jotaf **Journal of Tekirdag Agricultural Faculty**
Tekirdağ Ziraat Fakültesi Dergisi

Eylül/September 2025, 22(3)
Başvuru/Received: 19/12/24
Kabul/Accepted: 23/08/25
DOI: 10.33462/jotaf.1604217

http://dergipark.gov.tr/jotaf
http://jotaf.nku.edu.tr/

ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Drying Characteristics of Fresh Persimmons: Impacts on Color and Energy Consumption

Taze Hurmaların Kurutma Özellikleri: Renk ve Enerji Tüketimi Üzerindeki Etkileri

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Abstract

Persimmon *(Diospyros kaki)* constitutes a notable fruit in Türkiye. The fruit is consumed in its fresh state during specific periods of the year, which renders it of significant importance in the context of product preservation. Drying is the most commonly used method for preserving products. Drying requires significant energy consumption. The drying time and method employed have a direct impact on both energy consumption and product quality. Persimmon is a nutrient-dense fruit that needs to be dried for extended shelf life. This study investigated the drying behavior of persimmon slices having an initial moisture content of approximately %73.8 wet basis in a microwave oven. Moisture diffusion, shrinkage, color change and rehydration properties were investigated as a function of microwave power and slice thickness. Samples were prepared at two different thicknesses (5 mm and 9 mm) and tested at three microwave power levels (350 W, 460 W and 600 W). Curve fitting tools in the Matlab programmer were used to model the variation in moisture content over time. The study utilised six models: Lewis, Page, Henderson and Pabis, Logarithmic, Midilli, Wang and Singh. The logarithmic model has been demonstrated to provide the most accurate description of persimmon drying kinetics. The dried products' quality was evaluated through various parameters, including color metrics (L*, a*, b*), color difference (ΔE), browning index (BI), chroma, and hue angle, along with rehydration and shrinkage ratios. The effective diffusion coefficients of persimmon were found to range from 2.27×10^{-10} to 9.08×10^{-10} m²/s. Specific energy consumption ranged from 2.21 to 3.028 kWh/kg. The lowest ΔE value was observed in the samples dried at 460 W, suggesting that the highest power (460 W) effectively preserved the natural color of fresh persimmon and minimized browning reactions during the drying process. Results indicated that the applied microwave energy significantly influenced the drying process of the persimmon and the observed changes.

Keywords: Persimmon; Kinetic drying model, Shrinkage; Power, Color

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Atıf: Çelik, E., Parlak, N. (2025). Taze hurmaların kurutma özellikleri: renk ve enerji tüketimi üzerindeki etkileri. *Tekirdağ Ziraat Fakültesi Dergisi,* 22(3): 767-782.

Citation: Çelik, E., Parlak, N. (2025). Drying characteristics of fresh persimmons: impacts on color and energy consumption. *Journal of Tekirdag Agricultural Faculty,* 22(3): 767-782.

Öz

Trabzon hurması *(Diospyros kaki)* Türkiye'de önemli bir yere sahip meyvedir. Yılın belirli zamanlarında taze olarak tüketilen bir meyve olduğu için ürün muhafazası bakımından önemli bir potansiyele sahiptir. Kurutma, ürünleri muhafaza etmek için en yaygın kullanılan yöntemdir. Kurutma işlemlerinde önemli ölçüde enerji tüketimi gerektirir. Kurutma süresi ve kullanılan yöntem hem enerji tüketimi hem de ürün kalitesi üzerinde doğrudan bir etkiye sahiptir. Trabzon hurması, raf ömrünün uzatılması için kurutulması gereken besin değeri yüksek bir meyvedir. Bu çalışmada, yaklaşık olarak %73.8 yaş bazda ilk nem içeriğine sahip Trabzon hurması dilimlerinin mikrodalga fırında kurutma davranışı incelenmiştir. Nem difüzyonu, büzülme, renk değişimi ve rehidrasyon özellikleri mikrodalga gücünün ve dilim kalınlığının bir fonksiyonu olarak incelenmiştir. Örnekler iki farklı kalınlıkta (5 mm ve 9 mm) hazırlanmış ve üç mikrodalga güç seviyesinde (350 W, 460 W ve 600 W) test edilmiştir. Nem içeriğinin zaman içindeki değişimini modellemek için Matlab programındaki eğri uydurma araçları kullanılmıştır. Çalışmada altı model kullanılmıştır: Lewis, Page, Henderson ve Pabis, Logaritmik, Midilli, Wang ve Singh. Logaritmik model Trabzon hurması kurutma kinetiğini en iyi şekilde tanımlamaktadır. Kurutulmuş ürünlerin kalitesi, renk ölçümleri (L*, a*, b*), renk farkı (ΔE), kahverengileşme indeksi (BI), kroma ve ton açısı ile rehidrasyon ve büzülme oranları dahil olmak üzere çeşitli parametreler aracılığıyla değerlendirilmiştir. Trabzon hurmasının etkili difüzyon katsayılarının 2.27×10^{-10} ila 9.08×10^{-10} m^2/s arasında değiştiği bulunmuştur. Spesifik enerji tüketimi 2.21 ila 3.028 kWh/kg arasında değişmiştir. En düşük ΔE değeri 460 W'da kurutulan örneklerde gözlenmiştir, bu da en yüksek gücün (460 W) taze Trabzon hurmasının doğal rengini etkili bir şekilde koruduğunu ve kurutma işlemi sırasında kahverengileşme reaksiyonlarını en aza indirdiğini göstermektedir. Sonuçlar, uygulanan mikrodalga enerjisinin Trabzon hurmasının kurutma sürecini ve gözlemlenen değişiklikleri önemli ölçüde etkilediğini göstermiştir.

Anahtar Kelimeler: Trabzon hurması; Kinetik kurutma modeli, Büzülme; Güç, Renk

1. Introduction

The persimmon is a member of the *Ebenaceae* family. It is cultivated in warm regions of the world (Senadeera et al., 2020). The persimmon is recognised as a nutrient-rich fruit (Jesus et al., 2023). Persimmon are typically consumed in their fresh state. However, since fresh persimmons consist of up to %80 water and are susceptible to softening and rotting following harvesting, they result in significant wastage (Qin et al., 2022). Nevertheless, the high moisture, sugar and polyphenol content of persimmon fruits renders them susceptible to decay and browning after harvesting (Jia et al., 2019).

The high yield of persimmons coupled with the brief period of harvest has resulted in a notable rise in postharvest losses, with estimates reaching up to %30 of total production (Cervera-Chiner et al., 2024). Consequently, one of the most pressing issues currently facing the persimmon industry is the need to identify strategies that enhance the value of the discarded fruit (González et al., 2021). Drying is a common postharvest preservation technique. The process reduces the likelihood of spoilage, extends the shelf life of harvested agricultural products, and reduces the bulk weight of the products during transportation. The application of heat during the drying of agricultural products inactivates enzymatic reactions, resulting in a reduction in the moisture content of the product (Khaled et al., 2020). However, excessive heat exposure may lead to a decline in quality attributes, highlighting the need for efficient drying methods to maintain the sensory and nutritional properties of fresh fruits (Jesus et al., 2023). The oldest traditional method is natural drying. Despite no energy requirements, this method has disadvantages. These include extensive drying areas, prolonged drying periods, a high demand for labour, and pests adhering to the product. To eliminate these and obtain higher quality, novel drying methods are used (Yildiz et al., 2024). Microwave heating is a new technology. In comparison to conventional heating methods, microwave heating is capable of utilizing energy more efficiently due to its accelerated rate of heat transfer (Wu et al., 2024). Karacabey et al. (2020) examined dried seedless grape samples at varying temperatures and power values, using the microwave and hot air methods without pretreatment. The study presented drying kinetics and energy consumption values, depending on the method employed. The process of microwave drying involves the simultaneous heating of the material from both the inside and outside, with a minimal overall temperature differential, a relatively brief heating duration, and the prevention of surface hardening. This leads to an enhanced quality of the final product (Łechtańska et al., 2015). Microwave drying is a common method for the drying of a variety of food products, such as fruits (Huang et al., 2022; Rodriguez et al., 2019; Taşova et al., 2023; Yildiz et al., 2023;), vegetables (Lapczynska-Kordon et al., 2019); Bi et al., 2023); Dursun et al., 2023) and meat (Kamiloğlu et al., 2023; Kipcak et al., 2021).

Mathematical modeling is important to extend the shelf life in fruit drying. Mathematical models are used to design and optimize industrial drying systems. (Brasiello et al., 2013). Mathematical models describe the drying process. Thin layer drying models can be grouped into theoretical, semi-theoretical and empirical models (Doymaz, 2012; McMinn, 2006). The literature review showed that studies have been done on the drying behavior of persimmon, (Cárcel et al., 2007; Tülek and Demiray, 2014), and even theoretical models for drying kinetics have been proposed, but no comprehensive study has been carried out, including energy, color analysis, and shrinkage. Drying models are important in the control of drying machines. There is a need for mathematical models that both save energy and ensure product quality. The objectives of this study were: To investigate the effect of microwave power and slice thickness on drying time, moisture, drying rate, shrinkage and rehydration rate, (b) to the experimental data to the mathematical model, (c) calculating the effective moisture diffusion, (d) power, (g) specific energy consumption and (e) color evaluations.

2. Materials and Methods

2.1. Raw Materials

The harvesting of persimmon was carried out in the Sakarya region of Turkey. Fruits with homogeneous characteristics (of the same size and color) were chosen, and distorted fruits are discarded. The weight of the persimmon fruit was 100 g on average, and the thickness was cut between 5 mm and 9 mm. Persimmon samples were selected to be uniform in size. The initial moisture content was approximately 73.8 (w.b) (± 2). After these preparations are completed, they will be subjected to drying. *Figure 1* shows the persimmon sample used in the experiment.

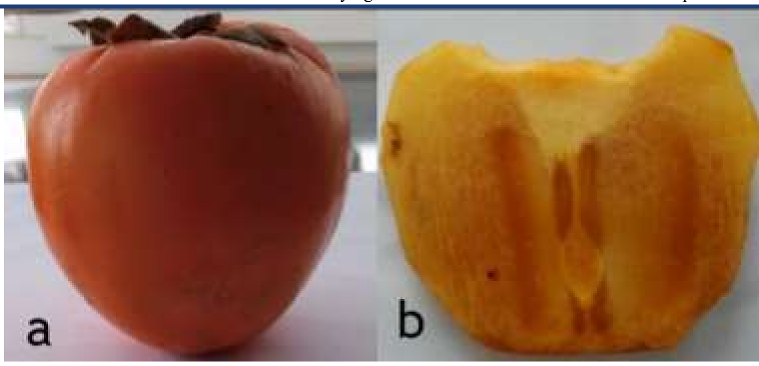

Figure 1. (a) All persimmon; (b) Internal see of the persimmon

Moisture measurements were conducted concurrently with the Sartorius MA30 device (Çelik et al., 2021). Persimmon samples were made at three different drying powers: 350 W, 460 W, and 600 W. In this study, persimmons (*Diospyros kaki*) with an initial moisture content of 73.8% (wetted base), an average length of 75 mm, an average width of 65 mm, and a thickness ranging between 5 and 9 mm were used.

2.2. Drying Processes

The experiments were performed using a precisely programmable microwave oven (Arçelik MD674 Microwave Oven). The microwave oven operates at 120, 350, 460, 540, 600, 700 and 900 W. The region of the microwave oven is 448 × 262 × 312 mm inner size. The samples were weighed manually throughout the drying process. The experiments were conducted in triplicate. See *Figure 2* for a schematic of the microwave drying procedure.

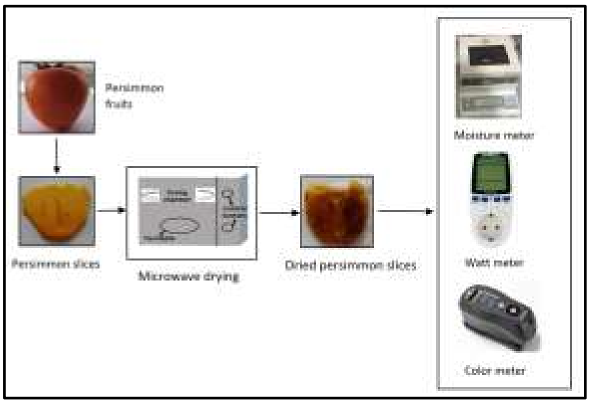

Figure 2. Microwave drying system cycle

Uncertainty analysis improves the precision of experiments used in modelling and design (Koç et al., 2008). Drying experiment discrepancies are usually due to measuring instruments, calibration, environmental conditions, observation and data interpretation (Koç et al., 2019). The general equation below expresses measurement uncertainty (Kaymak-Ertekin et al., 2005). The measurements were conducted with the following precision: ambient air temperature with an accuracy of ±0.2 °C, time ±0.1 minutes, mass ±0.05 grams, color ±0.01 nm, moisture content ±0.05 grams, and power ±0.02 kWh.

2.3. Mathematical Modeling of Hot Air Drying Kinetics

The moisture ratio (MR) for the persimmon was determined using the following equation, considering different microwave powers and thicknesses:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad \text{(Eq. 1)}$$

Here, M_t represents the moisture content (kg water kg^{-1} dry matter) at any given time t, while M_0 is the initial moisture content. M_e denotes the equilibrium moisture content, which remains constant during the hot air drying process (Karaaslan, 2014; Seremet et al., 2016; Zhao et al., 2021).

The drying rate (DR) of persimmon was calculated by the equation given below (Karaaslan, 2016);

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

Here, $M_{t+\Delta t}$ represents the moisture content at time t + Δt (kg water kg^{-1} dry matter), with Δt denoting the difference between the initial and final timescales. This study used experimental models to find the best way to define drying behavior (*Table 1*).

Table 1. Models used in modelling

Models	Model Equations	References
Lewis	*MR=exp(-kt)*	(Brooker et al., 1992)
Page	*MR=exp(-kt^n)*	(Hassan-Beygi et al., 2009)
Henderson and Pabis	*MR=a exp(-kt)*	(Ghodake et al., 2006)
Logarithmic	*MR=a exp(-kt)+b*	(Wang, 1978)
Midilli	*MR=a exp(-kt^n)+bt*	(Midilli et al., 2003)
Wang and Singh	*MR=a+bt+ct^2*	(Dağdeviren et al., 2023)

2.4. Effective Moisture Diffusivity

Efficient diffusion (D_{eff}) is considered a significant property of mass transfer along with the drying of agricultural products. The diffusion coefficient (D_{eff}) of persimmon was determined using Fick's second law, as represented by the following equation (Zhao et al., 2021):

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)}exp\left(\frac{-(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \quad \text{(Eq. 3)}$$

In this equation, L represents the half-thickness of the persimmon (m), t denotes the time required for air-drying (min), and n is an integer greater than or equal to 1.

Moreover, equation (3) was simplified to the following equation:

$$MR = \frac{8}{\pi^2}\left(e^{D_{eff}t\left(\frac{\pi}{2l}\right)^2}\right) \quad \text{(Eq. 4)}$$

The equation in its logarithmic form is as follows:

$$In(MR) = In\frac{8}{\pi^2} - D_{eff}\left(\frac{\pi}{2l}\right)^2 t \quad \text{(Eq. 5)}$$

2.5. Rehydration Ratio

The rehydration experiments were conducted by immersing approximately 25 grams of persimmon in 100 ml of purified water at ambient temperature for a 30-minute period. The examples were subjected to a process of removal, emptying and blotting in order to eliminate surface water, and were then subjected to a weighing procedure. The rehydration ratio (RR) was calculated using the equation from (Deng et al., 2008; Haneef et al., 2021; Jia et al., 2019).

$$RR = \frac{M_b}{M_a} \quad \text{(Eq. 6)}$$

The examples of the masses of the samples after and before rehydration(g), respectively, are labelled as M_b and M_a.

2.6. Shrinkage

The volume of persimmons was measured before and after drying using the toluene displacement technique (Dehghannya et al., 2019). The degree of shrinkage (S_b) of persimmon was calculated using the following equation, based on the measurement of primary and secondary volumes of material (Haneef et al., 2021; Kaveh et al., 2018; Miraei Ashtiani et al., 2018):

$$S_b = \frac{(\theta_o - \theta_f)}{\theta_o} \times 100 \quad \text{(Eq. 7)}$$

2.7. Power Consumption

Power consumption is calculated using the device output power and pass time. An overall calculation was conducted using the following formula:

$$P_t = P \times t \quad \text{(Eq. 8)}$$

Here, the variables are as follows: P_t represents power consumption, P denotes electronic output power (kW), and t is time (h) (Jia et al., 2019).

2.8. Energy Consumption Analysis

The specific energy consumed throughout the drying process, as defined by the equation (10), was calculated in order to represent the microwave drying method. This equation allows for the calculation of the amount of energy required to vaporize 1 kg of water from the crop (Jia et al., 2019; Taghinezhad et al., 2020):

$$SEC = \frac{P_t t}{m_w} \quad \text{(Eq. 9)}$$

The specific energy consumption (SEC) is represented by the microwave, and mw is mass of evaporated water (kg).

2.9. Color Evaluation

The color of persimmon samples was quantified using a tintometer. L*, a* and b* values are given for brightness, red, green and yellow. The L*, a*, and b* color parameters were measured for all samples. The hue angle (H°) represents the perceived color of a substance. The value in this instance was determined through the application of the following equation (Senadeera et al., 2020):

$$H = tan^{-1} \frac{b^*}{a^*} \quad \text{(Eq. 10)}$$

Furthermore, the browning index (BI) was determined in accordance with the formulary method described below(Karimi et al., 2021):

$$BI = \frac{100(x - 0.31)}{0.17} \quad \text{(Eq. 11)}$$

$$x = \frac{(a^* + 1.75\, L^*)}{(5.645L^* + a^* - 3.012b^*)} \quad \text{(Eq. 12)}$$

A hue angle of over 90° yields green, while under 90° yields an orange-red.

Total color changes (ΔE) were computed using equation (13) (İlter et al., 2018; Kaveh et al., 2021):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta b^*)^2 + (\Delta a^*)^2} \quad \text{(Eq. 13)}$$

In this equation, ΔL*, Δb*, and Δa* represent the differential values of the lightness, color parameter b, and color parameter a, respectively.

Chroma (C*) is a quantitative attribute that is used to quantify the colorfulness of a given hue. In order to ascertain the extent of the discrepancy between a specific hue and a grey color with an identical lightness, the C* value is utilized. C* is calculated using the following formula (Kayacan et al., 2020):

$$C^* = \sqrt{{a^*}^2 + {b^*}^2} \quad \text{(Eq. 14)}$$

3. Result and Discussion

The drying effect of persimmon with a microwave drying method at three different microwave power and two different thicknesses was investigated and compared with each other.

3.1. Drying Characteristics (Effect of microwave power and product thickness on drying time)

The initial moisture content of the persimmon samples used in the tests was between 73 and 75% and dried to 12% (w.b). *Figure 3* shows the moisture content variation of persimmon slices for different thicknesses during drying at various microwave powers.

Figure 3 demonstrates that an elevation in microwave power, coupled with a reduction in sample thickness, resulted in an accelerated rate of moisture loss. As the microwave power level was increased, a notable enhancement in the slope of the drying curve was observed during the initial time period of the process. Upon completion of the drying process, all curves demonstrated a proclivity towards flattening, indicative of a decline in the rate of moisture evaporation.

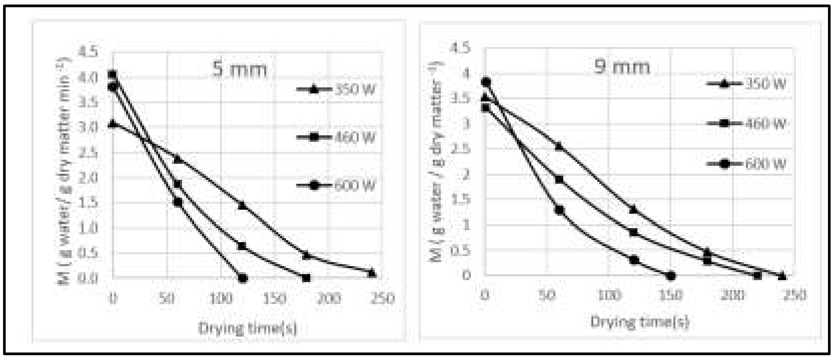

Figure 3. Moisture content (d.b) vs time a) for 5 mm thickness b) for 9 mm thickness

As the microwave power level increased, the drying time decreased in accordance with the expected relationship between these two variables. The maximum decrease in drying time was observed in the 5 mm thick persimmon samples, which showed a reduction of up to 50%. For 9 mm thick persimmon samples, the maximum decrease was found as 38 %. The mass and heat transfer are faster in higher microwave powers and thinner thicknesses. It is evident that elevated levels of power enhance both the kinetic energy and the energy absorbed, thus resulting in a greater disparity between the vapor pressures observed at the core and the external surface of the samples. This will, in turn, accelerate the rate of moisture elimination. Similarly Karaaslan (2014) observed a reduction in drying time as microwave power was increased.

Also, Jia et al. (2019) indicated that persimmon chips subjected to different drying air temperatures exhibited a notable influence on the evaporation and drying time. They showed that the moisture content decreased continuously until constant moisture content was reached. The drying rates of persimmon were evaluated at various time points, plotted against the moisture ratio for the second phase of the drying treatment, and illustrated in *Figure 4*.

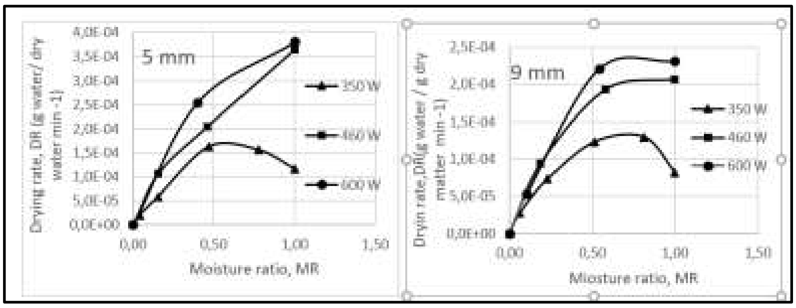

Figure 4. Drying rate vs Moisture ratio, a) for 5 mm thickness b) for 9 mm thickness at different microwave powers

Figure 4 shows the initial drying rate rises during drying. The samples' elevated moisture content causes them to absorb more energy at the surface. Moisture content and energy absorption decline, reducing drying rates. At a constant temperature, more microwave power means a faster drying rate, due to more energy being absorbed. The maximum drying rate was observed at 600 W and 5-9 mm. The drying period exhibited a declining rate, which suggests that diffusion was the primary force influencing the removal of water. These results align with those of (Çelen, 2019). The drying rate was influenced by enhanced drying power, accelerated moisture loss and reduced drying time.

3.2. Mathematical Analysis of Drying Kinetics

A variety of mathematical models have been utilized in order to forecast the kinetic processes involved in the drying of agricultural products. The moisture content of the product is calculated through experimental means. Once the weight loss of the product has been determined over time, a graph is created based on the results of mathematical models. In the present study, a selection of six thin-layer models was made and adapted to the empirical data. The objective of this process was to determine the most suitable model for the purposes of the study. *Table 2* presents the results of the statistical analysis of the various models. The evaluation criteria that were used to ascertain each model's suitability are also included. As illustrated in *Table 2*, the values for the coefficient of determination (R^2), the root mean square error (RMSE), and the sum of squares due to error (SSE) are documented. The model that offers the optimal explanation of the thin-layer drying characteristics of whole persimmons was selected based on the criteria of achieving the highest possible R2 and the lowest possible RMSE and SSE. With regard to the complete experiments, the R^2, SSE, and RMSE data for the models exhibited values between 0.9901 and 0.998, 0.00027 and 0.00930, and 0.01671 and 0.9933, respectively. As demonstrated in *Table 3*, the logarithmic model exhibited the highest R^2 values and the lowest values of RMSE and SSE. However, it should be noted that the results of this study differ from those reported in the literature. The Midilli model has been demonstrated to be an appropriate fit for the empirical drying data of persimmon, as indicated by the findings of studies (Karaaslan, 2014; Doymaz, 2012; Sampaio et al., 2017). These findings are supported by the results of other empirical models.

Table 2. Statistical Comparison of Models for Thin-Layer Drying of Persimmon

Model	Thickness	R^2			X^2			RMSE		
		350 W	460 W	600 W	350 W	460 W	600 W	350 W	460 W	600 W
Lewis	5 mm	0.9538	0.9889	0.9718	0.04322	0.004782	0.01377	0.07858	0.03992	0.05867
	9 mm	0.9212	0.9107	0.998	0.04809	0.03918	0.00087	0.1096	0.1143	0.02097
Henderson and Pabis	5 mm	0.9491	0.9889	0.9733	0.04235	0.004764	0.01305	0.09204	0.04881	0.06596
	9 mm	0.9305	0.9142	0.948	0.04240	0.03764	0.00087	0.1189	0.1372	0.02955
Logarithmic	5 mm	0.9901	0.9908	0.9942	0.00930	0.008705	0.00454	0.04315	0.06597	0.0674
	9 mm	0.998	0.9994	0.9933	0.00028	0.000279	0.00379	0.01674	0.01671	0.9933
Page	5 mm	0.9972	0.9893	0.985	0.00192	0.004714	0.00734	0.01963	0.04855	0.04946
	9 mm	0.9988	0.9633	0.9927	0.00075	0.01609	0.00415	0.01591	0.08971	0.03721
Midilli	5 mm	0.9978	0.994	0.9852	0.00181	0.000876	0.00723	0.02459	0.0296	0.08503
	9 mm	0.9996	0.8707	0.9433	6.648e-05	0.05672	0.03802	0.00815	0.1375	0.06166
Wangh and Singh	5 mm	0.9871	0.9693	0.9846	0.0107	0.01782	0.00753	0.05172	0.09439	0.06137
	9 mm	0.9841	0.9911	0.9851	0.00486	0.00392	0.00422	0.04931	0.06261	0.04595

Senadeera et al. (2020) indicated that the Page model was the most appropriate for characterizing persimmon drying curves across a range of temperatures (45-65°C). The findings indicate that the Page and Midilli models can be employed, however, the logarithmic model is the most optimal among the models presented in *Table 2*.

3.3. Evolution of Effective Moisture Diffusivity

Effective moisture diffusion (D_{eff}) was calculated by slope method for different microwave power and different slice thicknesses. Effective diffusivity (D_{eff}) values were defined by Equation 4 and *Figure 5* shows effective diffusivity (D_{eff}) values.

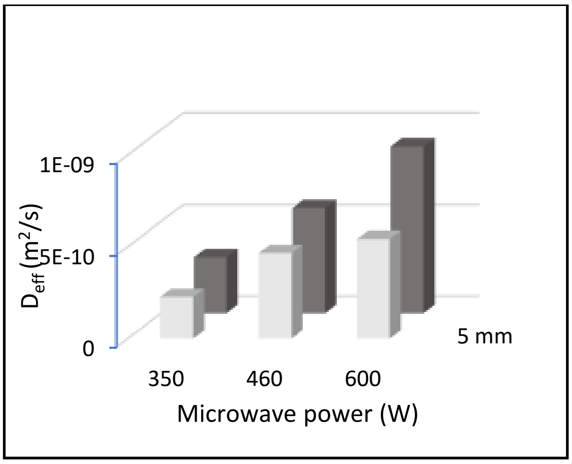

Figure 5. Effect of Microwave Power on Effective Moisture Diffusivity

Table 3. Comparison with results in the literature

Experiment conditions	Deff [m²/s]	Reference
Convective dryer; 40,50 and 60 ˚C	**$7.05x10^{-11}$ to 2.34×10^{-10}**	(Doymaz, 2012)
Convective dryer; 55–75°C	9.24×10^{-10} and 10.40×10^{-10} (Blanched) **7.76×10^{-10} and 9.63×10^{-10} (Solution immersed)**	(Demiray and Tülek, 2017)
Freeze dryer; -55 ˚C	**2.57×10^{-12}**	(Dağdeviren et al. 2023)
Microwave drying; 120 W and 600W	**2.97×10^{-8} and 4.63×10^{-6}**	(Çelen, 2019)
Convective dryer 50, 55, and 60˚C	**1.04×10^{-6} , 1.40×10^{-6} , and 8.27×10^{-7}**	(Sampaio et al., 2017)

In the literature, the effective diffusivity coefficient is reported to range from 10^{-12} to 10^{-8} m²/s for food crops (Doymaz, 2012; Dağdeviren et al., 2023). *Figure 6* illustrates the rise in diffusion coefficients as the thickness of the persimmon slices is increased. It was noted that the D_{eff} values exhibited a marked increase with the elevation of slice thickness and microwave power. The application of a higher microwave power during the drying process resulted in an elevated level of heating energy, which in turn increased the activity of water molecules and consequently enhanced moisture diffusivity. Furthermore, persimmon slices with a thickness of 9mm had higher moisture diffusivity than 5mm across all microwave power levels. The thickness allows water to move towards the persimmon surface, increasing the effective moisture coefficient. The experiments demonstrated that the effective diffusion coefficients exhibited a dependence on both thickness and microwave power. The diffusion coefficients ranged between 2.26×10^{-10} and 9.07×10^{-9}. The findings were consistent with those in *Table 3*.

3.4. Rehydration Rate

The rehydration of dried products is a widely employed method for the evaluation of their quality. The data shows the changes in the samples during drying (Doymaz, 2012). Rehydration ratio values of persimmon calculated from Equation (6), are illustrated in *Figure 6*.

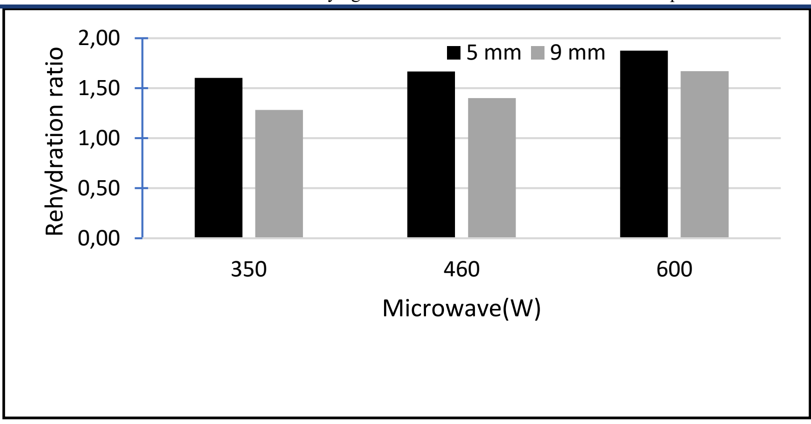

Figure 6. Rehydration graph for persimmon dried at 350, 460 and 600W

The rehydration rates of the 5 mm samples were higher than the 9 mm thick samples, which means that there is less structural damage and cell disruption during the drying process. The findings reported by Doymaz (2012); are comparable to , with rehydration ratios of persimmon reported to be between 2.3 and 3.1.

3.5. Shrinkage

Figure 7 illustrates the shrinkage percentage values for dried dates with varying strengths and two distinct thicknesses.

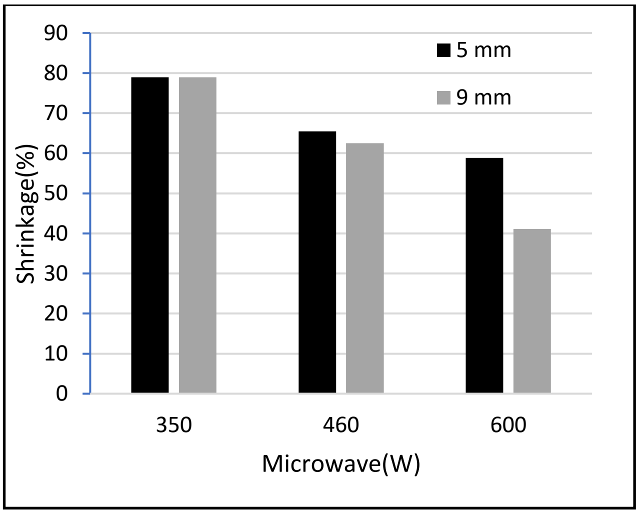

Figure 7. Shrinkage behavior of Persimmon samples

The shrinkage was observed to decrease at 5 and 9 mm slices with increasing drying power value. The lowest degree of shrinkage was observed at 600 W and a depth of 9 mm, while the highest degree of shrinkage was observed at 350 W and a depth of 5 and 9 mm.

3.6. Power

Energy consumption was measured with an energy counter. The graphic of persimmon power for microwave dryers is shown in *Figure 8*.

The energy consumption of a microwave oven was measured at different powers and slice thicknesses. At 5 mm, it was 0.05–0.23 kWh, at 9 mm, 0.05–0.46 kWh. 450 W and 9 mm may be the most energy-efficient. Çelen (2019), measured the system's energy consumption at 5 mm, 0.085 kWh; 7 mm, 0.1 kWh; and 9 mm, 0.09 kWh. Jia et al. 2019; said that persimmon chips were dried using a freeze-drying technique. Freeze-dried persimmon chips consumed 7-9 times more power than combined hot-air and hot-air microwave drying. The extended drying period necessitated by the freeze-drying process, which required approximately five times longer than that required for the hot-air and combined hot-air-microwave methods, may have contributed to the result. The maintenance of a vacuum and low temperatures within the cold trap necessitated a greater input of energy.

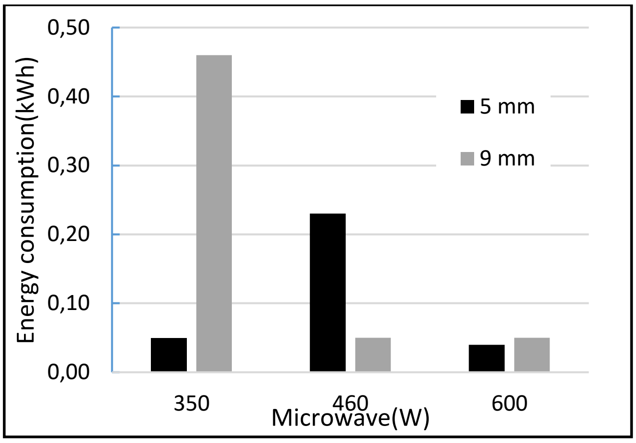

Figure 8. Energy consumption for drying of permission at different levels of microwave powers

3.7. Specific Energy Consumption (SEC)

Figure 9 demonstrates the values of the specific energy content (SEC) for two distinct persimmon slices (5 and 9 mm in thickness) subjected to microwave drying.

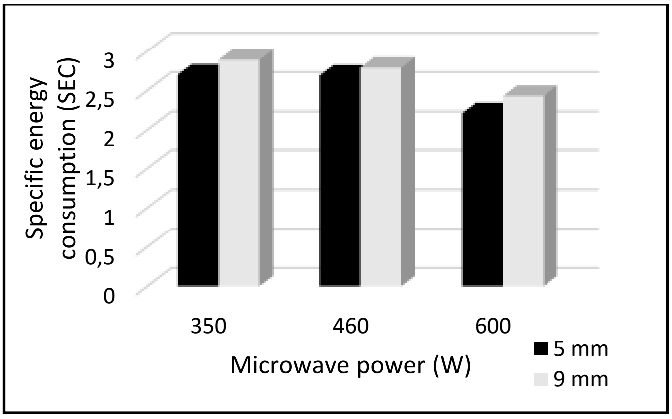

Figure 9. Specific energy consumption for microwave

This study found SEC ranged from 2.21 to 3.028 kWh/kg. *Figure 9* shows SEC declines with power. Kaveh et al. (2021) showed that drying pomegranate arils in a microwave dryer uses 35.42 kWh/kg at 270 W and 13.19 kWh/kg at 630 W. The ratio between the maximum and minimum values of SEC is 2.68. As MW power increases, SEC decreases significantly, reaching a value that is approximately three times less. The decrease in SEC is attributed to the impact of volumetrically heating, which reduces drying time. The reduction of drying times and the lowering of the specific energy consumption (SEC) are of significant importance in the process of improving microwave drying. Çelen 2019, reported that the maximum and minimum values of SEC were 14 and 28 MJ kg^{-1} at a microwave power range of 120–600 W.

3.8. Color

Food product color is important in marketing fresh and processed items, particularly in relation to quality. The microwave drying persimmon was determined for color changes depending on the time in the drying process. *Figure 10* shows the L*, a*, b* of dried persimmon for the microwave drying at different microwave power (350, 460, and 600W) and slice thickness. For the dried Persimmon, the lowest values of L*and b* were microwave power of 600 W but a* values are high.

Table 4. Comparative Colour Evaluation of Fresh and Dried Persimmon Samples

	Values						
Measured color values-5 mm	L*	a*	b*	C(Croma)	H(Hue)	ΔE	BI
Fresh	38.45	10.21	32.69	42.40	56.19		
350	37.80	10.39	21.24	23.78	50.71	31.23	73.59
460	33.50	10.92	15.80	19.27	52.34	19.66	79.02
600	31,15	11.17	16.03	19.70	50.49	21.19	86.00
Measured color values-9mm	L*	a*	b*	C(Croma)	H(Hue)	ΔE	BI
Fresh	43.15	13.20	34.85	37.27	69.26		
350	41.93	13.27	27.69	30.76	61.54	27.78	57.17
460	39.07	15.93	24.45	29.26	56.90	10.95	73.61
600	31,68	18.23	19.25	26.51	46.56	22.07	83.95

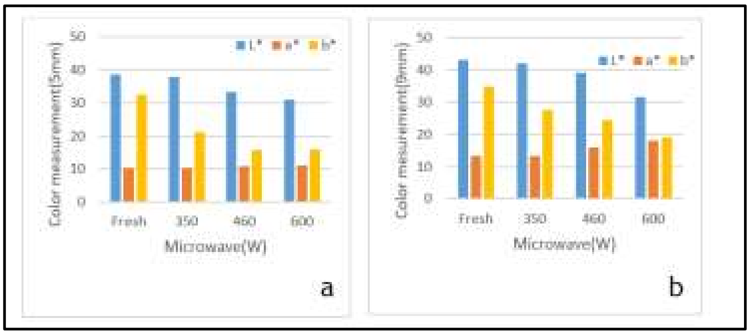

Figure 10. The color of persimmon, a) for 5 mm thickness b) for 9 mm thickness at different microwave powers

Çelen (2019) found that slice thickness has no effect on ΔL values. The impact of slice thickness on ΔE values was significant for samples sliced at 9 mm. The effects of microwave power levels on ΔL values were significant for samples dried at 600 W, while the effects on ΔE values were insignificant. The color alterations observed in the microwave power dryer are presented in *Table 4*.

The hue angle and total color variations from the Hunter values (L*, a*, and b*) provide a more nuanced representation of the color change in fresh and dried persimmons (Maskan, 2001). The optimal drying of persimmons is associated with minimal overall color change (ΔE), which plays a crucial factor in consumer approval (Senadeera et al., 2020). Moreover, the hue values of the dried samples differed from those of the fresh persimmons. Persimmon samples dried at 460 W with a thickness of 5 mm and at 350 W with a thickness of 9 mm showed a significant increase in hue angle values compared to other dried samples. The drying conditions notably influenced the total color differences of the dried samples. The lowest ΔE value was observed in the samples dried at 460 W, suggesting that the highest power (460 W) effectively preserved the natural color of fresh persimmon and minimized browning reactions during drying.

This result, which occurs in color change depending on the temperature, is also compatible with the general literature data. Yıldız Akbulut (2021) observed that in the microwave the L * (Brightness) value of Trabzon persimmon is increased. On the subject of a* (redness) and b* (yellowness) values, these values were observed to be decreased. Jia et al. (2024) observed a reduction in color with increased microwave power. The highest L* value and the lowest a*/b* value were observed at a power density level of 6.8 Wg^{-1}. Çelen (2019) observed a reduction in color change with increasing slice thickness. The lowest gloss and total color change were observed at 600 W and a slice thickness of 9 mm. The drying process results in oxidation, leading to a reduction in color intensity. Kaveh et al., (2021) indicated that the color changes in microwave dryers increased from 6.77 to 13.11 with the increase in microwave power from 270 to 630 W. Xu et al. (2020) emphasize that the alteration in pigment coloration can be attributed to the impact of elevated temperatures on heat-sensitive compounds, including carbohydrates, proteins and vitamins. This phenomenon also leads to colour change during the drying process. Senadeera et al. (2020) report that no significant differences were observed in the L* values between fresh and all dried persimmon slabs. The a* values of the samples were found to be influenced by the drying conditions, specifically the temperature and time. With regard to the dehydrated samples, there was an increase in a* values following the drying process. No statistically significant differences were observed in the b* values of the dried persimmon slices. The dried samples exhibited distinct H° values in comparison to the fresh persimmon fruit. The persimmon samples that were dried at 65°C demonstrated a higher hue angle and ΔE values in comparison to the other dried samples. Kayacan et al. 2020 observed that the ΔE value of persimmon exhibited a range of 21.57 to 23.63, indicating a notable color change following hot air drying, with freeze-drying demonstrating a less pronounced effect. As power density increased, brightness decreased. Power density increases caused temperature and vapor pressure to rise. This was a consequence of the transfer of energy into the product.

4. Conclusions

This study examined the effects of microwave power and slice thickness on drying time, drying rate, shrinkage, color, and rehydration rate. A mathematical model was proposed, and diffusion coefficients and specific energy consumption values were calculated. The results of the experimental and theoretical study can be summarized as follows.

a) As expected, the 5 mm samples dried faster than the 9 mm ones. Drying time decreased with increased microwave power. 5 mm samples showed a higher rehydration ratio than 9 mm samples. Effective moisture values ranged from 9.08×10^{-10} to 2.27×10^{-10} $m^2 s^{-1}$, across tested power levels.

b) The drying process was not observed to occur at a constant drying rate; rather, it took place in a falling rate period

c) The Midilli model demonstrated the most accurate representation of drying data across all experimental conditions.

d) The 5 mm and 9 mm samples consumed between 0.05 and 0.23 kWh and 0.05 and 0.46 kWh, respectively. Thermodynamic analysis showed that increasing microwave power and sample thickness reduced specific energy consumption (SEC). The lowest and highest SEC values were 2.2 and 3.0 kWh/kg, and 10.5 and 25.9 MJ/kg of water, respectively.

e) The lowest shrinkage was at 600 W and 9 mm, while the highest was at 350 W and 9 mm.

f) The results of the color change indicate that a color change of 10.95 (ΔE) was observed in the samples with a 9 mm slice thickness at 460 W power. It was also observed that while the a* values are high at 600 W microwave power, the L* and b* values have the lowest values.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

There is no conflict of interest between the article authors.

Authorship Contribution Statement

Concept: Parlak N., Çelik E., Design: Parlak N., Data Collection or Processing: Çelik E., Statistical Analyses: Parlak N., Literature Search: Çelik E., Writing, Review and Editing: Parlak N., Çelik E.

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