



Comparison of kinetics, mass diffusion and biochemical properties of black and finger mulberry varieties processing by different drying temperatures

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Abstract

In this study, black mulberry (*Morus nigra* L.) and finger mulberry (*Morus levigata* Wall.) cultivars were dried in an oven-dryer at 50, 55, and 60 °C drying temperatures. Drying durations under different drying temperatures varied between 2610–870 min for finger mulberry and between 4470–3360 min for black mulberry fruits. Effective diffusion values varied between 1.43 and $4.30 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ for finger mulberry and between 9.13×10^{-9} – $1.46 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ for black mulberry fruits. Among 3 drying models, Wang-Sing model was identified as the best model for estimating drying parameters. In terms of color criteria, the closest values to fresh values was observed at 60 °C for finger mulberry and 50 °C for black mulberry. In terms of water-soluble dry matter, acidity, titratable acidity, total antioxidant and total anthocyanin values, the best drying temperature for finger and black mulberry fruits was identified as 60 °C. In terms of all quality parameters examined, it is recommended that finger mulberry and black mulberry fruits should be dried at 60 °C drying temperature.

1 Introduction

Agricultural products contain quite large quantities of moisture ranging about 75–95%. Such high moisture contents result in post-harvest destructions in physical, chemical and biological characteristics of these products. To prevent these destructions, producers generally preserve agricultural products in cold storages or preserve through drying [8, 10].

The drying methods and dryer types used strongly affect the color containment of the product. In recent years, much attention has been paid to the quality of foods during drying. The method were used for drying affects different material properties such as color, texture, density, porosity, and sorption characteristics [16, 45]. Drying is the oldest method used in long-term preservation of foodstuffs [13, 19]. In drying,

significant reductions are encountered in product mass and volume, thus significant cost reductions are achieved in transportation of these products [22]. Several methods have been used for drying of harvested products. However, specific drying methods should be selected and optimum conditions (temperature, moisture, air flow rate, power, application duration, pre-processes) should be provided for an efficient drying of each product. Generally open-sun or shade drying are used since these methods do not require energy consumption and technical knowledge [20, 26]. However, drying durations are quite long in these methods and serious quality losses are encountered in final product [40, 42]. In open-sun drying processes, infra-red rays may have carcinogenic effects on products and there is a risk of contamination from agro-chemicals, dust and poisonous gasses coming from surrounding environments. Therefore, agricultural commodities should be dried in closed facilities and/or in specially designed artificial dryers. Such artificial dryers include microwave [6], vacuum, hot-air [38] and hybrid driers [36]. Among these methods, hot-air conventional driers are the most common ones. Range and demand of dried products are continuously increasing in markets. Such a case then generated new fields of employment and business opportunities. Mulberry is among the most common dried products.

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Mulberry fruits belong to *Moraceae* family and can grow in wide range of soil characteristics and climate conditions. They were first used in Asia in treatment of internal and infectious diseases, but now are being used worldwide as an alternative of chemical drugs in treatment of various diseases. Mulberry fruits are quite rich in functional substances such as anthocyanins, polysaccharides, phenols, alkaloids and flavonoids [41]. In food industry, mulberry fruits are used in fruit juice and wine production. Fruits are also used in fresh and dry forms [4, 46]. In Turkey, black mulberry (*Morus nigra* L.) and finger mulberry (*Morus laevigata* Wall.) fruits are largely preferred by consumers. Mulberry fruits are largely consumed in fresh and dry forms in Turkey, but some are also used in fruit juice production. Number of studies on optimum drying temperature of black and finger mulberry fruits is highly limited and already available studies are also lack in content and coverage.

A number of studies were done on effects of drying temperatures on drying properties in agriculture products and energy consumption in agriculture production. For instance, studies were done on rice [45], watercress [18], cotton [31], onion [24] etc. In present study, *Morus nigra* L. and *Morus laevigata* Wall. mulberry cultivars were dried in oven drier at 50, 55 and 60 °C drying temperatures and the best drying temperature in terms of drying parameters (duration, final moisture), thin layer drying models, effective diffusion, color, water soluble dry matter, acidity, titratable acidity, total antioxidant and anthocyanins was determined.

2 Materials and methods

2.1 Drying material

Black and finger mulberry fruits used as plant material were collected from the mulberry trees in Research and Implementation Orchard of Agricultural Faculty of Tokat Gaziosmanpaşa University. Harvested fruits were preserved in a fridge at $+4 \pm 0.5$ °C temperature. Drying experiments were conducted in drying laboratory of Tokat Gaziosmanpaşa University Agricultural Faculty.

2.2 Moisture content

Fresh mulberry samples of 30 ± 1.5 g were dried in an oven at 70 °C until a constant mass to determine initial moisture content of the samples [43].

2.3 Drying processes

The fruits were dried in an oven dryer at 50, 55 and 60 °C drying temperatures and 1 m/s air velocity until they reached

10% final moisture content on the wet bottom. The fruits were cylindrical and untreated. To monitor time-dependent change in fruit mass, samples were weighed in certain intervals with a precise balance (± 0.01 g). The device used in present drying experiments was Şimşek Laborateknik brand and ST-120 type. Drying air temperature is able to be adjusted with the use of PID (Proportional–Integral–Derivative) controllers mounted over the device.

2.4 Drying models

Moisture ratios released from the mulberry fruits during the drying processes at different temperatures were processed into thin layer drying equations to determine the best drying models. Available moisture ratio (AMR) throughout the drying processes was calculated with the use of Eq. 1 [7, 12, 44].

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

where;

AMR: Available moisture ratio.

M: Instant moisture.

M_e : Equilibrium moisture.

M_0 : Initial moisture.

The thin layer models used in present study are provided in Table 1. To model drying data of black and finger mulberry cultivars, Jena-Das, Lewis and Wang-Sing equations, commonly used in literatures, were selected.

2.5 Effective diffusion

The area to which time-dependent moisture release of drying temperatures diffused was calculated with the use of Eq. 2 [5, 37].

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

where; D_{eff} is effective diffusion ($m^2 s^{-1}$), L is half the product slice thickness (m).

Table 1 Equations of present models

Models	Equation	Reference
Jena and Das	$MR = h \cdot \exp(-j \cdot (t^k)) + (m \cdot t)$	Jena and Das [11]
Lewis	$MR = \exp(-k \cdot t)$	Lewis [17]
Wang Sing	$MR = 1 + k \cdot t + h \cdot t^2$	Wang and Sing [39]

2.6 Color analysis

Color measurements (L , a and b values) before and after drying processes were performed with the use of Minolta CR400 (Japan) color meter. L indicates color brightness and ranges between 0 and 100, with 0 indicating black and 100 indicating white color; (a) indicates red – green colors and (b) indicates yellow–blue colors and takes respectively (+, -) values. If the color values $a=0$ and $b=0$, then the color is gray [21]. The other color parameters calculated with the use of measured values are provided in Table 2.

2.7 Statistical analysis

Multiple range test (Duncan) was applied to experimental data to determine the effects of drying temperatures on investigated parameters of mulberry samples (SPSS17, $p<0.05$).

3 Results and discussion

3.1 Drying performance

Initial moisture content was measured as 75.11% for black mulberry samples and 72.18% for finger mulberry samples. Mulberry samples were dried to a final moisture range of 10–15%. Average drying durations under different drying temperatures are provided in Table 3.

As can be seen in Table 3, drying temperatures influenced drying performance (duration, final moisture) of mulberry cultivars. The longest drying duration was measured as 4470 min for black mulberry and 2610 min for finger mulberry fruits. In black mulberry fruits, as compared to 50 °C drying temperature, 4.03 and 24.83% less drying durations were measured at 55 and 60 °C drying temperatures, respectively. Such reductions in drying durations were respectively calculated as 34.48 and 66.67%. Khattak et al. [14] dried different mulberry cultivars in open-sun, microwave and hot-air dryer and reported significant effects of drying conditions on drying durations ($p<0.05$). Kıpçak [15] investigated drying kinetics of black mulberry fruits at 50 and 140 W infra-red powers and reported significant effects of power values on drying performance of the fruits ($p<0.05$).

3.2 Results for samples of the drying models

Results obtained from drying models for drying ratios of black and finger mulberry samples are provided in Table 4.

The mathematical model, best estimating drying values (AMR) under different drying temperatures was identified as Wang-Sing model at 60 °C for finger mulberry samples and Jena-Das model at 50 °C for black mulberry samples. Among the entire drying models, the greatest R^2 (0.9998) was obtained from finger mulberry drying at 55 °C drying temperature.

Table 2 Color parameters

Color parameters	Equation	References
Chroma, C	$C = (a^2 + b^2)^{\frac{1}{2}}$	Ramallo and Mascheroni [29]
Hue, °	$h^\circ = \tan^{-1} \left(\frac{b}{a} \right)$	Alemrajabi et al. [1]
Color change, ΔE	$\Delta E = \sqrt{(L - L^*)^2 + (a - a^*)^2 + (b - b^*)^2}$	Tan et al. [34]
BI	$BI = \frac{[100(x-0.31)]}{0.17}$	Plou et al. [27]
	$x = \frac{a+(xL)}{[(5.645xL)+(a-(3.0.12xb))]}$	

Where; Chroma (C): Color tone, hue°: color angle, Color change (ΔE): Change in product color as compared to fresh product color. Ratio of redness value to blueness value, Browning index (BI): Browning of dried products.

Table 3 Average drying performance content of mulberry samples

Varieties	Drying temperatures °C	Final moisture content (w.b.)	Drying time (min.)
Finger mulberry	50	14.74	4470
	55	14.48	4290
	60	12.47	3360
Black mulberry	50	14.75	2610
	55	14.85	1710
	60	12.08	870

Table 4 Results for thin-layer drying models

Materials	Drying temperatures	Models	Coefficients	R^2	P
Finger mulberry	50 °C	Lewis	k: -0.0009	0.9946	$p < 0.0001$
		Jena Das	k: 1.0162 h: 0.4043 j: 0.8068 m: 0.0113	0.9959	$p < 0.0001$
		Wang Sing	k: -0.0007 h: 1.3285	0.9996	$p < 0.0001$
		Lewis	k: 0.0015	0.9944	$p < 0.0001$
		Jena-Das	k: 1.0192 h: 0.4046 j: 0.8062 m: 0.0141	0.9962	$p < 0.0001$
		Wang Sing	k: -0.0011 h: 3.5217	0.9998	$p < 0.000$
	60 °C	Lewis	k: 0.0024	0.9828	$p < 0.0001$
		Jena-Das	k: 1.0260 h: 0.4052 j: 0.8051 m: 0.0221	0.9880	$p < 0.0001$
		Wang Sing	k: -0.0019 h: 9.2266	0.9995	$p < 0.0001$
		Lewis	k: 0.0006	0.9907	$p < 0.0001$
		Jena-Das	k: 0.9777 h: 0.4041 j: 0.8072 m: -0.0275	0.9968	$p < 0.0001$
		Wang Sing	k: -0.0004 h: 5.6666	0.9758	$p < 0.0001$
Black mulberry	55 °C	Lewis	k: 0.0007	0.9921	$p < 0.0001$
		Jena-Das	k: 0.9766 h: 0.4042 j: 0.8071 m: -0.0287	0.9982	$p < 0.0001$
		Wang Sing	k: -0.0005 h: 7.2461	0.9750	$p < 0.0001$
		Lewis	k: 0.0009	0.9967	$p < 0.0001$
		Jena-Das	k: 0.9869 h: 0.4043 j: 0.8069 m: -0.0183	0.9985	$p < 0.0001$
		Wang Sing	k: -0.0007 h: 1.2537	0.9798	$p < 0.0001$
	60 °C	Lewis	k: 0.0009	0.9967	$p < 0.0001$
		Jena-Das	k: 0.9869 h: 0.4043 j: 0.8069 m: -0.0183	0.9985	$p < 0.0001$
		Wang Sing	k: -0.0007 h: 1.2537	0.9798	$p < 0.0001$

3.3 Effective diffusion values

The effective moisture diffusion values of mulberry samples are provided in Table 5.

As can be inferred from Table 5, drying temperatures influenced effective diffusion values and increasing effective diffusion values were obtained with increasing drying temperatures. Effective diffusion values varied between 1.43×10^{-8} and $4.30 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ for finger mulberry and between 9.13×10^{-9} – $1.46 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ for black mulberry samples. Tao et al. [35] investigated the effects of ultrasound pre-process durations on effective diffusion values of mulberry samples and reported effective diffusion values of between

1.79 and $3.01 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$ with increasing effective diffusion values with increasing pre-process durations. Sablani et al. [30] reported effective diffusion values as between 2.2 and $3.4 \times 10^{-12} \text{ m}^2 \text{ s}^{-1}$ for blueberry fruits and between 1.3 and $2.2 \times 10^{-12} \text{ m}^2 \text{ s}^{-1}$ for raspberry fruits. Rad et al. [28]

Table 5 Effective diffusion values

Materials	Drying temperatures	Effective diffusion values ($\text{m}^2 \text{ s}^{-1}$)
Finger mulberry	50 °C	1.43×10^{-8}
	55 °C	2.21×10^{-8}
	60 °C	4.30×10^{-8}
Black mulberry	50 °C	9.13×10^{-9}
	55 °C	1.10×10^{-8}
	60 °C	1.46×10^{-8}

conducted a drying study with white mulberry fruits and reported effective diffusion values as between.

2.96×10^{-10} – $3.30 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$. Suna and Özkan-Karabacak [32] dried mulberry leathers in microwave, hot air and vacuum drier and reported effective diffusion values as between 4.42×10^{-9} – $8.47 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$.

3.4 Color parameters

Duncan's test results for color values of fresh and dried fruits are provided in Table 6.

As can be inferred from Table 6, dried finger mulberry samples failed to preserve brightness, redness-greenness, chroma and hue values as compared to the values of fresh samples. However, yellowness-blueness, total color change and browning index values were better preserved ($p < 0.05$) at 55 °C and 60 °C drying temperatures as compared to 50 °C. Özkan-Karabacak [25] dried mulberry leathers in a hot-air dryer and indicated that *L*, *a*, *b*, *C* and hue values of the samples dried at 50 °C and 60 °C drying temperatures were significantly different from the values of fresh samples ($p < 0.05$) and dry samples were not able to preserve initial color values. Boz et al. [2] reported *L* values of dried mulberry fruits as between 31.64 and 35.86. In present study, *L* values varied between 27.78 and 30.36. Similar findings were also reported by Şengül et al. [3, 33]. Water soluble dry matter (WSDM), acidity (pH), titratable acidity (*TA*) values of dried finger and black mulberry samples are provided in Table 7.

As can be inferred from Table 7, mean WSDM and pH values were lower and *TA* values were greater in black

mulberry fruits than in finger mulberry fruits. As compared to fresh fruits, effects of drying temperatures on WSDM, pH and *TA* values were found to be significant ($p < 0.05$). Again, as compared to fresh fruits, dried ones generally had greater WSDM, pH and *TA* values. In terms of WSDM, pH and *TA* analyses, optimum drying temperature for finger and black mulberry fruits was identified as 60 °C. Ojha et al. [23] dried mulberry fruits with the use of osmo-air method and indicated that drying increased pH values of the samples as compared to the fresh ones. Ercişli and Orhan [9] conducted a drying study and reported pH values of dried products as between 3.52 and 5.60. Results for total anthocyanins and total antioxidants of dried finger and black mulberry fruits are provided in Table 8 ($p < 0.05$).

As can be inferred from Table 8, as compared to fresh samples, black mulberry fruits significantly preserved total anthocyanins, but were not able to preserve total antioxidants. As compared to fresh fruits, while finger mulberry fruits were able to preserve total anthocyanin values at all drying temperatures, they were partially better-preserved antioxidant values at 50 and 60 °C drying temperatures than at 55 °C. Considering WSDM, pH, *TA*, total anthocyanins and total antioxidants of dried finger and black mulberry fruits together, the most appropriate drying temperature was identified as 60 °C. Present findings revealed that 55 °C could also be used as an alternative of 60 °C. Suna and Özkan-Karabacak [32] investigated the effects of drying methods on antioxidant characteristics of dried mulberry leathers and reported significant effects of drying conditions on antioxidant characteristics ($p < 0.05$). Antioxidant capacity of the samples were reported as between 105.35

Table 6 Duncan's test results for fresh and dried mulberry fruits

Varieties	Drying temperatures	L	a	b	C	hue	ΔE	BI
Finger mulberry	Fresh	13.71±0.21c	7.60±0.01a	−2.33±0.011a	7.99±0.12a	−17.60±0.4a	–	–
	50	29.87±0.18a	4.17±0.02b	−1.99±0.012a	4.65±0.013b	−25.63±0.2b	25.70±0.3a	3.37±0.01a
	55	29.32±0.30a	4.04±0.02b	−2.14±0.022a	4.58±0.1b	−27.93±0.3b	25.22±0.02a	2.71±0.02a
	60	27.78±0.18b	4.22±0.01b	−2.07±0.018a	4.74±0.02b	−26.84±0.1b	23.59±0.03b	3.44±0.02a
Black mulberry	Fresh	12.75±0.16b	9.96±0.1a	−1.77±0.015ab	10.20±0.2a	−0.20±0.001a	–	–
	50	29.16±0.22a	6.54±0.02b	−1.78±0.013ab	6.79±0.1b	−0.27±0.002a	15.41±0.02a	23.460.2±b
	55	30.36±0.23a	5.58±0.022bc	−1.57±0.011a	5.83±0.02b	−0.29±0.002a	16.37±0.01a	25.30±a
	60	29.99±0.31a	5.29±0.019a	−2.25±0.013b	5.84±0.03	−0.42±0.002b	23.87±0.03b	24.91±0.2a

Table 7 Chemical analysis results for dried mulberry samples

Varieties	Drying temperatures	WSDM	pH	TA
Black mulberry	Fresh	24.00b	3.28b	2.86c
	50	71.33a	3.41a	4.52b
	55	71.33a	3.41a	4.62b
	60	73.00a	3.29b	5.56a
Finger mulberry	Fresh	28.00c	5.31b	1.20c
	50	80.33a	5.55a	1.61b
	55	82.33a	5.56a	2.31a
	60	50.33b	5.17c	1.59b

Table 8 Results for chemical analyses of the fruits

Materials	Drying temperatures	Total anthocyanins ($\mu\text{g cy-3-glu g}^{-1}$)	Total antioxidants ($\mu\text{mol TE g}^{-1}$)
Black mulberry	Fresh	54.02a	57.89b
	50	38.67a	110.14a
	55	54.48a	128.83a
	60	59.31a	125.70a
Finger mulberry	Fresh	24.31a	49.25b
	50	7.13a	83.88ab
	55	10.44a	107.21a
	60	10.17a	85.27ab

and 181.37 ($\mu\text{mol TE } 100 \text{ g dry matter}^{-1}$). Chen et al. [3] indicated significant effects of drying methods on antioxidant values of dried mulberry fruits ($p < 0.05$) and reported antioxidant values of between 65.91 and 101.57 ($\text{mg TE g dry matter}^{-1}$). Ojha et al. [23] conducted a mulberry drying study with the use of osmosis and hot air drying methods. Total anthocyanin and antioxidant contents of the fresh samples were respectively reported as 1293 ($\text{mg } 100 \text{ g dry matter}^{-1}$) and 81.90 (% final activity). These values of the dried fruits were respectively reported as 154.86 ($\text{mg } 100 \text{ g dry matter}^{-1}$) and 74.33 (% final activity).

4 Conclusion

In present study, finger and black mulberry samples were dried in an oven-dryer at.

50, 55 and 60 °C drying temperatures. Present findings revealed that drying temperatures influenced drying durations, drying models, effective diffusion, color and phytochemical values. Significant decreases were observed in drying durations with increasing drying temperatures. Among all drying models, Wang-Sing model at 60 °C was identified as the best model for drying ratios of the samples. Effective diffusion values varied between.

$1.43\text{--}4.30 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ for finger mulberry and between 9.13×10^{-9} – $1.46 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ for black mulberry fruits. In terms of color parameters of dried fruits, optimum drying temperature was identified as 60 °C for finger mulberry and 50 °C for black mulberry fruits ($p < 0.05$). Drying temperatures had significant effects on WSDM, pH, TA, total anthocyanins and total antioxidants of finger and black mulberry fruits ($p < 0.05$). In terms of phytochemical traits of dried fruits, optimum drying temperature was identified as 60 °C ($p < 0.05$). If the fresh finger and black mulberry fruits are to be consumed in dry forms, in terms of quality traits investigated in present study, fruits should be dried at 60 °C drying temperature.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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