson, 2000). According to Kulling and Rawel (2008), the fruit consists of 74-80% water, 15.6-28.8% total soluble solids, 66-176 g/kg FW glucose and fructose, 3.4-5.8 g/kg FW pectin, 0.14% oil, and 13.1 g/kg FW malic acid. Horszwald et al. (2013) found that chokeberry powders are high in polyphenolic compounds.

Chokeberry's positive effects on human health have been noted, including benefits for cancer prevention, immune system support, digestive health, heart problems, obesity, and diabetes (Gasiorowski et al., 1997; Kulling and Rawel, 2008; Tolic et al., 2015; Boz and Poyraz Engin, 2019; Sidor and Gramza-Michalowska, 2019). Globally, chokeberry fruits are consumed both fresh and processed into products such as jam, fruit juice, ice cream, energy drinks, tea, sauce, syrup, natural colorants, and nutritional supplements (Bussieres et al., 2008). In Türkiye, while fresh consumption is common, processing into fruit juice, ice cream, and yogurt has recently begun (Poyraz Engin et al., 2016). Due to the fruit's excessive sourness, bitterness, and astringency, exploring various drying and processing techniques is necessary.

Drying is a primary method of food preservation, and new methods are being tested on various materials in numerous studies (Sadowska et al., 2019). Recently, significant attention has been given to new drying and milling methods for producing powdered fruits and vegetables. Convective dryers are the most widely accepted method for drying fruits and vegetables (Oszmianski and Lachowicz, 2016). Sadowska et al. (2019) compared different drying techniques (freeze-drying, vacuum drying, convection drying, and high-energy air stream) using a laboratory convection dryer at 70°C for 48 hours. Calin-Sanchez et al. (2015) processed convective drying at 60°C with an air velocity of 0.8 m/s. Various drying techniques, including freeze, convective, vacuum microwave, and combined drying, have been used for black chokeberry fruits.

Petkovic et al. (2019) examined different convective drying processes (50, 60, and 70°C) for producing chokeberry powder. Samoticha et al. (2016) investigated the effects of different drying methods (convective, vacuum, freeze, microwave, and combined drying) on chokeberry fruit quality. Alterations in chemicals causing flavor and nutrient loss were observed during convective drying (Krokida and Marinos-Kouris, 2003). Petkovic et al. (2019) found that at 50°C, a longer drying time and higher energy requirement were needed to produce chokeberry powder, but the best sensory characteristics were achieved compared to 60 and 70°C. Horszwald et al. (2013) stated that the quality of chokeberry powder may vary depending on the drying process applied. Drying fresh fruits promotes long-term consumption without spoilage. For example, the polyphenol content of chokeberry was studied in response to processing techniques by Hellstrom et al. (2007) and Mayer-Miebach et al. (2012). Samoticha et al. (2016) found that total phenolic and anthocyanin content in chokeberry fruits were more stable with microwave drying. However, only a few studies have focused on the convective drying of chokeberry and subsequent changes in its biochemical contents. Additionally, understanding the drying kinetics is critical for equipment design, process optimization, and product quality improvement. Mathematical model descriptions are important for enhancing process performance. These kinetic parameters can also be used to estimate the drying time of chokeberry to achieve a specific moisture content.

The objective of this study was to determine the optimal drying conditions to ensure the long-term quality of chokeberry fruits. Additionally, a preprint has previously been published.

## MATERIAL AND METHODS

### Material

In this study, 'Viking' [*Aronia melanocarpa* (Michx.) Elliott] chokeberry was used and purchased from Konya, Türkiye (38° 10' 51.2" N, 32° 24' 57.5" E). Fruit samples were randomly collected in their black color maturity (20 August 2020) and analyzed in the laboratories of Akdeniz and Isparta Applied Sciences Universities.

### Drying experiments

The convective drying experiments were conducted using a laboratory dryer (Corvus, Turkey). In these experiments, the effects of drying air temperatures of 50, 60, 70, and 80°C at a constant air velocity of 0.8 m/s, and the effects of air velocities of 0.5, 0.8, and 1.2 m/s at a constant air temperature of 70°C on the drying kinetics of chokeberry were measured. During the drying process, the weight of the samples was measured every 15 minutes to determine changes in moisture content. The effects of these conditions on color, antioxidant activity, total anthocyanin content, and total phenolic content were also investigated.

The reason for selecting an air velocity of 0.8 m/s is that this speed provides optimal conditions in many drying studies. Various studies have shown that an air velocity of 0.8 m/s optimizes drying time while preserving product quality (Erbay and Icier, 2010; Mujumdar, 2014; Vega-Gálvez et al., 2008). This air velocity is effective in maintaining the structural and chemical properties of sensitive products such as fruits and vegetables while ensuring sufficient drying speed.

Experiments conducted at different temperatures aimed to determine the most suitable temperature for drying chokeberry. The drying temperature significantly affects the evaporation rate of water content in the fruit and, consequently, the drying time. This study examined the effects of different temperatures on the drying kinetics, color, antioxidant activity, total anthocyanin content, and total phenolic content of chokeberry. The objective of the research is to determine the optimal drying temperature for chokeberry, thereby optimizing the drying process to be both efficient and protective of fruit quality.

### Mathematical modeling of drying processes

The 11 different models presented in Table 1 were used to describe the drying kinetics for the moisture ratio (MR, Eq. 1) data of the samples. Parameters in all models were decided using Sigma Plot 14.0 (Systat Software Inc., USA). Evaluation of the models was performed using the coefficient of determination ($R^2$), reduced chi-squared ($\chi^2$) value (Eq. 2) and root main-square error (RMSE) (Eq. 3). These parameters were calculated using the following equations.

Table 1. Selected drying models for describing sample drying data

| Model name | Model equation | Reference |
|---|---|---|
| Lewis | MR = exp(-k t) | Ertekin and Firat, 2017 |
| Henderson and Pabis | MR = a exp(-k t) | Sonmete et al., 2017 |
| Page | MR = exp(-k $t^n$) | Yaldiz and Ertekin, 2001 |
| Two-term | MR= a exp(-$k_0$ t) + b exp(-$k_1$ t) | Ertekin and Firat, 2017 |
| Two-term exponential | MR = a exp(-k t) + (1-a) exp(-k a t) | Ertekin and Heybeli, 2014 |
| Logarithmic | MR= a exp(-k t) + c | Kayisoglu and Ertekin, 2011 |
| Wang and Singh | MR = 1 +a t + b $t^2$ | Ertekin and Firat, 2017 |
| Midilli et al. | MR= a exp(-k $t^n$) + b t | Menges et al., 2019 |
| Verma et al. | MR = a exp(-k t) + (1-a) exp(-g t) | Karaaslan et al., 2021 |
| Diffusion approach | MR= a exp(-k t) + (1-a) exp(-k b t) | Ertekin and Firat, 2017 |
| Root of MR | MR= $(n + k t)^2$ | Ertekin and Firat, 2017 |

*t:* drying *time (min); MR: moisture ratio, k, a, b, c, g, n, $k_0$, $k_1$ are model constants.*

The moisture ratio (MR) of the samples during the drying processes was calculated according to Eq. (1):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

Where $M_0$ is the initial moisture content, $M_t$ is the moisture content at any time (t, min), and $M_e$ is the equilibrium moisture content during the drying process. The value of $M_e$ was assumed as zero because it is lower than $M_0$ or $M_t$ (Dincer et al., 2022; Kayisoglu and Ertekin, 2011). Contents of all moisture were exemplified as kg water/kg dry matter.

$$\chi 2 = \frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{n-z} \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2} \quad (3)$$

The predicted moisture ratio is $MR_{pre,i}$; where n is the number of observations; $MR_{exp,i}$ is the experimentally observed moisture ratio, and z is the number of constants in the models. The lower $\chi 2$ and RMSE values together with $R^2$ values close to 1 indicate better suited model of the data (Basar et al., 2019).

**Color measurement**

Fruit skin colors (fresh and dried samples) were determined using a colorimeter (3NH NR20XE Precision, Shenzhen Threenh Technology Co., Ltd., China) in terms of "L" (whiteness=darkness), "a" (redness=greenness), "b" (yellowness=blueness), C (chroma) and $h^o$ (hue angle). According to the Nsonzi and Ramaswamy (1998), the total color difference (ΔE) was estimated as follows:

$$\Delta E= [(L-L_o)^2 + (a-a_o)^2 + (b-b_o)^2]^{1/2} \quad (4)$$

where $L_o$, $a_o$ and $b_o$ demonstrate the brightness, redness, and yellowness of the dried samples, respectively.

**Preparation of extracts**

Extraction was performed according to the method by Liu et al. (2016) with some alterations. One gram of the sample was weighed into a 50 mL centrifuge tube after being crushed with a blender (Beko BKK-2155 Maxi Hand Blender, Türkiye) and added to 20 mL of 60% ethyl alcohol (containing 0.1% HCl). The tubes were located in an ultrasonic bath (Caliskan Ultrasonic cleaner 180 W, 40 kHz, Türkiye) and extracted at 40 kHz and 30$^o$C for 30 min. After the samples were centrifuged in a centrifuge (Eppendorf Centrifuge 5810, Germany) for 10 min at 4000 rpm, the supernatant was taken. Extraction was replicated in triplicate. The filtrate was obtained and stored at 4$^o$C until use.

*Determination of antioxidant activity using DPPH*

Antioxidant activity was measured using the DPPH assay determined by Fernandez-Leon et al. (2013). From the sample extract, 50 µL was added to 950 µL of diphenylpicrylhydrazyl (DPPH) solution (6 x $10^{-5}$ M in methanol). The mixtures were shaken and saved in the dark at room temperature for 30 min. Absorbances were recorded at 515 nm (Thermo Scientific Evolution 160 UV-Vis, USA). Trolox was chosen as the standard of the study and the antioxidant activity was expressed in mg Trolox equivalent (TE) /kg.

*Total monomeric anthocyanin content (TAC)*

The total monomeric anthocyanin content was measured using a pH-differential method reported by Wang and Xu (2007) in combination with a two-buffer system that utilized potassium chloride buffer (0.025 M, pH 1.0) and sodium acetate buffer (0.4 M, pH 4.5). Extracts were diluted with buffers (pH 1 or 4.5) and incubated for 30 min at room temperature before absorbances were reported at 520 and 700 nm (Thermo Scientific Evolution 160 UV-Vis, USA). Total anthocyanins were calculated as cyanidin-3-glucoside (mg/kg) according to the following Equation (1):

Monomeric anthocyanin (mg/kg) = A x MW X DF X 1000 / (ε X 1)

Where $A = (A_{520} - A_{700})pH_{1.0} - (A_{520} - A_{700})pH_{4.5}$ : MW (molecular weight) = 449.2 g/mol for cyanidin-3-glucoside; DF = dilution factor; 1 = path length in cm; ε = 26.900 molar extinction coefficient in kg/ (mol·cm) for cyanidin-3-glucoside; 1000 = conversion from g to mg.

*Determination of total phenolic content (TPC)*

The total phenolic content was determined with the method by Dincer et al. (2013). 0.5 mL of the extract was treated with 2.5 ml of 0.2 N Folin-Ciocalteu reagent and 2 mL of $Na_2CO_3$ (75 g/L). Then, the mixture was incubated in water bath at 50°C for 5 min and cooled in water bath at 25°C. The absorbance of the final solution was measured with a spectrophotometer (Thermo Scientific Evolution 160 UV-Vis, USA) at a wavelength of 760 nm with respect to the blank solution (60% ethyl alcohol (including 0.1% HCl). The outcome was reported as gallic acid equivalents (mg GAE/kg).

**Statistical Analysis**

The studies were performed in a totally randomized design with three replications. Statistics were analyzed using SAS. The analysis of variance and LSD multiple range test was used to determine the significant differences in the means (95% confidence level).

## RESULTS AND DISCUSSION

**Moisture content**

The drying process was carried out up to the final moisture content of 10% (w.b.). The effects of the drying air temperatures at the constant drying air velocity of 0.8 m/s are illustrated in Fig. 1. By increasing the temperature from 50°C to 80°C, the drying time decreased from 2265 minutes to 195 minutes.The drying time was 240, 285 and 360 min at the drying air velocities of 1.2, 0.8, and 0.5 m/s, respectively (Fig. 2). In different studies on chokeberry drying, Thi and Hwang (2016) found 12 hours by oven drying at 60°C and 7 days in sun drying. Petkovic et al. (2019) used the convective drying at 50, 60, and 70°C of chokeberry powders and estimated the drying time as 37 h at 50°C, 27 h at 60°C and 23 h at 70°C. Calin-Sanchez et al. (2015) found the shortest drying time to vary between 40 and 70 min with the vacuum microwave drying of chokeberry. Sadowska et al. (2017) found the drying time as 48 h at 50°C.

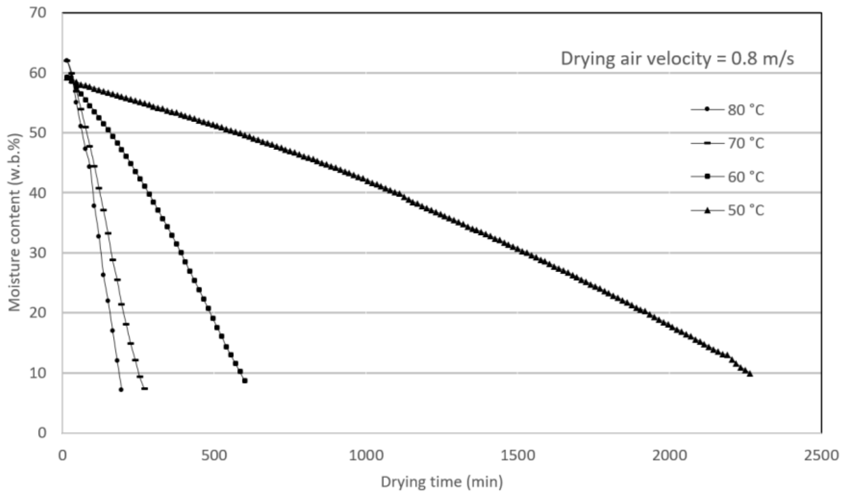

Fig. 1. The effect of drying air temperature on drying time of chokeberry.

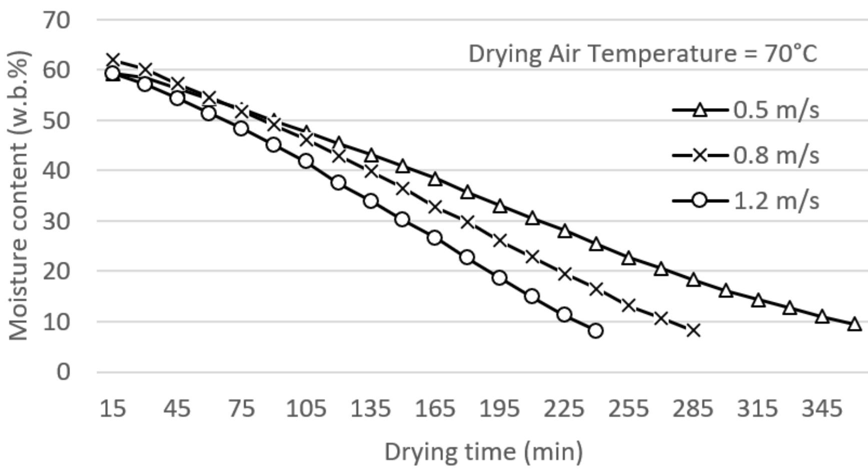

Fig. 2. The effect of drying air velocity on drying time of chokeberry.

**Fitting of experimental drying data to the models**

The regression coefficients ($R^2$), reduced chi-squared ($\chi^2$) values and root mean-square error (RMSE) values, of all the models calculated to describe the experimental drying data were given in Table 2. The $R^2$ values of the models varied between 0.9020 and 0.9997 for chokeberry. The $\chi^2$ values of the models varied between 0.0001 and 0.9784, while RMSE values of the models varied between 0.005 and 0.1037 for chokeberry. The Midilli et al. model exhibited best fit for the drying kinetic data ($R^2 \geq 0.9978$; $\chi^2 \leq 0.0003$; RMSE $\leq$ 0.0161). Additionally, as seen from Fig. 3 the Midilli et al. model presented a successful prediction for the drying characteristics of the sample when the experimental moisture ratios were compared with those predicted by the model. This was followed by Logarithmic, Wang and Singh, and Verma et al. models, respectively.

Martin-Gomez et al (2020) reported that Page model showed the better predictions for drying of blueberry. Shi et al (2008) stated that Thompson model gave better predictions for infrared drying of fresh and sugar-infused blueberries. On the other hand, Dincer et al. (2022) reported that the Midilli et al. model give a successful prediction for the drying characteristics of the black and white myrtle samples. In addition, Bingol et al. (2008), who worked with grapes, reported that the Midilli et al. model showed the best fit to the experimental drying data.

The constants of the Midilli et al., Logarithmic, Wang and Singh, and Verma et al. models, which showed the best fit to the experimental drying data, were presented in Table 2. The k value of the Midilli et al. model for chokeberry varied between 0.0019 and 0.2578 in the present study (Table 3). The k value of the dried chokeberry samples) increased with increasing temperature (50-80$^o$C) and air velocity (0.5-1.2 m/s). Bingol et al. (2008) and Dincer et al. (2022) reported k values for grape between 0.001-0.010, and for myrtle samples between -0.0090-0.0620, respectively.

Table 2. Parameters of the kinetic models used to fit drying data for chokeberry dried by various drying temperatures and velocities.

| | | Lewis | Henderson and Pabis | Page | Two-term | Two-term exponential | Logarithmic |
|---|---|---|---|---|---|---|---|
| 50°C, 0.8 m/s | $R^2$ | 0.9191 | 0.9453 | 0.9943 | 0.9488 | 0.9852 | 0.9970 |
| | $\chi^2$ | 0.0065 | 0.0045 | 0.0005 | 0.0044 | 0.0012 | 0.0003 |
| | RMSE | 0.0808 | 0.0670 | 0.0216 | 0.0660 | 0.0348 | 0.0159 |
| 60°C, 0.8 m/s | $R^2$ | 0.9068 | 0.9363 | 0.9917 | 0.9415 | 0.9799 | 0.9966 |
| | $\chi^2$ | 0.0073 | 0.0051 | 0.0007 | 0.0049 | 0.0016 | 0.0003 |
| | RMSE | 0.0854 | 0.0715 | 0.0258 | 0.0702 | 0.0401 | 0.0167 |
| 70°C, 0.5 m/s | $R^2$ | 0.9020 | 0.9292 | 0.9916 | 0.9420 | 0.9768 | 0.9970 |
| | $\chi^2$ | 0.0096 | 0.0073 | 0.0009 | 0.0068 | 0.0024 | 0.0003 |
| | RMSE | 0.0981 | 0.0857 | 0.0294 | 0.0823 | 0.0490 | 0.0181 |
| 70°C, 0.8 m/s | $R^2$ | 0.9199 | 0.9447 | 0.9955 | 0.9565 | 0.9861 | 0.9971 |
| | $\chi^2$ | 0.0075 | 0.0055 | 0.0004 | 0.0048 | 0.0014 | 0.0003 |
| | RMSE | 0.0865 | 0.0738 | 0.0211 | 0.0695 | 0.0370 | 0.0174 |
| 70°C, 1.2 m/s | $R^2$ | 0.9195 | 0.9443 | 0.9959 | 0.9577 | 0.9868 | 0.9971 |
| | $\chi^2$ | 0.0075 | 0.0055 | 0.0004 | 0.0048 | 0.0013 | 0.0003 |
| | RMSE | 0.0867 | 0.0743 | 0.0201 | 0.0693 | 0.0362 | 0.0176 |
| 80°C, 0.8 m/s | $R^2$ | 0.9404 | 0.960 | 0.9974 | 0.9740 | 0.9941 | 0.9906 |
| | $\chi^2$ | 0.0056 | 0.0040 | 0.0003 | 0.0031 | 0.0006 | 0.0010 |
| | RMSE | 0.0750 | 0.0632 | 0.0161 | 0.0554 | 0.0244 | 0.0321 |

| | | Wang and Singh | Midilli et al. | Verma et al. | Diffusion approach | Root of MR |
|---|---|---|---|---|---|---|
| 50°C, 0.8 m/s | $R^2$ | 0.9964 | 0.9993 | 0.9964 | 0.9191 | 0.9814 |
| | $\chi^2$ | 0.0003 | 5.5727E-05 | 0.0003 | 0.0068 | 0.0015 |
| | RMSE | 0.0171 | 0.0075 | 0.0174 | 0.0822 | 0.0391 |
| 60°C, 0.8 m/s | $R^2$ | 0.9988 | 0.9997 | 0.9986 | 0.9068 | 0.9738 |
| | $\chi^2$ | 9.7840E-05 | 2.5460E-05 | 0.0001 | 0.0077 | 0.0021 |
| | RMSE | 0.0099 | 0.0050 | 0.0106 | 0.0875 | 0.0458 |
| 70°C, 0.5 m/s | $R^2$ | 0.9969 | 0.9993 | 0.9968 | 0.9020 | 0.9733 |
| | $\chi^2$ | 0.0003 | 7.7151E-05 | 0.0004 | 0.0108 | 0.0028 |
| | RMSE | 0.0180 | 0.0088 | 0.0188 | 0.1037 | 0.0526 |
| 70°C, 0.8 m/s | $R^2$ | 0.9959 | 0.9995 | 0.9959 | 0.9199 | 0.9826 |
| | $\chi^2$ | 0.0004 | 5.7336E-05 | 0.0004 | 0.0084 | 0.0017 |
| | RMSE | 0.0202 | 0.0076 | 0.0208 | 0.0914 | 0.0414 |
| 70°C, 1.2 m/s | $R^2$ | 0.9959 | 0.9996 | 0.9958 | 0.9195 | 0.9821 |
| | $\chi^2$ | 0.0004 | 4.6332E-05 | 0.0004 | 0.0085 | 0.0018 |
| | RMSE | 0.0203 | 0.0068 | 0.0210 | 0.0924 | 0.0422 |
| 80°C, 0.8 m/s | $R^2$ | 0.9881 | 0.9978 | 0.9879 | 0.9404 | 0.9890 |
| | $\chi^2$ | 0.0012 | 0.0003 | 0.0013 | 0.0065 | 0.0011 |
| | RMSE | 0.0346 | 0.0161 | 0.0364 | 0.0805 | 0.0334 |

Table 3. Kinetic parameters of selected models for chokeberry samples

| Mathematical Model | Drying conditions | Model constants | | | | |
|---|---|---|---|---|---|---|
| | | A | k | b | n | g |
| Midilli et al. | 50°C, 0.8m/s | 0.9741 | 0.0019 | -0.0027 | 1.6218 | |
| | 60°C, 0.8m/s | 0.9913 | 0.0164 | -0.0368 | 1.6146 | |
| | 70°C, 0.5m/s | 0.9893 | 0.0945 | -0.0582 | 1.6040 | |
| | 70°C, 0.8m/s | 0.9889 | 0.1254 | -0.0363 | 1.5519 | |
| | 70°C, 1.2 m/s | 0.9910 | 0.1449 | -0.0406 | 1.5559 | |
| | 80°C, 0.8m/s | 0.9816 | 0.2578 | 0.0044 | 1.6617 | |
| Logarithmic | 50°C, 0.8m/s | 1473.8414 | 1.1202E-005 | -1472.8188 | | |
| | 60°C, 0.8m/s | 4990.2922 | 1.7832E-005 | -4989.2516 | | |
| | 70°C, 0.5m/s | 2303.1178 | 9.1882E-005 | -2302.0819 | | |
| | 70°C, 0.8m/s | 14.5429 | 0.0147 | -13.5150 | | |
| | 70°C, 1.2 m/s | 2311.7200 | 9.8947E-005 | -2310.6945 | | |
| | 80°C, 0.8m/s | 2.2095 | 0.1530 | -1.1673 | | |
| Wang and Singh | 50°C, 0.8m/s | -0.0148 | | -2.4640E-005 | | |
| | 60°C, 0.8m/s | -0.0678 | | -0.0019 | | |
| | 70°C, 0.5m/s | -0.1750 | | -0.0070 | | |
| | 70°C, 0.8m/s | -0.1908 | | -0.0023 | | |
| | 70°C, 1.2 m/s | -0.2071 | | -0.0039 | | |
| | 80°C, 0.8m/s | -0.2918 | | 0.0119 | | |
| Verma et al. | 50°C, 0.8m/s | -106.7720 | -0.0015 | | | -0.0014 |
| | 60°C, 0.8m/s | -100.5536 | -0.0210 | | | -0.0202 |
| | 70°C, 0.5m/s | -107.6427 | -0.0325 | | | -0.0306 |
| | 70°C, 0.8m/s | -80.2464 | -0.0123 | | | -0.0098 |
| | 70°C, 1.2 m/s | 90.9108 | -0.0153 | | | -0.0178 |
| | 80°C, 0.8m/s | -74.2250 | 0.0451 | | | 0.0484 |

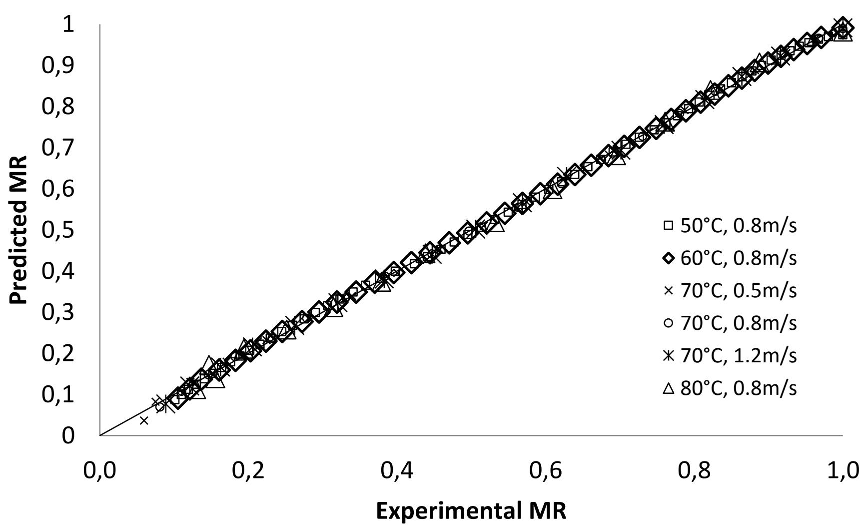


Fig. 3. Experimental and predicted values of MR change in chokeberry for the Midilli et al. model

**Color (L, a, b, C, h°, ΔE)**

Fig. 4 and Fig. 5 give the results of fruit color values as L (lightness), a (redness), b (yellowness), C (chroma value), h° (hue angle) and ΔE (color difference) at the constant drying air velocity of 0.8 m/s for different drying air temperatures. Among the examined applications, it is stated that, while statistical differences are found insignificant in terms of L value, found significant in terms of a and b values. In addition, it can be said that increasing drying air temperature raised the a and b values statistically. Depending on the applications, L values ranged from 19.14 to 20.13, a value from 1.11 to 5.03, b value from -1.30 to 2.98 (Fig. 4).

Statistical differences are found significant in terms of C value. The lowest color intensity (C) was in the fresh fruits with 1.85, while the highest value was measured at 80 °C with 5.69. Therefore, it was found that, drying increased C value of the fruit. Statistically, the highest C value was found at 60, 70 and 80°C, respectively (Fig. 5).

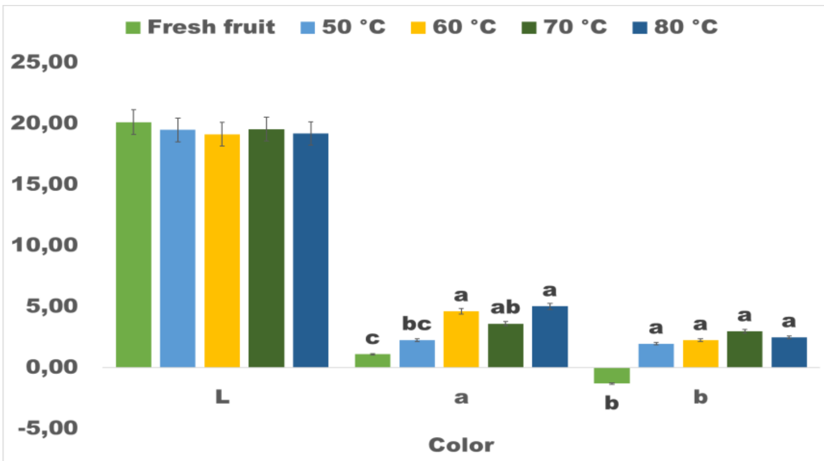


Fig. 4. L, a, b changes at air velocity 0.8 m·s$^{-1}$, different air temperatures.

*Different letters of upper index within the column show significant differences at $P < 0.05$. The columns without letters demonstrated no significant statistical differences.

$LSD_L$ = NS, $LSD_a$ = 2.247, $LSD_b$ = 1.666

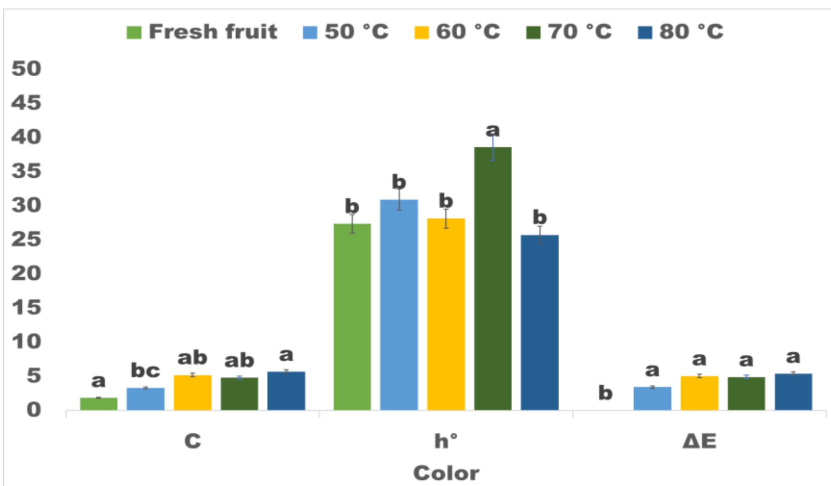


Fig. 5. C, h° and ΔE changes at air velocity 0.8 m·s$^{-1}$, different air temperatures.

*Different letters of upper index within the column show significant differences at $P < 0.05$

The columns without letters demonstrated no significant statistical differences.

$LSD_C$ = 2.093, $LSD_{h°}$ = 5.344, $LSD_{\Delta E}$ = 2.173

It is seen that, h° value of the fruit in drying process was affected by drying air temperatures. Nevertheless, the highest h° value was stated by 38.61; the lowest was stated at 80°C in the experiment. On the other hand, among the different drying air temperatures, there was no significant difference stated in terms of ΔE values. These values changed between 3.43 and 5.40 depending on different treatments (Fig. 5).

Consequently, all the applied treatments increased a, b, C values compared to fresh fruits. The highest a, b, C values were determined specifically at drying air temperature of 80°C.

Fig. 6 and Fig. 7 give the results of fruit color values as L (lightness), a (redness), b (yellowness), C (chroma value), h° (hue angle) and ΔE (color difference) at constant drying air temperatures of 70°C and different drying air velocities. Statistical differences were found insignificant in terms of L value, changing between 19.45 and 20.16. All the tried different drying air velocity treatments increased a and b values compared to fresh fruits. As a matter of fact, the lowest a (1.11) and b (-1.03) values determined in fresh fruits. The highest a (5.12) and b (3.85) values were stated at drying air velocity of 1.2 m/s (Fig. 6).

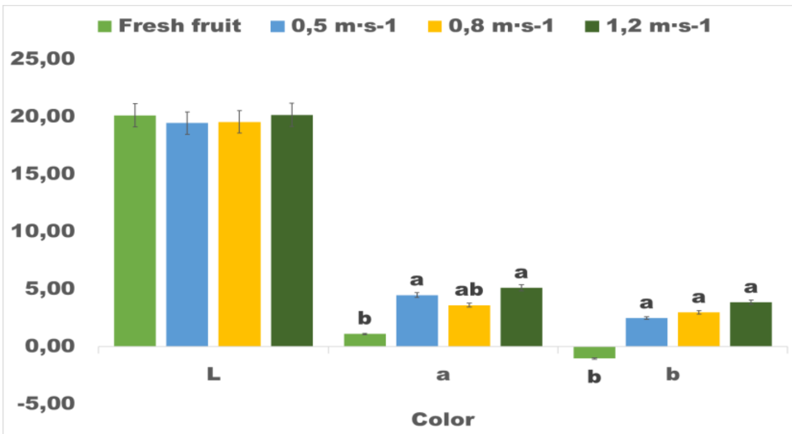


Fig. 6. L, a and b changes at air temperature 70°C, different air velocity.

*Different letters of upper index within the column show significant differences at $P < 0.05$.
The columns without letters demonstrated no significant statistical differences.
$LSD_L$ = NS, $LSD_a$ = 2.645, $LSD_b$ = 3.499

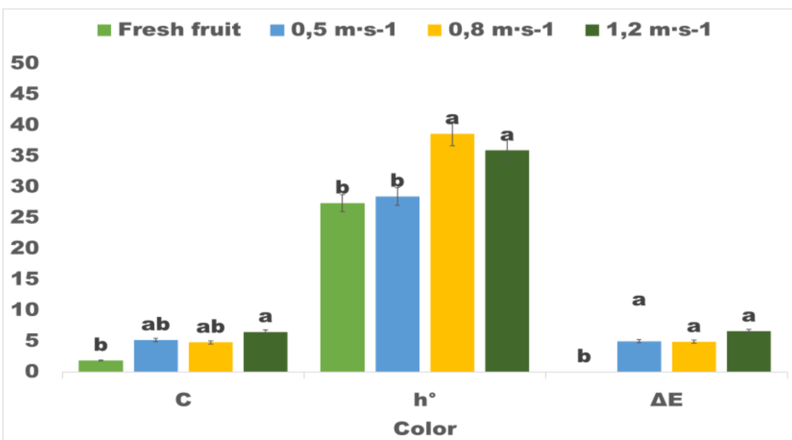


Fig. 7. C, h° and ΔE changes at air temperature 70°C, different air velocity.

*Different letters of upper index within the column show significant differences at $P < 0.05$.
The columns without letters demonstrated no significant statistical differences.
$LSD_C$ = 4.044, $LSD_{h°}$ = 6.090, $LSD_{\Delta E}$ = 4.082

Effects of the treatments on fruit color C values were found statistically significant (Fig. 7). All the applied drying air velocities increased C value compared to fresh fruits. Additionally, the highest C value was determined at 6.50 and 1.2 m/s drying air velocity. There was significant difference in terms of h° value among the drying air velocity treatments. ΔE changed between 0.00 and 6.61 depending on the treatments. There was no significant difference in terms of ΔE values among the drying air velocity treatments (Fig. 7). There is one study about fruit color changes of processed chokeberry powders (Sadowska et al., 2019). Sadowska et al. (2019) stated the highest L (18.10), a (9.20) and b (4.57) values of chokeberry powders color via high energy air stream drying method in this study on which they compared freeze-drying, vacuum drying, convection drying. Besides L value is 15.05, a value is 4.75 and b value is 1.76 in convection drying (CD) method. Adak et al. (2017) indicated that, increasing drying air temperature lowered the L, a, b and C values, but the h° increased small amount for infrared drying of strawberries. In the same research, it was also stated that regarding to the drying air velocity of 1.0 m/s was found as the best in terms of L, a, b, C, h° and ΔE values compared to the 1.5 and 2.0 m/s and increasing air velocity had led to decrease in lightness, color intensity but not the color which showed an increase. Samoticha et al. (2016) indicated that, the drying process caused alterations in the appearance and brightening of color and raised the contribution of yellow color in the fruits at higher levels.

As a consequence, all the applied drying air velocity treatments increased a, b and C values compared to fresh fruits. Particularly, 1.2 m/s drying air velocity stands out with high a, b and C values.

**Antioxidant Activity, Total Anthocyanins, Total Phenolic Content**

Effects of different drying air temperature under constant drying air velocity of 0.8 m/s on fruit biochemical features are shown in Table 4. As given in Table 4, significant statistical differences in terms of antioxidant activity, total anthocyanin (TAC) and total phenolic content (TPC) were determined.

According to findings, drying air temperatures affected the biochemical content in a dramatic way. In fact, all the drying air temperatures proportionally increased antioxidant activity, total anthocyanin content and total phenolic content in dried fruits compared to the fresh ones because significant water was removed from the dried samples. In general, it is observed that antioxidant activity, phenolic and anthocyanin content increase proportionally with the temperature increase from 50 $^{o}$C to 70 $^{o}$C, and decreases slightly at 80 $^{o}$C compared to 70 $^{o}$C. The highest antioxidant activity (3105.60 mg TE/kg FW), total anthocyanin content (115.83 mg·Cyd-3-glu/kg) and total phenolic content (918.52 mg GAE/kg) were found at drying air temperature of 70$^{o}$C. In this study, specifically 70$^{o}$C drying air temperature stands out in terms of this qualities. These findings were similar to Adak et al. (2017)'s results. Adak et al. (2017) indicated that, infrared drying of strawberries increased antioxidant activity, total anthocyanin and phenolic contents of the fruits compared to fresh forms. They reported the highest antioxidant activity, phenolic and anthocyanin content in samples dried at 60 °C. It was stated that these values were lower in samples dried at 80 °C and 100 °C, compared to 60 °C (Adak et al. 2017).

Effect of different drying air velocities at constant drying air temperature of 70$^{o}$C on nutritional fruit quality characteristics of chokeberries were indicated in Table 5. As shown in Table 5, significant statistical differences were found in terms of all examined features among the treatments. The lowest antioxidant activity was found in fresh fruits (1680.0 mg TE/kg) and the highest value was found at drying air velocity of 1.2 m/s (3140.00 mg TE/kg). In other words, with the increased drying air velocity from 0.5 m/s to 1.2 m/s, antioxidant activity in fruits proportionally increased (Table 5).

When the results examined in terms of total anthocyanin content, all the drying air velocities proportionally increased this value compared to fresh fruits. As a matter of fact, the lowest total anthocyanin content was stated in fresh fruits (66.04 mg Cyd-3-glu $kg^{-1}$ FW). Total anthocyanin content decreased depending on the drying air velocity rise, however, that decrease statistically made no difference. These values varied between 105.31 mg Cyd-3-glu/kg FW and 117.67 mg Cyd-3-glu /kg FW depending on drying air velocities (Table 5).

Table 4. Effect of different air temperature, at air velocity 0.8 $m \cdot s^{-1}$ on nutritional fruit quality characteristics of chokeberries.

| Treatments | Antioxidant Activity [A] (mg TE/kg) | Total anthocyanin content (TAC) [B] (mg Cyd-3-glu $kg^{-1}$) | Total phenolic content (TPC) [C] (mg GAE $kg^{-1}$) |
|---|---|---|---|
| Fresh fruit | 1680.0 d | 66.04 c | 278.09 c |
| 50 °C | 2496.7 c | 52.15 c | 734.88 b |
| 60 °C | 2772.3 b | 106.79 ab | 873.15 a |
| 70 °C | 3105.6 a | 115.83 a | 918.52 a |
| 80 °C | 2906.9 ab | 81.60 bc | 877.47 a |
| $LSD_{\%5}$ | 247.66 | 30.734 | 123.79 |

*Values in the same column that are followed by different letters are significantly different ($p<0.05$) using LSD comparison test.
**A** The antioxidant activity was analyzed by DPPH assay according to the procedure of Fernández-León et al. (2013). Values were expressed as mg TE $kg^{-1}$.
Antioxidant activity was analyzed using the DPPH assay described by Fernández-León et al. (2013).
**B** Total monomeric anthocyanin content was calculated using a pH-differential method described by Wang and Xu (2007). Values were expressed as mg Cyd-3-glu $kg^{-1}$ by spectrophotometer.
**C** The total phenolic content analyses were performed using the method described by Dincer et al. (2013). Values were expressed as mg gallic acid equivalents (GAE) $kg^{-1}$ by spectrophotometer.
**The results based on as wet basis for fresh fruit and dry weight for dried fruits.

Table 5. Effect of different air velocity at air temperature 70°C on nutritional fruit quality characteristics of chokeberries.

| Treatments | Antioxidant Activity[A] (mg TE/kg) | Total anthocyanin content (TAC)[B] (mg·Cyd-3-glu $kg^{-1}$) | Total phenolic content[C] (TPC) (mg·GAE $kg^{-1}$) |
|---|---|---|---|
| Fresh fruit | 1680.00 b | 66.04 b | 278.09 b |
| 0.5 $m \cdot s^{-1}$ | 2938.97 a | 117.67 a | 909.57 a |
| 0.8 $m \cdot s^{-1}$ | 3105.64 a | 115.83 a | 918.52 a |
| 1.2 $m \cdot s^{-1}$ | 3140.00 a | 105.31 a | 917.28 a |
| $LSD_{\%5}$ | 241.200 | 26.132 | 118.910 |

*Values in the same coloumn that are followed by different letters are significantly different ($p<0.05$) using LSD comparison test.
[A] The antioxidant activity was analyzed by DPPH assay according to the procedure of Fernández-León et al. (2013). Values were expressed as mg TE $kg^{-1}$.
Antioxidant activity was analyzed using the DPPH assay described by Fernández-León et al. (2013).
[B] Total monomeric anthocyanin content was calculated using a pH-differential method described by Wang and Xu (2007). Values were expressed as mg Cyd-3-glu $kg^{-1}$ by spectrophotometer.
[C] The total phenolic content analyses were performed using the method described by Dincer et al. (2013). Values were expressed as mg gallic acid equivalents (GAE) $kg^{-1}$ by spectrophotometer.
**The results based on as wet basis for fresh fruit and dry weight for dried fruits.

The effects of all the applied drying processes on total phenolic content (TPC) of fruits were found statistically significant. While the lowest TPC was stated in fresh fruit (278.09 mg GAE /kg FW), all the applied drying air velocities increased TPC compared to fresh forms. These values, also, varied between 909.57 mg GAE /kg DW and 918.52 mg GAE/kg DW (Table 5).

Current findings indicated that, at constant drying air temperature of 70°C with different drying air velocity treatments affected the biochemical content of fruits in a significant way compared to fresh ones. In fact, the lowest values of antioxidant activity, TAC and TPC were found in fresh fruits. Therefore, all the drying air velocity treatments from 0.5 m/s to 1.2 m/s can be suggested as their positive effects on biochemical fruit contents.

In this concern, some scholars have reported different results. The reason of these differences is the usage of different drying techniques and differently processed fruits.

In this regard, findings of this study was found partly similar to strawberry drying study Adak et al. (2017). Hence, these researchers stated that convective drying treatment increased biochemical content compared to the fresh fruits. Additionally, the researchers indicated that, increasing drying air velocity from 1 m/s to 2 m/s caused decrease in total anthocyanin and total phenol contents, but increase in the antioxidant activity. In this study, change of the drying air velocity did not affect the antioxidant activity, total anthocyanin and total phenol contents. Petkovic et al. (2019) used 50, 60 and 70°C of convective drying temperatures for chokeberry powders and suggested 50°C in terms of bioactive components (anthocyanins, flavonoids, phenols) and antioxidant activity. They stated the results as the drying air temperature of 50°C had the highest ratio of total anthocyanins (376.89 ± 5.73 mg Cyn-3-glu $[100\ g\ dm]^{-1}$), total flavonoids (1037.19 ± 3.83 mg CE $[100\ g\ dm]^{-1}$), phenols (1918.79 ± 3.26 mg GAE $[100\ g\ dm]^{-1}$) and antioxidant activity (37.11 ± 0.28 mg TE $[100\ g\ dm]^{-1}$). On the other hand, findings showed that, rising temperature increased the biochemical content. In fact, the highest values of antioxidant activity, total anthocyanin and total phenolic content are stated at 70°C drying air temperature.

Calin-Sanchez et al. (2015) reported that, vacuum microwave and combined drying were found as the best two different drying techniques of black chokeberry fruit. This suggestion led to shorter drying time (40-70 min). Sadowska et al. (2019) applied freeze, vacuum, convection and high energy air stream drying on chokeberry powders. According to their results, high energy air stream drying was the best method in terms of vitamin C (80.57 mg $[100\ g\ dry\ matter]^{-1}$), polyphenol contents (2484.60 mg GAE $[100\ g\ dry\ matter]^{-1}$), antioxidant activity (58.91 mmol Trolox $[100\ g\ dry\ matter]^{-1}$), and anthocyanin (1035.51 mg $[100\ g\ dry\ matter]^{-1}$ Cyanidin-3,5-digalactoside). In addition, Horszwald et al. (2013) were stated that, there was a correlation between bioactive compounds and antioxidant capacity. In other studies, Samoticha et al. (2016) indicated that, the highest content of bioactive compounds and antioxidant activity were found in freeze-dried samples, compared with fresh fruits. In addition, the rise in drying air temperature during convective drying as well as the increase in material temperature during microwave drying deteriorated the dried product quality in terms of the content of phenolic compounds, antioxidant activity and color.

## CONCLUSION

To sum up, among the proposed models, the Midilli et al. equation exhibited the best fit for predicting the drying behavior of chokeberry samples. It is suggested to use the convective drying system under specific conditions of 70°C and an air velocity of 0.8 m/s to attain high nutritive biochemical features, high fruit quality, and suitable drying time, in addition to good consumer acceptance of dried chokeberries. These conditions were found to optimize the drying process by providing sufficient drying speed while maintaining the structural and chemical properties of the fruit. Besides, drying chokeberries under these conditions provides both shelf stability and flexibility in different processing techniques.

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**PREPRINT**
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**AUTHORS' CONTRIBUTIONS**
Nafiye Ünal: Investigation, conceptualization, writing-review and editing, Ahmet Süslü: methodology, resources, data curation, Recep Külcü: investigation, resources, Cüneyt Dincer: methodology, data curation, writing-review and editing, Eda Elif Yavuzlar İmirgi: methodology, Can Ertekin: project administration, conceptualization, investigation, visualization, supervision, writing-review and editing

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**CONFLICT OF INTEREST STATEMENT**
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**DATA AVAILABILITY STATEMENT**
The data presented in this study are not available in this article.

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