Effect of pre-treatment on color quality and energy consumption parameters of jerusalem artichoke dried by microwave and convective methods

S.K. Dursun[1], B. Aksut[2,*] and M. Taşova[1]

[1]*Tokat Gaziosmanpaşa University, Agricultural Faculty, Biosystems Engineering Department, 60250, Tokat-Türkiye*
[2]*Tokat Gaziosmanpaşa University, Agricultural Faculty, Horticulture Department, Sustainable Agriculture Program, 60250, Tokat-Türkiye*
*__Corresponding author__: burcu.aksutt@gmail.com

ABSTRACT The shortest drying time was determined in the microwave dryer at 720 W power and ethyl oleate pre-treated samples. The longest drying time was determined in the convective dryer at 50 °C. Control samples dried in a convective dryer at 50 °C preserved the chroma color property of fresh. The drying data was best estimated by the Midilli-Küçük model. It was determined that the effective diffusion coefficients values varied between $3.14 \cdot 10^{-9}$ – $2.35 \cdot 10^{-7}$ m^2/s. The highest specific moisture removal rate (0.0344 kg/kWh) value was determined in ethyl oleate pre-treated samples dried at 720 W microwave power. The lowest specific energy consumption (29.07 kW/kg) value was determined in the ethyl oleate pre-treated samples dried in a microwave dryer at 720 W power. The highest evaporation energy (2.70 kWh) is in the convective dryer. The highest energy efficiency was calculated as 7.20 % in the same drying process. It has been found that the drying process at 540 W power is more suitable in terms of both quality characteristics, energy consumption and mass diffusion parameters of Jerusalem artichoke.

KEYWORDS Drying kinetic; Physico-chemical; Energy consumption; Moisture diffusion; Energy efficiency

1. Introduction

Helianthus tuberosus L. is also known as "Jerusalem artichoke". Jerusalem artichoke is a low-calorie fruit because it contains very little starch and oil (Baltacıoğlu and Esin, 2012). Besides being used as a fodder plant, industrial and biomass source, yams are also grown as a source of inulin in terms of health (Heiser, 2015; Marx et al., 1997; Baltacıoğlu and Esin, 2012; Kaya-Mert, 2021). Jerusalem artichoke is insufficient in terms of 6-9 % crude protein and mineral, phosphorus (P) content is insufficient in terms of calcium (Ca), potassium (K) and magnesium (Mg) content (Seiler, 1988; Karslı and Bingöl, 2009). In addition, the plant, which is rich in vitamins A, B and C, grows in temperate climate conditions (Kaya-Mert, 2021).

Due to the rich nutritional value of jerusalem artichoke, when it is stored for a long time, microbial and enzymatic activities result in deterioration in the structure of the plant and its quality decreases (Doymaz, 2018; Kaya-Mert, 2021). In developing countries, approximately 30-40 % of the products go to waste after harvest due to the lack of knowledge of appropriate storage methods and the lack of infrastructure (Lewicki and Lenart, 2006; Bonazzi and Dumoulin, 2011). Jerusalem artichoke, which has a high nutritional value, needs to be preserved after the harvest season in order to store it for a long time. Drying is one of the most commonly preferred storage methods.

Drying is a heat-mass diffusion event in which the high moisture content of the products is reduced to the critical humidity level where they can be kept intact under controlled conditions, and changes occur in the biological, physical and chemical properties of the product in this process (Polatcı and Taşova, 2020).

There are many methods of product drying. Open drying method, which has been used since ancient times and traditionally, is a convenient method in terms of energy and costs. However, this method necessitates different methods due to factors such as large areas, the need for more manpower and the exposure of drying products to adverse environmental conditions (dust, exhaust gas, emulsion and insect infestation, etc.) (Özkan et al., 2007; Arslan et al., 2019; Alibas et al., 2020; Yilmaz and Alibas, 2021). In artificial hot air drying methods, the undesirable conditions in open drying methods are eliminated, but energy consumption and drying time properties increase. The use of microwave dryers is becoming increasingly common in order to obtain dried products in a shorter time by consuming less energy (Polatcı et al., 2020). Microwave heating is based on the transformation of alternating electromagnetic field energy into thermal energy by affecting the polar molecules of a material. Many molecules in food (such as water and fat) are electric dipoles, meaning that they have a positive charge at one end and a negative charge at the other, and therefore, they rotate as they try to align themselves with the alternating electric field induced by the microwave rays. The rapid movement of the bipolar molecules creates friction and results in heat dissipation in the material exposed to the microwave radiation. Microwave heating is most efficient on water (liquid) and much less on fats and sugars which have less molecular dipole moment (Sutar and Prasad, 2008). Karacabey et al. (2011) in their drying study, they

DOI: 10.52292/j.laar.2024.1289
Received: October 24, 2022.
Accepted: March 16, 2023.
Recommended by José L. Díaz de Tuesta.

sliced the jerusalem artichoke slices in 2 mm thickness and cut them in the conventional convective dryer. They were dried at 50, 70, 80 and 90 °C drying temperatures, in a microwave dryer at 100, 200 and 300 W microwave powers. They found that the microwave technique can be used to dry the jerusalem artichoke slices and is an alternative to the traditional convective dryer drying system. Antal et al. (2017) investigated the drying properties of jerusalem artichoke cubes using three different drying methods (mid-infrared (MIR)), freeze-dried (FD) and mid-infrared assisted freeze-drying (MIR-FD). As a result of the study, they found that the MIR-FD method is more advantageous in terms of drying time. Aydar et al. (2022) applied ultrasound pretreatment for 5 and 10 minutes to reduce drying times in the jerusalem artichoke drying study. As a result of the study, it was determined that the pre-treated samples dried in a shorter time and with better quality. Ethyl oleate pretreatment affects the microstructure of the fruit, increasing the drying rate and thus reducing the drying time. This situation provides positive contributions to both energy consumption parameters and quality characteristics (Polatcı et al., 2020). In the literature review, no study was found in which the effect of pre-treatments on the physico-chemical and energy consumption parameters of the jerusalem artichoke drying process was investigated. With this study, it is aimed both to eliminate the important deficiency in the literature and to reveal the effects of drying process combinations on quality and energy consumption characteristics.

In this study, to examine the effect of ethyl oleate pretreatment and drying conditions on jerusalem artichoke slices, they were dried in convective and microwave drying convective dryers and investigated in terms of mathematical modeling, effective diffusion-activation energy, SMER, SEC, total energy consumption and thermodynamic properties.

2. Methods

2.1 Trial material

The Jerusalem artichoke used in the study was purchased from a public market in Tokat and stored at +4±0.5 °C until the drying process was completed. Moisture determination and drying processes were carried out in Tokat Gaziosmanpaşa University Biosystem Engineering drying laboratory.

2.2 Pre-treatment

After washing the Jerusalem artichokes, they were sliced with a sharp knife for drying. For 3 % ethyl oleate solution, it was prepared by adding 15 mL of ethyl oleate liquid and 485 mL of distilled water to a 500 mL glass beaker. Sliced fruits were kept in ethyl oleate solution for 15 minutes.

2.3 Drying method

Jerusalem artichoke was stored at +4±0.5 °C until the drying process was completed. From the heap of Jerusalem artichokes, those of homogeneous size and color were selected and sliced in 1.70±0.16 mm thickness. Then, ethyl oleate was pre-treated and dried in a convective dryer at 50 and 60 °C and in the microwave at 540 and 720 W. Drying temperatures of 60, 70 and 80 °C for convective drying (Doymaz, 2018), and 600, 900 W power values for microwave drying (Baltacıoğlu and Esin, 2012) were selected in the drying studies related to Jerusalem artichoke in the literature. The samples in the dryers were taken out at certain intervals and weighed with a scale with a sensitivity of 1 g, and the moisture of the product was dried up to 5-7 % according to the wet base.

2.4 Determination of moisture

An average of 40±0.15 g samples were used to calculate the initial moisture value according to the wet basis before the drying process of fresh yams. Moisture determination drying air was dried in a convective dryer at 70 °C in 4 parallels until the weight changes were constant (Yağcıoglu, 1999). Moisture content according to wet and dry basis was calculated using Eqs. 1 and 2.

$$N_y = (W_i - W_s)/W_i \times 100 \tag{1}$$

$$N_k = (W_i - W_s)/W_s \times 100 \tag{2}$$

where N_y: Moisture on wet basis (%), N_k: Moisture on dry basis (%), W_i: Weight of wet sample, W_s: Weight of dry sample (g).

2.5 Determination of moisture

The color values of fresh and dried Jerusalem artichokes were measured using a Minolta brand CR300 colorimeter. Hue, chroma, browning index and total color change values were determined by using the measured values. While the L value shows the brightness value of the samples used, it takes values between 0 and 100. a value represents red-green and b value represents yellow-blue colors. If the measured values are positive (+), a value indicates red color and b value indicates yellow. If the measured values are negative (-), it indicates that a is green and b is blue (McGuire, 1992).

The hue value represents a color radiant calculated using the redness and yellowness values measured from the Materials. Hue value was calculated using Eq. 3.

$$h^\circ = \tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{3}$$

The chroma value indicates the saturation of the color. Materials in vibrant colors receive high values. Materials in pale colors have low values. The chroma value was calculated using the equation number 4.

$$C = \left(a^2 + b^2\right)^{1/2} \tag{4}$$

Total color change value (ΔE): It calculates how much the color values of the jerusalem artichoke have changed after being freshly measured and dried. The total color change value was calculated with equation 8 using the results obtained from Eqs. 5, 6 and 7 (Çelen et al., 2015).

$$\Delta L = L_{fresh} - L \tag{5}$$

$$\Delta a = a_{fresh} - a \tag{6}$$

$$\Delta b = b_{fresh} - b \tag{7}$$

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{8}$$

Browning index value (BI): It calculates the browning value of the jerusalem artichoke after the drying process. The browning index was calculated by Eq. 10 (Palou et al., 1999).

$$X = \frac{a + (1.75 \times L)}{[(5.645 \times L) + (a - (3.012 \times b))]} \tag{9}$$

$$BI = \frac{100\,(x - 0.31)}{0.17} \tag{10}$$

Whiteness index (WI): Whiteness indices (WI) are commonly measured to derive numbers that closely correlate with consumers' preference for white color. It mathematically combines lightness and yellow-blue into one term. WI represents the overall whiteness of food products, which can indicate the degree of discoloration during the drying process (Hsu et al., 2003; Pathare et al., 2013). Eq. 11 was used to calculate the whiteness index (Rhim et al., 1999).

$$WI = \sqrt{(100 - L)^2 + a^2 + b^2} \tag{11}$$

Yellowness Index (YI): Yellowness is associated with exposure to light, chemicals, and extreme heat and processing, contamination, and general product spoilage. Yellowness indices are mainly used to measure such deterioration with a single value. They can be used to measure clear, colorless liquids or solids in transmission and nearly white, opaque solids in reflection (Pathare et al., 2013). Eq. 12 was used to calculate the jaundice index (Rhim et al., 1999).

$$YI = \frac{142.86 \times b}{L} \tag{12}$$

2.6 Drying rate and humidity

Equation 13 was used to determine the drying rate values of jerusalem artichoke.

$$DR = \frac{M_t - M_{(t+dt)}}{dt} \tag{13}$$

where: M_t; Moisture content at time t (g water/g drying substance), dt; minutes, DR; drying rate (g water/g dry matter min).

Equation 14 was used to determine the time-dependent drying rates of the samples.

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{14}$$

where: MR: Separable humidity, M: Instant moisture content of the product (g moisture/g dry matter), M_e: Equilibrium moisture content of the product (g moisture/g dry matter), M_0: The initial moisture content of the product (g moisture/g dry matter).

2.7 Mathematical modeling

In order to determine the most suitable thin layer drying model for Jerusalem artichoke slices, the mathematical equations commonly used in the literature were chosen. Modeling data were made using SigmaPlot 10.0 package program (Midilli et al., 2002; Wang and Singh, 1978; Lewis, 1921).

$$\text{Midilli-Küçük: } MR = h \cdot \exp\left(-j \cdot \left(t^k\right)\right) + (m \cdot t) \tag{15}$$

$$\text{Wang-Singh: } MR = 1 + k \cdot t + h \cdot t^2 \tag{16}$$

$$\text{Lewis: } MR = \exp(-k \cdot t) \tag{17}$$

2.8 Effective diffusion

The removal of moisture from the product during drying is explained by the second issue of Fick's law. This law shows the amount of moisture emitted from the product to the area per unit time, depending on the time. When calculating the effective diffusion, it is assumed that the tissue structure of the product is preserved and the moisture is removed from the environment only by diffusion. The effective diffusion value was calculated using equation number 18-19 (Crank, 1979; Türker and Işleroğlui, 2017)

$$\begin{aligned} MR &= \frac{M - M_e}{M_0 - M_e} \\ &= \frac{8}{\pi} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left[(2n+1)^2 \frac{\pi^2}{4} \frac{D_{eff}t}{L^2}\right] \end{aligned} \tag{18}$$

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2}{4} \frac{D_{ehf}t}{L^2} \tag{19}$$

In the equation used; D_{eff}: represents the effective diffusion value (m^2/s); L: represents half of the slice thickness (m) of the product and t: indicates the drying time of the product.

2.9 Energy analysis

The specific moisture removal rate (SMER), specific energy consumption (SEC), and energy efficiency of the drying processes were calculated (Surendhar et al., 2019).

The specific moisture removal rate is calculated as kilograms of moisture removed per kilowatt-hour energy delivered to the dryer. Specific energy consumption (SMER) is defined as the amount of energy required to dry one kilogram of sample. The SMER value was calculated using Eq. 20.

$$SMER = \frac{\text{moisture removed during drying}}{\text{Total energy supplied to the dryer}} \frac{\text{kg}}{\text{kWh}} \tag{20}$$

The amount of energy consumed to remove one kilogram of moisture in drying processes was calculated using Eq. 21 (Motevali et al., 2012).

$$SEC = \frac{E_t}{m_w} \tag{21}$$

where: SEC: specific energy consumption (kWh/kg water), E_t: total consumed energy (kWh), m_w: amount of water removed (kg).

2.10 Evaporation energy

Equation 22 was used to calculate the latent heat of evaporation (Beigi, 2016).

$$
\begin{aligned}
&Q_w = h_{fg} \times m_w \\
&h_{fg} = 2.503 \cdot 10^6 - 2.386 \cdot 10^3 \cdot (T_d - 273.16) \\
&\quad 273.16 \leq T_d \text{ (K)} < 338.72 \\
&h_{fg} = \sqrt{7.33 \cdot 10^{12} - 1.60 \cdot 10^7 \cdot T_d^2} \\
&\quad 338.72 \leq T_d \text{ (K)} < 533.16
\end{aligned} \tag{22}
$$

where Q_w: evaporation energy (kWh), h_{fg}: latent energy of evaporation (kJ/kg), m_w: the amount of evaporated moisture (kg), T_d: drying temperature (K).

2.11 Energy efficiency

According to the equation used in the literature, the temperature values of the drying processes are a necessary parameter for calculating the evaporation energy. For this reason, energy efficiency was calculated only for the convective drying process. Equation 23 was used to calculate the energy efficiency (EE) in drying the jerusalem artichoke (Beigi, 2016).

$$n_e = \frac{Q_w}{E_t} \tag{23}$$

2.12 Uncertainty analysis

Equation 24 was used to calculate the total uncertainty value arising from the standard deviation values occurring during the drying process and measurement stages (Moffat, 1988).

$$W_x = \sqrt{(X_1)^2 + (X_2)^2 + (X_3)^2 + \cdots + (X_n)^2} \tag{24}$$

X_1, X_2, X_3, ... X_n show the sensitivity values of measuring instruments.

2.13 Statistical analysis

Multiple comparison test was performed with SPSS22. program to evaluate the findings. Reliability values were calculated according to $P < 0.05$.

3. Results

The Jerusalem artichoke samples were dried at 50 and 60 °C drying temperatures in a convective dryer and at 540 and 720 W power in the microwave. The samples were dried to 5-7 % (w.b.) lower moisture level with and without pretreatment (ethyl oleate). The initial moisture content of the jerusalem artichoke samples was determined as 79.58±0.82 %. Antal et al. (2017) determined the moisture content as 78.70 % in the jerusalem artichoke drying study conducted by applying three different drying methods (Infrared-Freeze-Hybrid). Resti-Puyanda et al. (2020) determined the moisture content as 75.46 % in the jerusalem artichoke drying process with two different types of dryers. Jahromi et al. (2022) found the initial moisture content of 76.09 % in the drying trial of the jerusalem artichoke samples in the dryer with solar energy cabinet. The moisture value obtained within the scope of the study was found close to the literature.

3.1 Color values

The measured and calculated color values of fresh and dried jerusalem artichoke samples are given in Table 1.

When the color values given in Table 1 were examined, it was determined that statistically ($P < 0.05$) similar results were obtained in the color values measured in L, a and b. Considering the L values, the convective dryer 50 °C control and microwave 540 W control samples gave statistically ($P < 0.05$) similar results compared to the fresh samples. This is thought to be due to the fact that the pure gloss value of the ethyl olet solution is higher than the gloss value of the fruit. A finding similar to the result we obtained in the literature was found in samples that were pre-treated with ethyl oleate at a drying temperature of 50 °C in a convective dryer. It was determined that both of the pre-treated and untreated samples in the convective dryer at 60 °C in the red/green color value were statistically ($P < 0.05$) similar compared to the fresh ones. This suggests that the red/green color pigments of jerusalem artichoke are better preserved at 60 °C. In terms of yellow/blue and chroma color values, the closest to fresh ($P < 0.05$) was determined in the samples that were pretreated with ethyl oleate at 50 °C drying temperature in a convective dryer.

In this case, the yellow/blue color pigment of jerusalem artichoke is thought to be sensitive to a temperature of 50 °C. However, ethyl oleate pretreatment is thought to reduce the color pigment degradation of jerusalem artichoke with heat. When compared to the fresh dried jerusalem artichoke fruits, it was found that the convective dryer (50 °C) and microwave (720 W) drying processes were statistically more appropriate. When dried samples were compared in terms of yellowness index, it was seen that there were ethyl oleate-convective dryer (50 °C) and control-convective dryer (60 °C) treatments. This situation is thought to be related to the effect of the yellow color pigment. When the hue color angle value was examined, statistically ($P < 0.05$), the closest convective dryer to fresh was detected in the control samples at 60 °C drying temperature. While the most color change was seen in the pre-treated samples, which were dried in the convective dryer, the least color change was determined in the control samples made at 540 W power in the microwave. In this case, the color values were preserved more because the product was exposed to heat for a shorter time in microwave drying processes. However, since the temperature value created by the 720 W power is higher than the 540 W power, it is thought that the color values are further removed than the fresh one.

Pre-treatment and convective drying method changed the color values of the jerusalem artichoke more than the other drying processes. The lowest BI (browning index) value was calculated as 12.89±1.95 in the ethyl oleate pretreatment in a convective dryer at 60 °C. It was determined that the closest values to fresh in terms of all color values were the control samples in a convective dryer at 60 °C. In terms of chroma values, ethyl-oleate pre-treatment at 50 °C is recommended as an alternative.

Doymaz (2018), dried citric acid-treated and non-

Table 1: Measured and calculated color values of jerusalem artichoke.

Method	Drying conditions	Pre-treatment	L	a	b	C	Hue	WI	YI	ΔE	BI
Fresh	-	-	61.05 ± 3.47^{de}	1.12 ± 0.54^{d}	9.26 ± 1.98^{d}	9.35 ± 1.92^{d}	82.45 ± 4.68^{a}	809.10 ± 138.14^{bc}	21.73 ± 5.02^{e}	-	-
Convective Dryer	50 °C	Un-pretreatment	61.40 ± 1.81^{de}	3.14 ± 0.80^{bc}	12.18 ± 1.51^{c}	12.58 ± 1.62^{c}	75.65 ± 2.35^{d}	826.98 ± 68.42^{bc}	28.34 ± 3.47^{d}	50.06 ± 1.97^{c}	25.49 ± 3.74^{d}
		Ethyl oleate	70.95 ± 2.78^{a}	2.82 ± 0.41^{bc}	9.69 ± 1.45^{d}	10.09 ± 1.47^{d}	73.66 ± 1.90^{d}	447.40 ± 96.64^{e}	19.60 ± 3.52^{e}	61.46 ± 3.65^{a}	17.41 ± 3.21^{e}
	60 °C	Un-pretreatment	58.51 ± 2.79^{e}	1.19 ± 0.40^{d}	8.65 ± 1.51^{de}	8.74 ± 1.50^{de}	81.98 ± 3.12^{a}	903.34 ± 109.80^{ab}	21.06 ± 3.24^{e}	50.87 ± 2.43^{bc}	17.13 ± 2.71^{e}
		Ethyl oleate	68.37 ± 6.29^{ab}	1.51 ± 0.20^{d}	7.38 ± 1.04^{e}	7.54 ± 1.05^{e}	78.34 ± 1.39^{c}	547.02 ± 224.04^{de}	15.52 ± 2.36^{f}	61.23 ± 6.14^{a}	12.89 ± 1.95^{f}
Microwave	540 W	Un-pretreatment	60.60 ± 3.08^{de}	5.77 ± 1.45^{a}	19.03 ± 1.95^{a}	19.93 ± 2.08^{a}	73.20 ± 3.69^{d}	980.77 ± 123.16^{a}	44.88 ± 4.17^{a}	$\mathbf{44.56\pm2.77^{d}}$	44.19 ± 5.76^{a}
		Ethyl oleate	64.73 ± 2.25^{c}	3.28 ± 0.98^{b}	16.74 ± 1.86^{b}	17.07 ± 1.07^{b}	79.05 ± 2.44^{bc}	771.74 ± 92.39^{c}	37.01 ± 4.51^{bc}	50.22 ± 2.80^{c}	33.24 ± 5.17^{b}
	720 W	Un-pretreatment	63.80 ± 1.90^{cd}	2.68 ± 1.03^{bc}	17.12 ± 1.43^{b}	17.35 ± 1.55^{b}	81.26 ± 2.67^{ab}	808.32 ± 73.71^{bc}	38.36 ± 3.25^{b}	49.35 ± 2.19^{c}	33.78 ± 4.24^{b}
		Ethyl oleate	67.73 ± 3.15^{b}	2.40 ± 0.65^{c}	15.99 ± 1.91^{b}	16.17 ± 1.95^{b}	81.48 ± 1.86^{ab}	655.57 ± 128.54^{d}	33.87 ± 5.28^{c}	53.97 ± 4.06^{b}	29.24 ± 5.24^{c}

Table 2: Mathematical modeling data.

Method	Drying conditions	Pre-treatment	Models	k	h	j	m	p	R^2
Convective Dryer	50 °C	Un-pretreatment	Lewis	0.0057	-	-	-	<0.0001	0.9622
			Wang-Sing	-0.0041	0.0000038	-	-	<0.0001	0.9976
			Midilli-Küçük	1.3304	0.9852	0.0009	-0.0003	<0.0001	0.9989
		Ethyl oleate	Lewis	0.0062	-	-	-	<0.0001	0.9611
			Wang-Sing	-0.0045	0.0000041	-	-	<0.0001	0.9993
			Midilli-Küçük	1.1666	0.9898	0.0019	-0.0007	<0.0001	0.9992
	60 °C	Un-pretreatment	Lewis	0.0154	-	-	-	<0.0001	0.9744
			Wang-Sing	-0.0116	0.000033	-	-	<0.0001	0.9986
			Midilli-Küçük	1.3892	0.9898	0.0030	-0.000071	<0.0001	0.9985
		Ethyl oleate	Lewis	0.0162	-	-	-	<0.0001	0.9653
			Wang-Sing	-0.0118	0.000032	-	-	<0.0001	0.9982
			Midilli-Küçük	1.2212	0.9918	0.0052	-0.0009	<0.0001	0.9979
Microwave	540 W	Un-pretreatment	Lewis	0.2883	-	-	-	<0.0001	0.9750
			Wang-Sing	-0.2107	0.0111	-	-	<0.0001	0.9896
			Midilli-Küçük	1.4682	1.0038	0.1685	0.0025	<0.0001	0.9996
		Ethyl oleate	Lewis	0.2863	-	-	-	<0.0001	0.9600
			Wang-Sing	-0.2138	0.0115	-	-	<0.0001	0.9916
			Midilli-Küçük	1.5236	0.9935	0.1455	-0.0005	<0.0001	0.9995
	720 W	Un-pretreatment	Lewis	0.4093	-	-	-	<0.0001	0.9603
			Wang-Sing	0.3018	0.0225	-	-	<0.0001	0.9938
			Midilli-Küçük	1.4907	0.9960	0.2534	-0.0021	<0.0001	0.9996
		Ethyl oleate	Lewis	0.3936	-	-	-	<0.0001	0.9399
			Wang-Sing	-0.2792	0.0170	-	-	<0.0001	0.9884
			Midilli-Küçük	1.6145	0.9984	0.2153	-0.0046	<0.0001	**0.9999**

treated jerusalem artichoke samples in a cabin type dryer at 60, 70 and 80 °C drying temperatures and reported L values as between 73.26 - 78.42 for fresh samples and between 70.09 - 77.17 for dried samples. Aydar et al. (2022), in the study in which they examined the effect on drying kinetics and quality of jerusalem artichoke samples in the drying process by applying ultrasound pretreatment, they found the L brightness value of the samples subjected to ultrasound pretreatment for 5 minutes at 60 °C drying temperature as 72.72±2.71. It was seen that the data obtained in the study were compatible with the findings in the literature.

3.2 Drying-moisture ratio

The drying rate and drying rate graph of dried jerusalem artichoke samples are given in Fig. 1. According to Fig. 1 the effects of drying temperatures and microwave output powers on drying speed values are significant. In the convective dryer drying method, the drying speed values of the drying process at 50 °C were found to vary between 0.0026-0.0201 g moisture/g dry matter minute and at 60 °C 0.014-0.0407 g moisture/g dry matter minute. In the microwave drying method, it was determined that this value changed between 0.0307-0.4375 g moisture/g dry matter.minute at 540 W output power, and 0.0640-1.0756 g moisture/g dry matter.minute at 720 W output power. It has been observed that the drying rates of microwave drying processes are higher than that of convective drying processes. It is thought that this situation causes the moisture content to be higher than the product due to the working principle of the microwave drying process.

It was determined that the drying time of the samples decreased significantly during the drying process in microwave and convective dryer drying methods at 60 °C, and then the drying rate slowed down. It was determined that the ethyl oleate pretreatment applied to the jerusalem artichoke samples shortened the drying time. It is thought that ethyl oleate pretreatment enlarges the micro-channels in the tissue structure of the fruit and causes an increase in the moisture content. Torki-Harchegani et al. (2016), in the study in which they dried mint leaves with microwave (200, 400, 600 and 800 W) and hot air at 50, 60 and 70 °C), the average drying rates were determined as 0.0116, They determined 0.0185 and 0.0299 g moisture/g dry matter·minute.

3.3 Modeling data

Mathematical modeling values of dried Jerusalem artichoke samples are given in Table 2. According to Table 2, among all drying models, the Midilli-Küçük model predicted the best drying data in samples pre-treated with 720 W power (R^2: 0.9999). Since the highest R^2 value and the lowest reliability values were determined in this model, it was determined as the best estimating mathematical model.

3.4 Effective diffusion coefficients

The effects of drying temperatures, microwave output power values and pretreatment (ethyl oleate) application on effective diffusion coefficients are given in Table 3. According to Table 3, it was observed that the pre-treatment, microwave power and drying temperature significantly affected the effective diffusion coefficients. The effective diffusion coefficients of dried yam samples varied between $3.14{\cdot}10^{-9}$ – $2.35{\cdot}10^{-7}$ m^2/s. It was determined that the highest effective diffusion value was in the samples that were pre-treated with 720 W power in the microwave dryer. This situation is thought to cause high values to be calculated because the moisture diffusion process of microwave dryers is carried out effectively from inside the product to the outside. In addition, considering that the ethyl-oleate pre-treatment has an osmotic effect on the micro-channels of the product, the mass diffusion was calculated to be higher. Poorfallah et al. (2010) found that the effective diffusion coefficients were between $5.13{\cdot}10^{-9}$ – $1.2{\cdot}10^{-8}$ m^2/s in the study of dried yams in different thicknesses and that while the effective diffusion coefficients increased with the increase in temperature, the effective diffusion coefficients decreased with the increase in thickness. Aydar et al. (2022) found that the effective diffusion coefficients varied between 1.72 – $2.94{\cdot}10^{-8}$ m^2/s in the jerusalem artichoke drying study in which they applied ultrasound pre-treatment.

Table 3: Effective diffusion coefficients.

Method	Drying conditions	Pre-treatment	Effective Diffusion (m^2/s)	R^2
Convective Dryer	50 °C	Un-pretreatment	$3.14{\cdot}10^{-9}$	0.9099
		Ethyl oleate	$3.75{\cdot}10^{-9}$	0.8418
	60 °C	Un-pretreatment	$7.18{\cdot}10^{-9}$	0.9744
		Ethyl oleate	$8.53{\cdot}10^{-9}$	0.9241
Microwave	540 W	Un-pretreatment	$1.03{\cdot}10^{-9}$	0.9901
		Ethyl oleate	$1.42{\cdot}10^{-7}$	0.9624
	720 W	Un-pretreatment	$2.01{\cdot}10^{-7}$	0.9740
		Ethyl oleate	$2.35{\cdot}10^{-7}$	0.9200

3.5 Energy values

SMER, SEC and total energy consumption values of dried yam samples are given in Table 4. When the energy values are examined in Table 4, the highest SMER value was determined as 0.03440 kg/kWh in the drying process of the ethyl oleate samples belonging to the microwave drying method at 720 W power. The lowest SMER value was found as 0.00606 kg/kWh in the control samples at 60 °C in the convective dryer. It is thought that this situation causes the SMER values to be calculated higher since the moisture content away from the product is higher at high microwave power. In the convective dryer, on the other hand, it is thought that the total amount of energy consumed at high temperatures is much more effective than the amount of moisture removed from the product. This event is estimated to cause the SMER values to be underestimated. When the SEC values were examined, it was determined that the ethyl oleate samples belonging to the

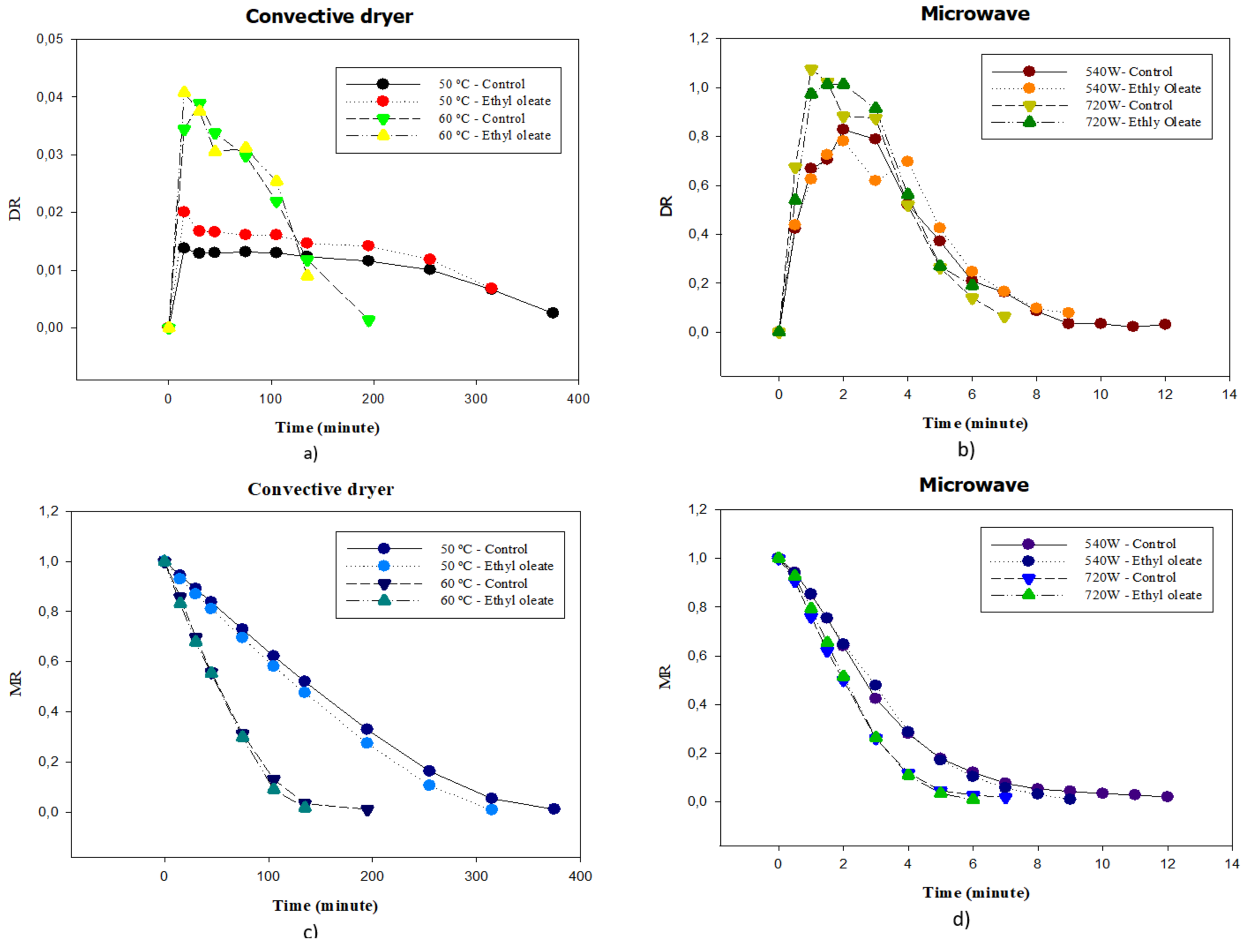


Figure 1: Drying rate and moisture curves of the jerusalem artichoke sample a) drying ratio for convective, b) drying ratio for microwave, c) moisture ratio for convective, d) moisture ratio for microwave.

lowest microwave drying method were 29.07 kWh/kg in the drying process at 720 W power. This situation caused the total amount of energy consumed to be measured less, since the drying time is shorter at high microwave power values. For this reason, it is estimated that it causes the SEC values to be calculated lower. Since the drying time of the ethyl oleate pre-treated samples was shorter than the control group, the total energy consumed was also measured more. This is thought to reduce the SEC values of the pre-treated drying processes.

The total energy consumption was found to be 0.594 kWh at 60 °C for the samples dried in the convective dryer. Ihediwa et al. (2022), in their study, they dried elephant grass and gamba grass in a hot air convective dryer, microwave and in the open sun. As a result of the drying study, the specific energy consumption (SEC) values were determined as 33.2 - 81.5 kWh/kg for gamba herb in microwave drying method. In the hot air furnace, the specific moisture absorption rate (SMER) was calculated as 0.28-0.38 kg/kWh. It is thought that the reason for the differences in the specific moisture absorption rate in the literature is due to the variability of the initial moisture in the product to be dried. The lowest total energy consumption was determined as 0.105 kWh in the samples dried at 720 W power of the ethyl oleate samples belonging to the microwave drying method. While the total energy consumption is 0.387 - 0.594 kWh in convective dryer drying methods, it varies between 0.105 - 0.172 kWh in microwave drying. In terms of energy parameters, it has been determined that drying processes made in the microwave are more advantageous than other processes. The 3D distribution of the energy values changing during the drying processes is given in Fig. 2.

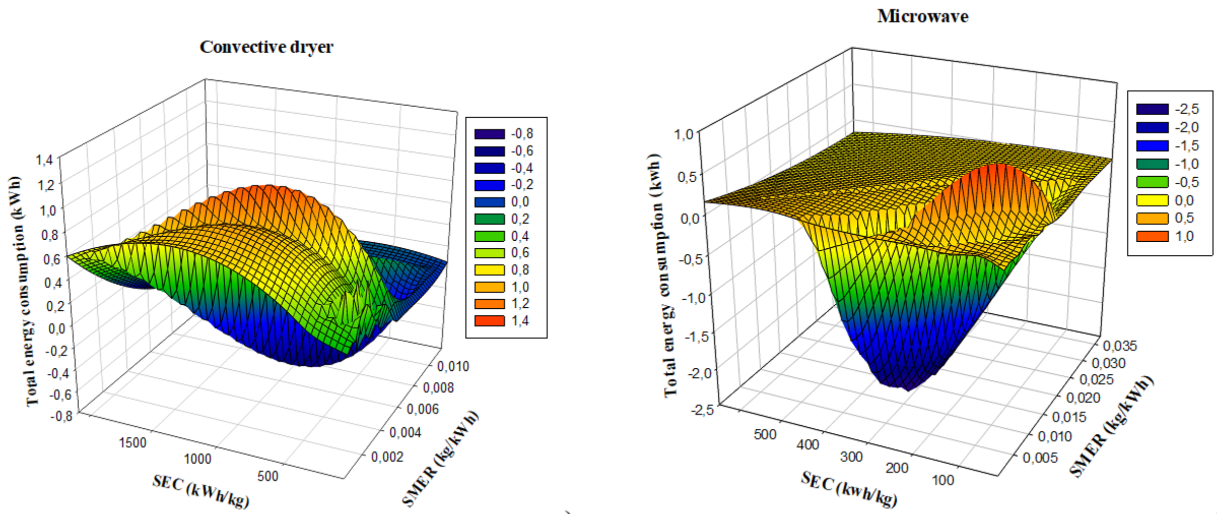
3.6 Evaporation energy and energy efficiency

The evaporation energy and energy efficiency values calculated after the jerusalem artichoke drying process are given in Table 5.

When Table 5 is examined, the evaporation energy of the jerusalem artichoke control samples dried in a convective dryer at 50 and 60 °C was calculated as 2.40 and 2.38 kWh, respectively, while it was calculated as 2.79 and 2.38 kWh for the pre-treated samples, respectively. In this case, it is thought that the total amount of moisture (kg) removed in the drying process at 50 °C is higher than the other drying process. When the energy efficiency values were examined, it was calculated as 5.4 % in the control samples at 50 °C, while it was calculated as 7.2 % in the pre-treated samples. While it was calculated as 4 % in the control samples at 60 °C drying temperature, it was calculated as 5.7 % in the samples treated with

Table 4: Energy values of dried jerusalem artichoke samples.

Method	Drying conditions	Pre-treatment	SMER (kg/kWh)	SEC (kWh/kg)	Total Energy Consumption (kWh)
Convective Dryer	50 °C	Un-pretreatment	0.00806	124.13	0.447
		Ethyl oleate	0.01079	92.69	0.387
	60 °C	Un-pretreatment	0.00606	165.12	0.594
		Ethyl oleate	0.00856	116.81	0.42
Microwave	540 W	Un-pretreatment	0.02076	48.17	0.172
		Ethyl oleate	0.02779	35.99	0.13
	720 W	Un-pretreatment	0.03149	31.75	0.114
		Ethyl oleate	0.03440	29.07	0.105



a) b)

Figure 2: 3D distribution of energy values of jerusalem artichoke drying processes. a) energy distribution for convective, b) energy distribution for microwave.

Table 5: Energy evaporation energy and energy efficiency values of jerusalem artichoke samples.

Method	Drying conditions	Pre-treatment	Evaporation energy (kWh)	Energy efficiency (%)
Convective Dryer	50 °C	Un-pretreatment	2.4	5.4
		Ethyl oleate	2.79	7.2
	60 °C	Un-pretreatment	2.38	4
		Ethyl oleate	2.38	5.7

Table 6: Sensitivity values.

Measuring instruments	Sensitivity values
Power analyzer	±0.02 kWh
Weighing device	± 0.001 g
Caliper	± 0.2 mm
Colorimeter (for ΔE)	± 0.6

ethyl oleate. This situation is thought to cause the energy efficiency ratio to be calculated higher due to the low amount of energy consumed and the high evaporation energy value of the drying process at 50 °C. As a result of the study, it was determined that the pre-treated samples increased the energy efficiency values at both drying temperatures. Torki-Harchegani et al. (2016) calculated the highest energy efficiency as 5.47 % in their study.

3.7 Uncertainty analysis

The uncertainty analysis value due to the sensitivity values of the measuring instruments and equipment used during the drying processes was made. The sensitivity values of the measuring instruments and equipment used in the study are given in Table 6. The data were processed in equation 23 and the uncontrollable uncertainty value in the drying process was calculated as 0.633 %. Taşova et al. (2022), in their study, determined the uncertainty analysis result as 2.32 %.

4. Conclusions

In this study, jerusalem artichoke slices were dried in a convective dryer and microwave dryer as pre-treated (ethyl oleate) and without pre-treatment (control). Method and pre-treatment affected the drying time of jerusalem artichoke. It has been determined that the applied pre-treatment reduces the drying times. Pretreatment and drying methods affected the color values of fresh yams. It especially affected the chroma and color changes at a significant level ($P < 0.05$). It has been observed that the effective diffusion values increase the pre-treatment effect. Microwave drying method and pretreatment improved energy parameters compared to convective drying method. It was observed that the pre-treatment evaporation energy and energy efficiency values were significantly affected ($P < 0.05$). It is recommended to use the pre-treatment in order to preserve the quality characteristics, reduce energy consumption values and improve energy efficiency in jerusalem artichoke drying studies.

In this study, 540 W power value and drying kinetics in terms of quality parameters and 720 W power value in terms of energy parameters are recommended as the optimum drying condition. However, ethyl oleate pre-treatment was found to be suitable for jerusalem artichoke.

References

Alibas, I., Zia, M. P., Yilmaz, A., and Asik, B. B. (2020). Drying kinetics and quality characteristics of green apple peel (Mallus communis L. var. “Granny Smith”) used in herbal tea production. *J. Food Process. Preserv.*, 44(2).

Antal, T., Tarek, M., Tarek-Tilistyák, J., and Kerekes, B. (2017). Comparative effects of three different drying methods on drying kinetics and quality of jerusalem artichoke (Helianthus tuberosus L.). *J. Food Process. Preserv.*, 41(3):e12971.

Arslan, A., Uysal, M., Yılmaz, A., Al-mashhadani, M., Canpolat, O., Şahin, F., and Aygörmez, Y. (2019). Islatma-kurutma kür sisteminin yapısı takviyeli metakaolin betonarme yapılarına etki eder. *İnşaat ve Yapı Malzemeleri.*, 225:909–926.

Aydar, A. Y., Mataraci, C. E., Saglam, T. B., and Yilmaz, T. (2022). Effect of ultrasound pre-treatment on drying kinetics and quality properties of jerusalem artichoke. *Lat. Am. Appl. Res. - An Int. J.*, 52(2):77–82.

Baltacıoğlu, C. and Esin, A. (2012). Chips production from jerusalem artichoke (Helianthus tuberosus L.). *Food Nutr. Sci.*, 03(09):1321–1328.

Beigi, M. (2016). Energy efficiency and moisture diffusivity of apple slices during convective drying. *Food Sci. Technol.*, 36(1):145–150.

Bonazzi, C. and Dumoulin, E. (2011). Quality changes in food materials as influenced by drying processes. In *Mod. Dry. Technol.*, pages 1–20. Wiley.

Çelen, I., Çelen, S., Moralar, A., Buluş, H., and Önler, E. (2015). Mikrodalga bantli kurutucuda patatesin kurutulabilirliğinin deneysel olarak incelenmesi. *Electron. J. Vocat. Coll.*, 5(4):57.

Crank, J. (1979). *The mathematics of diffusion*. Oxford University Press, London, UK.

Doymaz, I. (2018). Effect of pre-treatment and air temperature on drying kinetics and quality of jerusalem artichoke. *Stud. şi Cercet. Ştiinţifice*, 19(4):395–409.

Heiser, C. B. (2015). Taxonomy of helianthus and origin of domesticated sunflower. pages 31–53.

Hsu, C., Chen, W., Weng, Y., and Tseng, C. (2003). Chemical composition, physical properties, and antioxidant activities of yam flours as affected by different drying methods. *Food Chem.*, 83(1):85–92.

Ihediwa, V. E., Ndukwu, M. C., Abada, U. C., Ekop, I. E., Bennamoun, L., Simo-Tagne, M., and Abam, F. I. (2022). Optimization of the energy consumption, drying kinetics and evolution of thermo-physical properties of drying of forage grass for haymaking. *Heat Mass Transf.*, 58(7):1187–1206.

Jahromi, M. S. B., Iranmanesh, M., and Akhijahani, H. S. (2022). Thermo-economic analysis of solar drying of Jerusalem artichoke (Helianthus tuberosus L.) integrated with evacuated tube solar collector and phase change material. *J. Energy Storage*, 52:104688.

Karacabey, E., Baltacıoğlu, C., and Çevik, M. (2011). Microwave drying of jerusalem artichoke (Helianthus tuberosus L.). *Akad. Gıda Dergisi.*, 9:13–22.

Karslı, M. and Bingöl, N. (2009). The determination of planting density on herbage yield and silage quality of jerusalem artichoke (Helianthus tuberosus L.) green mass. *Kafkas Univ. Vet. Fak. Derg.*

Kaya-Mert, G. (2021). *Yer Elması Dilimlerinin Farklı Yöntemlerle Kurutulması ve Kalite Özelliklerinin İncelenmesi*. PhD thesis, Süleyman Demirel Üniversitesi.

Lewicki, P. and Lenart, A. (2006). Osmotic dehydration of fruits and vegetables. In *Handb. ındustrial drying. 3rd ed.* CRC Press, Boca Raton, FL, USA.

Lewis, W. K. (1921). The rate of drying of solid materials. *J. Ind. Eng. Chem.*, 13(5):427–432.

Marx, S., Nosberger, J., and Frehner, M. (1997). Seasonal variation of fructan-beta-fructosidase (FEH) activity and characterization of a beta-(2-1)-linkage specific FEH from tubers of Jerusalem artichoke (Helianthus tuberosus). *New Phytol.*, 135(2):267–277.

McGuire, R. G. (1992). Reporting of objective color m easurements. *HortScience*, 27(12):1254–1255.

Midilli, A., Kucuk, H., and Yapar, Z. (2002). A new model for single-layer drying. *Dry. Technol.*, 20(7):1503–1513.

Moffat, R. J. (1988). Describing the uncertainties in experimental results. *Exp. Therm. Fluid Sci.*, 1(1):3–17.

Motevali, A., Abbaszadeh, A., Minaei, S., Khoshtaghaza, M., and Ghobadian, B. (2012). Effective moisture diffusivity, activation energy and energy consumption in thin-layer drying of jujube (Zizyphus jujube Mill). *J. Agric. Sci. Technol.*, 14:523–532.

Özkan, I. A., Akbudak, B., and Akbudak, N. (2007). Microwave drying characteristics of spinach. *J. Food Eng.*, 78(2):577–583.

Palou, E., Lopez-Malo, A., Barbosa-Canovas, G. V., Welti-Chanes, J., and Swanson, B. G. (1999). Polyphenoloxidase Activity and Color of Blanched and High Hydrostatic Pressure Treated Banana Puree. *J. Food Sci.*, 64(1):42–45.

Pathare, P. B., Opara, U. L., and Al-Said, F. A.-J. (2013). Colour Measurement and Analysis in Fresh and Processed Foods: A Review. *Food Bioprocess Technol.*, 6(1):36–60.

Polatcı, H. and Taşova, M. (2020). Sicaklik kontrollü mikrodalga kurutucu geliştirilmesi ve portakal kurutma performansinin belirlenmesi. *Mühendislik Bilim. ve Tasarım Derg.*, 8(1):131–138.

Polatcı, H., Taşova, M., Ergüneş, G., and Kırmık, G. (2020). Mahlep (Prunus mahaleb) meyvesinin kuruma kinetiği ve renk değişimi. *Akad. Ziraat Derg.*, 9(1):23–32.

Poorfallah, Z., Nahardanı, M., Salaminya, M., Noorian, S., and Muhammedi, M. (2010). Kinetıcs of dryıng jerusalem artıchoke (helıanthus tuberosus l.) slıces by hot aır convectıve dryıng. *Innov. Food Sci. Technol.*, 3:1–12.

Resti-Puyanda, I., Iriyapongson, S., and Uriyapongson, J. (2020). Influence of drying method on qualities of Jerusalem artichoke (Helianthus tuberosus L.) tuber harvested in Northeastern Thailand. *Songklanakarin J. Sci. Technol.*, 42(1279-1285).

Rhim, J. W., Wu, Y., Weller, C. L., and Schnepf, M. (1999). Physical characteristics of a composite film of soy protein isolate and propyleneglycol alginate. *J. Food Sci.*, 64(1):149–152.

Seiler, G. J. (1988). Nitrogen and mineral content of selected wild and cultivated genotypes of jerusalem artichoke. *Agron. J.*, 80(4):681–687.

Surendhar, A., Sivasubramanian, V., Vidhyeswari, D., and Deepanraj, B. (2019). Energy and exergy analysis, drying kinetics, modeling and quality parameters of microwave-dried turmeric slices. *J. Therm. Anal. Calorim.*, 136(1):185–197.

Sutar, P. and Prasad, S. (2008). Microwave drying technology-recent developments and R&D needs in India. In *42nd ISAE Annu. Conv.*

Taşova, M., Polatcı, H., and Gökdoğan, O. (2022). Effect of osmotic dehydration pre-treatments on physicochemical and energy parameters of Kosia (Nashi) pear slices dried in a convective oven. *J. Food Process. Preserv.*, 46(11).

Torki-Harchegani, M., Ghanbarian, D., Ghasemi Pirbalouti, A., and Sadeghi, M. (2016). Dehydration behaviour, mathematical modelling, energy efficiency and essential oil yield of peppermint leaves undergoing microwave and hot air treatments. *Renew. Sustain. Energy Rev.*, 58:407–418.

Türker, I. and Işleroğlui, H. (2017). Mahlep Püresinin Kızılötesi Işınım İle Kurutulması İşleminde Antosiyanin, Fenolik Madde Ve Antioksidan Kapasite Değişim Kinetiği. *Gıda Derg.*, 42:422–430.

Wang, C. and Singh, R. (1978). A single layer drying equation for rough rice. In *ASAE Pap. No 78-3001*. ASAE, St. Joseph, MI, USA.

Yağcıoglu, A. (1999). Tarımsal Ürünleri Kurutma Tekniği. In *Ege Üniversitesi Ziraat Fakültesi yayınları No 536*. Bornova, İzmir.

Yilmaz, A. and Alibas, I. (2021). The impact of drying methods on quality parameters of purple basil leaves. *J. Food Process. Preserv.*, 45(7).