



## Determination of Drying Characteristics, Energy Consumption and Quality Values of Black Mulberry Fruit (*Morus nigra* L.) Dried Under Different Conditions

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There are about 68 types of mulberry fruit with a wide ecological production area. Different mulberry species are grown in large fields in Turkey. Mulberries are largely dried-consumed, but sometimes they are used as fruit juice. In this study, black mulberry fruit was collected in two different ripening levels (semi-ripe and full-ripe) and oven-dried at 50, 60 and 70°C drying temperatures. Initial moisture contents of semi-ripe and full-ripe fruits were determined as 86.74% and 82.95%, respectively. Fruits were dried to have final moisture levels of 10-15%. Drying duration, drying models, effective diffusion, activation energy, specific energy consumption, color parameters and chemical properties of dried fruits were examined and the effect of ripening levels and drying temperatures were investigated. In terms of drying duration, while full-ripe fruits dried in a shorter time, effective diffusion, activation energy and specific energy consumption values were found to be higher than semi-ripe fruits. In terms of color parameters, semi-ripe fruits are recommended to be dried at 50 or 60°C drying temperatures and full-ripe fruits should be dried at 50°C drying temperature for better preservation of color parameters. On the other hand, a common proper drying temperature could not be identified for acidity (pH), water soluble dry matter and titratable acidity.

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### Introduction

Fruits are easily perished after the harvest because of high moisture contents. Therefore, for long-term preservations without any deterioration, fruits are either subjected to drying processes or cold storage operations (Doymaz, 2011; Ghanbarian et al., 2019). Initial investment costs and energy consumption values of cold storage operations are greater than the drying processes, thus cold storage could not be used by every growers. Tellez et al. (2019) indicated the primary target of the drying process as to reduce water activity through removing a majority of product moisture and thus to reduce microbic formations. Besides, drying significantly reduces fruit weight and volumes, thus facilitate loading-unloading and transportation operations. Drying also offers alternative products with high market values.

Producers generally dry their products in trays or layout over concrete surfaces under direct sunlight (open drying) (Wojdylo et al., 2014; Panagopoulou et al., 2019). In open-drying methods (sun-shade), process durations are too long, it is hard to control drying temperature and it is generally impossible to prevent dust, odor, etc. coming

from the environment, thus it is most of the time hard to get quality and hygienic final products (Doymaz et al., 2003; Özgen, 2014; Polatçı et al., 2018). Then, to eliminate such negative issues or conditions, conventional drying methods, in which drying is conducted in closed ambient and product specific drying conditions are controlled, were developed. Among these methods, oven-drying offers various advantages, significantly reduces drying durations and yields quality final products (Figiel, 2010). Black mulberry fruit is largely used in jam, smoothie, pancake, sweet and sauces. In terms of human health, black mulberry fruit is rich in vitamins, minerals and carbohydrates supplying energy to the cells through converting sugar into glucose. Mulberry also increases iron uptake of the body and supplies sufficient oxygen to tissues. Black mulberry is among the commonly dried fruits.

There are some studies available in the literature about mulberry drying. Ergüneş et al. (2003) investigated the effects of different drying techniques on the quality of dried mulberry samples and reported that conventional

driers yielded greater darkened color parameters as compared to sun-dried samples. Chen et al. (2017) investigated the effects of combined hot air drying and explosion puff drying and freeze drying and puff drying on physicochemical characteristics of mulberry samples. Researchers reported that the best anthocyanin conservation was achieved with freeze drying and a combination of freeze drying and explosion puff drying yielded the best outcomes in terms of color conservation, taste and texture. In the same study, drying durations were also compared and optimum drying duration for final moisture of 7% was reported as 9 hours for hot air drying, 6 hours for hot air and explosion puff drying, 48 hours for freeze drying and 15 hours for freeze drying and explosion puff drying. Dobooglu (2012) dried black mulberry samples with the use of lyophilization, conventional and vacuum drying methods and analyzed anthocyanin content, moisture content, rehydration capacity and color parameters. It was reported that as compared to conventional drying, vacuum drying offered better preservation of investigated parameters; the samples dried with conventional and vacuum drying methods had denser anthocyanin and volatile compounds, thus greater values for these parameters when they were subjected to high temperature, then had darker colors than the samples dried with fresh and lyophilization methods; besides, these samples had lower L and a values; samples drier with lyophilization method had lower losses in anthocyanin content and greater rehydration capacity than the samples dried with the other drying methods; the lowest bulk density, water activity and moisture contents were observed in lyophilization method; because of low heat treatment, low level of loss was observed in L and a values, thus dried products had greater color quality. Despite the aforementioned studies, the number of studies about the effects of ripening stages and drying temperatures on drying kinetics and quality indicators of black mulberry is quite limited.

In this study, black mulberry fruit was dried in an oven at 50, 60 and 70 °C temperatures and the effects of ripening levels and drying temperatures on drying duration, drying model, specific energy consumption, effective diffusion, activation energy, color, acidity (pH), water soluble dry matter (WSDM) and titratable acidity (TA) of black mulberry fruit were investigated.

## Material and Method

### Fruits to be Dried and Ripening Levels

Semi and full-ripe black mulberry fruits to be used as the drying material were collected from a grower orchard in Kemalpaşa village of Tokat province on 14th of July, 2020. Fresh samples were brought to drying laboratory of Biosystems Engineering Department of Tokat Gaziosmanpaşa University and preserved at +4±0.5°C temperature. Bruised fruits were removed from the samples (Figure 1). Fruits were kept in a fridge until the end of drying process.

To separate fruits into two different ripening levels, color brightness (L) was measured with a color meter and fruits were classified into ripening levels as; Semi-ripe for L values of between 29.44-40.26 and full-ripe for L values of between 18.33-29.44.



Figure 1. Drying material

### Moisture Content (%) and Drying Temperature

Before the drying process of black mulberry samples separated into two different ripening levels, wet-basis initial moisture content (%) was determined. For moisture content analysis, about 30.41±0.69 g and 39.87±0.52 g samples were taken from semi-ripe and full-ripe black mulberry fruits, respectively and samples were dried in an oven at 70°C until a constant mass (Pixton and Warburton, 1973). For drying process, 47±2.38 g and 34±1.28 g samples were taken from semi-ripe and full-ripe black mulberry fruits, respectively and samples were dried in an oven at 50, 60 and 70°C temperatures in 3 replicates. Samples were dried until final moisture levels of 10-15% (Polatçı and Tarhan, 2009). During the drying process, sample weight changes were monitored with the use of precise balance (±0.01 g) (AND brand GF-3000 model). Şimşek Labortechnik brand ST-120 type oven was used in drying experiments and drying air temperature was adjusted with a PID controller installed on the device.

### Drying Model

The moisture removed (MR) throughout the drying process of semi-ripe and full-ripe black mulberry fruits were calculated with the use of Equation 1, then thin-layer mathematical drying models were generated.

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

Where;

MR : Moisture ratio

M : Actual moisture

M<sub>e</sub> : Equilibrium moisture

M<sub>0</sub> : Initial moisture

The thin-layer drying models used to model drying ratios of the dried fruits mathematically are provided in Table 1.

While modeling drying ratios of the dried fruits, commonly used Midilli et al., Page and Yağcıoğlu models were selected.

### Effective Diffusion and Activation Energy

Effective diffusion designates the time-dependent diffusion area of the moisture released from the fruits during the drying process. Effective diffusion values were calculated with the use of Equation 2 (Crank, 1979; Türker and İşleroğlu, 2017).

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

Where;

$D_{eff}$  : Effective diffusion ( $m^2 \cdot s^{-1}$ ),

$L$  : Product thickness (m).

Temperature-dependent change of resultant effective diffusion value was expressed with the use of Arrhenius equation. Activation energy values were calculated with the use of Equation 3:

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{RT}\right) \quad (3)$$

Where;

$D_0$  : Diffusion ( $m^2 \cdot s^{-1}$ ),

$R$  : Gas constant ( $8.3143 \text{ kJ} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ ),

$E_a$  : Activation energy ( $\text{kJ} \cdot \text{mol}^{-1}$ ),

$T$  ( $^{\circ}\text{K}$ ) : Drying air temperature.

Activation energy ( $E_a$ ) values were calculated from the slope of the line drawn with the use of natural logarithm of effective diffusion ( $D_{eff}$ ) coefficients versus  $1/T$  values.

### Energy Consumption

Energy consumption of drier is measured in kWh and final value was recorded when the desired product moisture content was achieved. Then, total energy consumption was used to calculate specific energy consumption values based on removed moisture quantities (Equation 5).

$$SEC = \frac{TEEC}{TML} \quad (5)$$

Where;

$SEC$  : Specific energy consumption ( $\text{kWh} \cdot \text{kg water}^{-1}$ ),

$TEEC$  : Total electrical energy consumption (kWh),

$TML$  : Total moisture loss (kg).

### Color Measurements

The  $L^*$ ,  $a^*$  and  $b^*$  color parameters of fresh and semi-ripe and full-ripe dried fruits were measured with the use of a color meter (Minolta brand CR300 model).

$L^*$  represents the brightness and gets values of between 0-100 with 0 indicating black fruit color and 100 indicating white fruit color. Color parameter of  $a$  represents red-green colors and  $b^*$  represents yellow-blue colors. Negative  $a^*$  values indicate more intense green color and positive  $a^*$  values indicate more intense red color. The  $a^*$  and  $b^*$

values equal to zero indicate grey color (McGuire, 1992). With the use of measured  $L^*$ ,  $a^*$  and  $b^*$  values, chroma, hue angle and total color change reviling more distinctive color information was calculated.

Chroma indicates color tone of fresh and semi-ripe and full-ripe dried fruits. Pale colors have low and vivid colors have high chroma values. Hue angle designates the position of color on  $360^{\circ}$  color radiant. The boundary values,  $0^{\circ}$  represent red,  $180^{\circ}$  green,  $90^{\circ}$  yellow and  $270^{\circ}$  blue colors. Total color change designates the color differentiation through heat-induced non-enzymatic reactions as compared to fresh color of the product.

The equations provided in Table 2 were used to calculate the chroma, hue angle and total color change parameters.

Where;  $L^*$ ,  $a^*$  and  $b^*$  values represent the measured color values of fresh, semi-ripe and full-ripe black mulberry fruits;  $L^*$ ,  $a^*$  and  $b^*$  values represent the measured color values of dried semi-ripe and full-ripe black mulberry fruits.

### Chemical Analyses

Acidity (pH), water soluble dry matter (WSDM), titratable acidity (TA), total phenol (TP), total antioxidant capacity (TAC) and total anthocyanin content of semi-ripe and full-ripe fresh and dried products were determined (Figure 2).

Before the analyses, fresh and dried black mulberry fruits were diluted 4 and 9 times and extractions were performed in a blender.

**Acidity:** The pH values were measured in extracts of fresh and dry fruits with a pH meter.

**Titratable acidity (%):** About 5 mL extracts of fresh and dried fruits were taken and titrated with 0.1 N NaOH solution until a pH of 8.2. Titrations were conducted in 3 parallels and average was taken as titratable acidity (%) of the samples.

**Water soluble dry matter (WSDM) (%):** Fresh and dry fruit extracts were pressed to get juice and water-soluble dry matter contents were measured in a portable digital precise ( $\pm 0.01$ ) refractometer (Karaçalı, 1990; Cemeroğlu, 1992).

### Statistical Analysis

Experimental data on semi-ripe and full-ripe fresh and dried samples were subjected to variance analysis with the use of SPSS 20 software and significant means were compared with the use of Duncan's multiple range test.

Table 1. Equations for drying models

Model	Equation	Reference
Midilli et al.	$MR = h \cdot \exp(-j \cdot t^k) + mt$	Midilli et al. (2002)
Page	$MR = \exp(-kt^h)$	Page (1949)
Yağcıoğlu	$MR = k \cdot \exp(-h \cdot t) + j$	Yağcıoğlu (1999)

Table 2. Calculated color parameters

Color parameters	Equation	Reference
Chroma, C	$C = (a^{*2} + b^{*2})^{1/2}$	Ramallo and Mascheroni (2012)
Hue angle, $^{\circ}$	$h^{\circ} = \tan^{-1}\left(\frac{b^*}{a^*}\right)$	Alemrajabi et al. (2012)
Total color change, $\Delta E$	$\Delta E = \sqrt{(L^* - L^{*0})^2 + (a^* - a^{*0})^2 + (b^* - b^{*0})^2}$	Tan et al. (2001)



Figure 2. Phytochemical analyses of fresh and dried fruits

## Results and Discussion

### Drying Performance

Initial moisture contents of semi-ripe and full-ripe black mulberry samples were respectively measured as 86.74% and 82.95%. Such values indicated that sugar-like water soluble substances increased, thus moisture contents decreased with the progress of ripening. Average length, width and thickness of semi-ripe fruits were respectively measured as 2.6 cm, 1.6 cm and 1.5 cm and the values of full-ripe fruits were respectively measured as 2.7 cm, 1.8 cm and 1.6 cm. Average drying durations and final moisture values of semi-ripe and full-ripe black mulberry samples are provided in Table 3.

As can be seen from Table 3, semi-ripe fruits had longer drying durations than the full-ripe fruits since semi-ripe fruits had greater initial moisture levels and water molecules are tighter bound to fruit tissue because these fruits did not complete ripening fully.

Tlatempa-Becerro et al. (2020) investigated the effects of different drying temperatures and ripening levels on drying durations of green and ripened hawthorn fruits. Researchers reported wet-basis initial moisture content of green and ripened fruits respectively as 79.81% and 78.01% and indicated that green fruits had longer drying durations to reach the desired final moisture levels. Pirone et al. (2014) applied different pre-treatments to sweet cherry fruits at different ripening levels and investigated the effects of these pre-treatments on drying and quality parameters. Researchers classified ripening levels as green and ripened and reported shorter drying durations for ripened fruits than for the green fruits.

### Thin-Layer Drying Models

Time-dependent drying ratios of semi-ripe and full-ripe fruits were determined throughout the drying duration and these values were incorporated into thin layer drying models. The mathematical models best estimating drying ratios were determined. Results for Page model are provided in Table 4.

As can be seen from Table 4, Page model best estimated drying ratios of semi-ripe and full-ripe fruits at 60°C drying temperature ( $R^2 = 0.9963$ ). The results for Midilli-Küçük mathematical model are provided in Table 5. As can be seen from Table 5, Midilli-Küçük model best estimated drying ratios of semi-ripe fruits at 60°C drying temperature ( $R^2 = 0.9995$ ). For full-ripe fruits, the best estimations were achieved at 70°C drying temperature ( $R^2 = 0.9994$ ). The results for Yağcıoğlu model are provided in Table 6.

As can be seen from Table 6, Yağcıoğlu model best estimated drying ratios of semi-ripe fruits at 50°C drying temperature ( $R^2 = 0.9996$ ). For the full-ripe fruits, the best estimations were achieved at 50 and 70°C drying temperatures ( $R^2 = 0.9984$ ). Mathematical models that as best estimate drying curves of semi-ripe and full-ripe black mulberry fruits, respectively; was identified Yağcıoğlu-50°C and Midilli-Küçük-70°C.

### Effective Diffusion

Effective diffusion and activation energy values of dried semi-ripe and full-ripe black mulberry fruits are provided in Table 7.

Effective diffusion values of dried semi-ripe fruits varied between  $9.140 \times 10^{-7}$ - $3.830 \times 10^{-6} \text{ m}^2 \cdot \text{s}^{-1}$  and activation energy value was identified as  $65.87 \text{ kJ} \cdot \text{mol}^{-1}$ . Effective diffusion values of full-ripe fruits varied between  $1.449 \times 10^{-6}$ - $6.773 \times 10^{-6} \text{ m}^2 \cdot \text{s}^{-1}$  and activation energy value was identified as  $70.94 \text{ kJ} \cdot \text{mol}^{-1}$ . Darvishi et al. (2014) investigated the effects of microwave power on effective diffusion values of microwave-dried white mulberry fruits and reported that effective diffusion values increased with increasing microwave powers and the values varied between  $1.06 \times 10^{-8}$ - $3.45 \times 10^{-8} \text{ m}^2 \cdot \text{s}^{-1}$ . Activation energy was identified as  $14.19 \text{ W} \cdot \text{g}^{-1}$ . Doymaz and Kıpçak (2019) dried mulberry fruit in an infrared drier at 50, 62, 74, 88 and 104 W powers and reported that effective diffusion values increased with increasing powers and the values varied between  $1.14 \times 10^{-9}$ - $3.08 \times 10^{-9} \text{ m}^2 \cdot \text{s}^{-1}$ .

Table 3. Average drying durations and final moisture values of the samples

Material	Temperature (°C)	Final moisture (wet-basis)	Drying duration (hour)
Semi-ripe	50	11.47	92
	60	11.99	48
	70	11.79	22
Full-ripe	50	10.38	77
	60	10.35	42
	70	11.58	17

Table 4. Results for Page model

Material	Temperature (°C)	k	h	R <sup>2</sup>	P
Semi-ripe	50	0.0125	1.1923	0.9940	P<0.0001
	60	0.0590	1.0190	0.9963	P<0.0001
	70	0.0866	1.1369	0.9952	P<0.0001
Full-ripe	50	0.0108	1.2785	0.9901	P<0.0001
	60	0.0356	1.2118	0.9963	P<0.0001
	70	0.0541	1.4102	0.9960	P<0.0001

Table 5. Results for Midilli-Küçük model

Material	Temperature (°C)	k	h	j	m	R <sup>2</sup>	P
Semi-ripe	50	1.0267	0.9827	0.0180	-0.0015	0.9995	P<0.0001
	60	0.9427	0.9827	0.0645	-0.0014	0.9990	P<0.0001
							P<0.0001
							P<0.0001
							P=0.0002
	70	0.9960	0.9957	0.0991	-0.0048	0.9988	P<0.0001
							P<0.0001
							P<0.0001
							P=0.0069
Full-ripe	50	1.1717	0.9635	0.0120	-0.0018	0.9986	P<0.0001
	60	1.1760	0.9734	0.0348	-0.0012	0.9990	P<0.0001
							P<0.0001
							P<0.0001
							P=0.0020
	70	1.2924	0.9895	0.0577	-0.0056	0.9994	P<0.0001
							P<0.0001
							P<0.0001
							P=0.0084

Table 6. Results for Yağcıoğlu model

Material	Temperature (°C)	k	h	h	R <sup>2</sup>	P
Semi-ripe	50	k: 1.2444	0.0165	-0.2598	0.9996	P<0.0001
	60	k: 1.0304	0.0523	-0.0609	0.9989	P<0.0001
	70	k: 1.1472	0.0874	-0.1542	0.9989	P<0.0001 P=0.0002
Full-ripe	50	k: 1.4093	0.0157	-0.4264	0.9984	P<0.0001
	60	k: 1.1483	0.0487	-0.1486	0.9984	P<0.0001
	70	k: 1.4807	0.0692	-0.4606	0.9974	P<0.0001 P=0.0042

Table 7. Effective diffusion and activation energy values

Material	Temperature (°C)	Effective diffusion (m <sup>2</sup> .s <sup>-1</sup> )	Activation energy (kJ.mol <sup>-1</sup> )
Semi-ripe	50	9.140×10 <sup>-7</sup>	65.87
	60	1.685×10 <sup>-6</sup>	
	70	3.830×10 <sup>-6</sup>	
Full-ripe	50	1.449×10 <sup>-6</sup>	70.94
	60	2.954×10 <sup>-6</sup>	
	70	6.773×10 <sup>-6</sup>	

Table 8. Specific energy consumptions

Material	Temperature (°C)	Specific energy consumption (kWh.kg water <sup>-1</sup> )
Semi-ripe	50	106.14
	60	141.45
	70	95.31
Full-ripe	50	126.15
	60	177.27
	70	95.93

Activation energy was reported as 2.015 kW.kg<sup>-1</sup>. Kıpçak and Doymaz (2020) conducted a mulberry drying study with microwave oven at 90, 180 and 360 W powers and reported effective diffusion values as between  $4.79 \times 10^{-8}$ - $2.60 \times 10^{-7}$  m<sup>2</sup>.s<sup>-1</sup>. Activation energy was identified as 13.15 kW.kg<sup>-1</sup>

### Specific Energy Consumption

Specific energy consumption values of dried semi-ripe and full-ripe black mulberry fruits at different drying temperatures are provided in Table 8.

Specific energy consumptions varied between 95.31-141.45 kWh.kg<sup>-1</sup> water for semi-ripe fruits and between 95.93-177.27 kWh.kg<sup>-1</sup> water for full-ripe fruits. Golpour et al. (2020) conducted a white mulberry infrared drying study at 40, 55 and 70°C temperatures, 500, 1000 and 1500 W infrared powers and 0.4, 1 and 1.6 m.s<sup>-1</sup> air velocities and used artificial neural networks for optimization of drying parameters. Researchers reported the specific energy consumption of the best method (70°C temperature, 1464.57 W infrared power and 0.4 m.s<sup>-1</sup> air velocity) as 166.55 MJ.kg<sup>-1</sup> (46.27 kWh.kg<sup>-1</sup>). Rad et al. (2018) determined specific energy consumptions of white mulberry drying operations under hot air and infrared drying conditions. The greatest specific energy consumption (916.89 kWh.kg<sup>-1</sup>) was observed in hot air drier and the lowest value (113.92 kWh.kg<sup>-1</sup>) was observed in infrared drier. Taghinezhad et al. (2020) dried blackberry fruits in a hybrid drier (hot air infrared drier) and reported the greatest and the lowest specific energy consumptions as 239.91 kWh.kg<sup>-1</sup> and 70.57 kWh.kg<sup>-1</sup>, respectively.

### Color Parameters

Measured and calculated color parameters of semi-ripe black mulberry fruits under different drying conditions are provided in Table 9.

Effects of drying methods on color parameters of semi-ripe black mulberry fruits were found to be significant ( $P < 0.05$ ) (Table 9). In terms of brightness ( $L^*$ ), the closest values to fresh semi-ripe fruits were observed at 50 and 60°C drying temperatures. In terms of the other color parameters, as compared to fresh fruits, there were not any significant similarities. Therefore, semi-ripe black mulberry fruits are recommended to be dried at 50 or 60°C drying temperatures for better preservation of color parameters. Measured and calculated color parameters of

full-ripe black mulberry fruits under different drying conditions are provided in Table 10.

Effects of drying methods on color parameters of full-ripe black mulberry fruits were found to be significant ( $P < 0.05$ ) (Table 10). As compared to color values of fresh fruits, the closest blueness ( $b^*$ ) value was observed at 50 50°C drying temperature and the closest Hue angle value was observed again at 50°C drying temperature. Therefore, full-ripe black mulberry fruits are recommended to be dried at 50°C drying temperatures for better preservation of color parameters. When the results provided in Table 9 and Table 10 were assessed together, drying methods, drying temperatures and ripening levels significantly influenced final color values of dried mulberry fruits. Özkan and Karabacak (2019) dried white mulberry sheets in hot-air drier at 50 and 60°C temperatures and reported significant differences in  $L^*$ ,  $a^*$ ,  $b^*$ ,  $C^*$  and hue values of dried products and fresh products ( $P < 0.05$ ) and indicated that color parameters could not be preserved. Boz et al. (2016) reported  $L$  values of dried white mulberry fruits as between 31.64-35.86, on the other hand, present values varied between 27.78-30.36.

Chemical analysis results for semi-ripe black mulberry fruits dried under different temperatures are provided in Table 11.

Effects of drying methods on pH, TA and WSDM of semi-ripe fruits were found to be significant ( $P < 0.05$ ) (Table 11). As compared to fresh fruits, the closest pH value was observed at 50°C drying temperature. In terms of titratable acidity, different drying temperatures did not yield significant differences. The closest WSDM values to fresh fruits were observed at 70°C drying temperature. Chemical analysis results for full-ripe black mulberry fruits dried under different temperatures are provided in Table 12.

Effects of drying methods on pH, TA and WSDM of full-ripe fruits were found to be significant ( $P < 0.05$ ) (Table 12). As compared to fresh fruits, the closest pH value was observed at 60°C drying temperature. Drying temperature of 70°C was found to be more suitable for titratable acidity and 50°C for WSDM. There are previous studies about the effects of drying methods on quality traits of white mulberry fruits. Ojha et al. (2017) conducted an osmo-air drying study and reported increased pH values of white mulberry fruits. Ercişli and Orhan (2007) reported pH values of dried white mulberries as between 3.52-5.60.

Table 9. Color parameters of semi-ripe fruits

Drying method	Temperature (°C)	$L^*$	$a^*$	$b^*$	C	Hue°	$\Delta E$
Fresh	-	35.41 <sup>b</sup>	25.73 <sup>a</sup>	14.90 <sup>a</sup>	29.94 <sup>a</sup>	30.17 <sup>a</sup>	-
Oven	50	36.97 <sup>ab</sup>	12.39 <sup>b</sup>	4.29 <sup>b</sup>	13.28 <sup>b</sup>	17.02 <sup>b</sup>	27.11 <sup>a</sup>
	60	38.64 <sup>a</sup>	13.88 <sup>b</sup>	4.97 <sup>b</sup>	14.79 <sup>b</sup>	19.67 <sup>b</sup>	27.94 <sup>a</sup>
	70	37.58 <sup>ab</sup>	14.55 <sup>b</sup>	5.80 <sup>b</sup>	15.72 <sup>b</sup>	21.95 <sup>b</sup>	26.88 <sup>a</sup>

Table 10. Color parameters of semi-ripe fruits

Drying method	Temperature (°C)	$L^*$	$a^*$	$b^*$	C	Hue°	$\Delta E$
Fresh	-	16.44 <sup>c</sup>	11.43 <sup>a</sup>	-0.80 <sup>a</sup>	11.49 <sup>a</sup>	-4.73 <sup>a</sup>	-
Oven	50	31.41 <sup>a</sup>	8.18 <sup>b</sup>	-0.50 <sup>a</sup>	8.23 <sup>b</sup>	-4.24 <sup>a</sup>	24.70 <sup>a</sup>
	60	25.64 <sup>b</sup>	5.83 <sup>c</sup>	-1.76 <sup>b</sup>	6.13 <sup>c</sup>	-17.13 <sup>b</sup>	20.60 <sup>b</sup>
	70	30.65 <sup>a</sup>	5.63 <sup>c</sup>	-1.97 <sup>b</sup>	5.99 <sup>c</sup>	-19.34 <sup>b</sup>	25.45 <sup>a</sup>



Table 11. Chemical analysis results for semi-ripe black mulberry fruits

Drying method	Temperature (°C)	pH	TA	WSDM
Fresh	-	3.16 <sup>a</sup>	7.50 <sup>b</sup>	1.73 <sup>d</sup>
Oven	50	2.99 <sup>b</sup>	15.47 <sup>a</sup>	4.10 <sup>a</sup>
	60	2.83 <sup>c</sup>	14.45 <sup>a</sup>	3.67 <sup>b</sup>
	70	2.87 <sup>c</sup>	14.69 <sup>a</sup>	3.30 <sup>c</sup>

Table 12. Chemical analysis results for full-ripe black mulberry fruits

Drying method	Temperature (°C)	pH	TA	SÇKM
Fresh	-	3.45 <sup>ab</sup>	3.38 <sup>d</sup>	3.10 <sup>c</sup>
Oven	50	3.39 <sup>c</sup>	6.98 <sup>a</sup>	5.23 <sup>b</sup>
	60	3.45 <sup>ab</sup>	6.10 <sup>b</sup>	5.87 <sup>a</sup>
	70	3.50 <sup>a</sup>	5.42 <sup>c</sup>	5.60 <sup>ab</sup>

## Conclusion

Present findings revealed that drying air temperatures and ripening levels had significant effects on drying performance, drying model, specific energy consumption, effective diffusion, activation energy, color and chemical characteristics of black mulberry fruits ( $P < 0.05$ ). Significant decreases were observed with increasing drying temperatures. The shortest drying duration and the greatest specific energy consumptions were observed in full-ripe fruits. Effective diffusion and activation energy values of full-ripe fruits were greater than the values of semi-ripe fruits. In terms of color parameters, semi-ripe fruits are recommended to be dried at 50 or 60°C drying temperatures and full-ripe fruits should be dried at 50°C drying temperature for better preservation of color parameters. On the other hand, a common proper drying temperature could not be identified for acidity (pH), water soluble dry matter and titratable acidity.

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