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Effect of microwave power on drying behavior and essential oil yield of microwave dried Eucalyptus *camaldulensis* Dehnh. leaves

Mikrodalga gücünün mikrodalgada kurutulmuş *Eucalyptus camaldulensis* Dehnh. yapraklarının kuruma davranışı ve uçucu yağ verimi üzerine etkisi

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Abstract

In this study, the aim was to microwave dry Eucalyptus camaldulensis Dehnh. leaves, while evaluating the role of microwave power regarding drying behavior, drying rate, drying time, drying kinetics, moisture diffusivity, energy consumption and essential oil yield. The leaves were dried by microwave at four different power levels (180, 360, 600 and 720 W). The results found that increasing the increment power levels decreased the time for drying and increased the drying rate. To fit the experimental data, nine widely used thin layer drying kinetics models were used. The analysis of the drying curves indicated that the Page model was the most appropriate. There was a significant difference in moisture diffusivity between 2.36×10^{-11} and $11.45\times10^{-11} m^2/s$. Increasing microwave power was led to an increase in moisture diffusivity. In accordance with the Arrhenius equation, a value of 7.4225 W/g was determined for the activation energy. In terms of specific energy consumption, the results ranged from 8.56 to 9.93 kWh/kg. When leaves were dried with a microwave power of 180 W, the maximum yield of essential oil was obtained.

Keywords: : Eucalyptus leaves, Microwave drying, Thin layer drying kinetics, Mathematical modeling, Effective moisture diffusivity, Essential oil yield.

Öz

Bu çalışmada, Okaliptüs camaldulensis Dehnh. yapraklarının mikrodalga kurutulması bu esnada mikrodalga gücünün kuruma davranışı, kuruma hızı, kuruma süresi, kuruma kinetiği, nem diffüzivitesi, enerji tüketimi ve uçucu yağ verimi üzerindeki etkisinin değerlendirilmesi amaçlanmıştır. Yapraklar dört farklı mikrodalga güç seviyesinde (180, 360, 600 ve 720 W) kurutulmuştur. Sonuçlar, artan güç seviyelerinin kuruma süresini azalttığını ve kuruma hızının arttığını göstermiştir. Deneysel veriler, yaygın olarak kullanılan dokuz ince tabaka kurutma kinetiği modeline uydurulmuş ve Page modelinin kurutma eğrilerine uyan en iyi model olduğu bulunmuştur. Efektif nem diffüzivitesi 2.36×10^{-11}–$11.45\times10^{-11} m^2/s$ aralığında bulunmuştur. Artan mikrodalga gücü, nem yayılımında bir artışa yol açmıştır. Aktivasyon enerjisi Arrhenius denklemine göre 7.4225 W/g olarak belirlenmiştir. Spesifik enerji tüketimi 8.56 ile 9.93 kWh/kg arasında değişmektedir. Maksimum uçucu yağ verimi, 180 W mikrodalga gücünde kurutulan yapraklardan elde edilmiştir.

Anahtar kelimeler: Okaliptus yaprakları, Mikrodalga kurutma, İnce tabaka kurutma kinetiği, Matematiksel modelleme, Etkin nem yayılımı, Uçucu yağ verimi.

1 Introduction

Among the various processes of drying is the oldest and most significant downstream operations for removing moisture from products within a certain range by evaporation in different industries such as food, chemical, agricultural, and so forth [1]-[3]. The purpose of drying is to decrease water activity, thus, minimizes biological, physical, and chemical changes in product during storage [3]-[7]. Drying occurs because of both mass and energy transfer. Energy efficiency is closely tied to the time it takes for drying [1].

Microwave drying (MWD) is widely used, as it offers many advantages-such as a shorter drying time, lower energy requirements, uniform moisture distribution, power economy, certain process control, and higher product quality than other methods, including hot-air, vacuum drying, and sun-drying. Therefore, it has been replaced with the traditional ones in recent years [1],[7]-[10]. This form of dielectric heating involves converting microwave (MW) energy directly into thermal energy on the inside of the material, resulting in rapid evaporation of water [3],[4],[8].

Many researchers investigated the MWD process by applying to several leafy agricultural products, such as bay leaves [11], celery leaves [6],[12], chamomile leaves [13], chard [14], coriander [7],[9],[15], grape leaves [16], leek [17], mint (*Mentha spicata* L.) [18], nettle leaves [19],[20], olive leaves [5], parsley [10], peppermint [21],[22], rosemary leaves [23], spinach [6],[24], wormwood leaves [25], among others.

Mathematical modeling is an appropriate and effective way to describe drying kinetics. The use of mathematical models decreases the consumption of time and costs, and therefore, designing new dryers and controlling the drying process are possible with it [4].

The process of thin layer drying (TLD), which is designated by one layer of sample leaves drying, is described using many mathematical models. The drying kinetics is a significant factor in determining the moisture content (MC) and time required for drying of the final product [26]. TLD kinetic models are divided into three classifications as theoretical, semi-empirical, and empirical [7],[26]. In general, the models of semi-theoretical are described using Fick's law of diffusion by way of simplicity. The models empirically derived indicate a direct correlation between MC and drying time without considering the basic

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principles of the drying processing. There are several TLD models in the literature for modeling and predicting the curves of drying, including Newton model, Midilli et al. model, Page model, diffusion approach model, Henderson and Pabis model, Logarithmic model, two-term exponential model, and modified Page [4],[26],[27]. Using these, the most convenient TLD kinetics model was determined for corresponds data from the experiment. The TLD kinetics of leafy products exposed to different microwave output powers (MWOPs) have also been investigated [10]-[25]. These studies showed that separate articles on typical drying kinetics, drying models, activation energy (Ea), effective diffusion coefficient (D_{eff}), and specific energy consumption (SEC), and so on. As a model, Midili et al. and Page models were mostly models that fit the experimental data studies as mentioned earlier.

Eucalyptus camaldulensis Dehnh. (*EC*Dehnh.) which is native to Australia, contains about 700 species belonging to the Myrtaceae family, more than 500 of these are essential oil (EO) producers. For respiratory disorders such as bronchitis and croup, Eucalyptus leaves and oils are particularly beneficial. *EC*Dehnh. is the most widely cultivated species in many parts of the world thanks to being able to adapt to various climatic conditions is also known as river red gum [28]-[32]. *EC*Dehnh. is an important medicinal plant, and its EOs (1,8-cineole-rich) have a wide range of antimicrobial, antifungal, antibacterial activities, and so on [29].

A variety of factors, from the crop area to the drying time, can affect the yields of EOs [28]. One of the crucial factors is the drying method, which significantly affects oil content [4], [15], [22],[33]. It was reported that the EO yields both increase and decrease according to the drying method applied [15],[34],[35].

Numerous studies including those implied above have been carried out to appraise the EO content, the drying behavior, and the energy efficiency of various leafy herbs using different methods of drying, including MWD. So far, no information has been obtained concerning the examination of dried *EC*Dehnh. by MW nor the impact of the MWOP on the EO yield. In this aspect, the present study is the first. This paper is aimed at investigating the drying behavior of *EC*Dehnh. leaves dried in a MW oven at several MWOPs and finding the best TLD model devoted to describing curves of drying, calculating the D_{eff}, E_a, SEC, and investigating the effect of microwave power (MWP) on the EO yield of the *EC*Dehnh. leaves.

2 Material and methodology

2.1 Plant material

Eucalyptus cameldulensis Dehnh. (*EC*Dehnh.) leaves were collected from Gökova Gulf-Muğla, Turkey, in October 2019. Until the drying experiments were begun, the leaves were stored in a refrigerator to preserve their fresh quality. Before experiments, the leaves were found to have an average initial MC of 41.7±0.10% (w.b.) using moisture analyzer equipment (OHAUS MB45, Switzerland) at 110 °C.

2.2 Drying of *EC*Dehnh. leaves

MWD experimentation was conducted using a MW oven for the home (Arçelik MD-555S, Turkey) with a maximum power output of 800 W operating at a frequency of 2.45 GHz. The MW cavity has dimensions of 310×294×205 mm. The experiments on drying were performed with four different MWOPs of 180, 360, 600, and 720 W for weights of 50 g. During the process of drying, the moisture losses of samples were weighed with an accurate digital balance (RADWAG PS 3500.R2, Warsaw, Poland) at an interval of 30s with an accuracy of ±0.01 g. Following the power-on time, the sample was removed from the drying chamber, weighed, and put back into the chamber for a following drying run. It has been dried to an MC of less than 5% (wet basis) [1].

2.3 Mathematical modeling of drying data

Equation 1 was utilized to calculate the moisture ratio (MR) of the samples.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

The MC at time t is M_t, while the MC at initial condition is M_0, and the MC at equilibrium is M_e.

According to Equation 2, the drying rate (DR) is calculated as kg water/kg dry matter/min.

$$DR = \frac{M_{t+dt} - M_t}{dt} \tag{2}$$

Moisture contents M_{t+dt} and M_t are determined at times t + dt and t, respectively, while dt is the interval in minutes.

The experimental MW drying data were fitted to the nine TLD models used, which are listed in Table 1.

Table 1. Applied mathematical thin layer drying kinetics models.

Model No.	Model	Model Equation	Reference
1	Newton	$MR = \exp(-k * t)$	[36]
2	Midilli et al.	$MR = a * \exp(-k * t^n) + b * t$	[37]
3	Page	$MR = \exp(-k * (t^n))$	[38]
4	Diffusion approach	$MR = a * \exp(-k * t) + (1 - a) * \exp(-k * b * t)$	[39]
5	Henderson and Pabis	$MR = a * \exp(-k * t)$	[40]
6	Modified Henderson and Pabis	$MR = a * \exp(-k * t) + b * \exp(-g * t) + c * \exp(-h * t)$	[41]
7	Two-term exponential	$MR = a * \exp(-k * t) + (1 - a) * \exp(-k * a * t)$	[42]
8	Logarithmic	$MR = a * \exp(-k * t) + c$	[43]
9	Modified Page	$MR = \exp(-(k * t)^n)$	[44]

MR: Moisture ratio. a, b, c, g, h: Coefficients; n, microwave drying exponent specific to each equation. k: drying coefficient specific to each equation. t: Time.

Matlab *fmincon*, a function from the optimization toolbox, was utilized to decide the constants applied to the tested models. This function is based on a non-linear optimization strategy, Sequential Quadratic Programming (SQP). The various statistical performance coefficient values such as coefficient of determination (R^2), mean absolute percentage error (MAPE%), and root mean square error (RMSE) were used to evaluate the best fitting models according to the Equations (3-5).

$$R^2 = 1 - \left[\frac{\sum(MR_{exp} - MR_{prd})^2}{\sum(MR_{exp} - \overline{MR}_{exp})^2}\right] \tag{3}$$

$$MAPE(\%) = \frac{100}{N}\sum\left|\frac{MR_{exp} - MR_{prd}}{MR_{prd}}\right| \tag{4}$$

$$RMSE = \sqrt{\frac{\sum(MR_{prd} - MR_{exp})^2}{N}} \tag{5}$$

Where, MR_{exp}, MR_{prd}, $\overline{MR}_{exp}$ and N are the experimental MR, predicted MR, average experimental MR, and the number of the observations totaled, respectively.

2.4 Calculation of D_{eff} and Ea

The second diffusion equation according to Fick's law was utilized to calculate the D_{eff}. Crank's computational solution gives the distribution in a plane of infinite dimensions in Equation 6 for drying takes too long [45].

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\,exp\left(-\frac{\pi^2 D_{eff}}{4L^2}t\right) \tag{6}$$

Where D_{eff}; effective diffusion coefficient (m^2/min), L; the thin-layer half-thickness (m), t; drying time (min).

To calculate the D_{eff} of the samples, Equation 7 was put into logarithmic form by plotting the experimental data as ln(MR) against drying time t, since the curve is linear with a slope equal to ($\pi^2 D_{eff}/4 * L^2$).

$$ln(MR) = ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}\right)t \tag{7}$$

Effective moisture diffusivity and MWOP were compared using an Arrhenius-type equation (Equation 8) in logarithmic form, and E_a (in units of W/g) was determined based on the slope of the curve ln(D_{eff}) versus the reciprocal of MWOP (1/P).

$$ln(D_{eff}) = ln(D_0) - E_a\left(\frac{m}{P}\right) \tag{8}$$

Where D_0 is the pre-exponential factor (m^2/min) and m is raw sample mass (g).

2.5 Specific energy consumption (SEC)

Equation 9 gives the specific energy required to evaporate 1 kilogram of water from the item, i.e. the energy amount consumed during the drying process[1],[3],[46].

$$SEC = \frac{Pt}{m_w} \tag{9}$$

This equation takes SEC as the specific energy consumption for the MW (kWh/kg), P as the operating MWOP (W), t as the drying time (s), and m_w as the mass of water evaporated (kg).

2.6 Essential oil extraction

The EO was yielded by hydrodistillation with a Clevenger apparatus for 3 hours at a constant temperature of 5 ºC. 100 g each of the dried samples were submitted to Clevenger apparatus and extracted with 1000 mL of water until no more EO was obtained. The EOs were collected, and their amount was determined volumetrically. The extractions were performed three times. The obtained EOs were stored at 4 ºC for further studies. Except for drying MWOP, all experimental parameters (such as distillation duration, temperature, etc.) except drying MWOP were kept constant

3 Results and evaluation

3.1 Microwave drying behavior of *EC*Dehnh. leaves

MRs as a function of drying time for *EC*Dehnh. leaves for the selected MWOPs are shown in Figure 1. The MR of leaves reduces with increasing drying time. In this study, increasing the MWOP (180 to 720 W) decreased the time needed to reach a constant MC because the higher output power accelerated the drying process. The overall drying times were 24, 11.5, 8, and 7 minutes at 180, 360, 600, and 720 W, respectively. This finding is consistent with the findings of other studies conducted by various researchers [6]-[12].

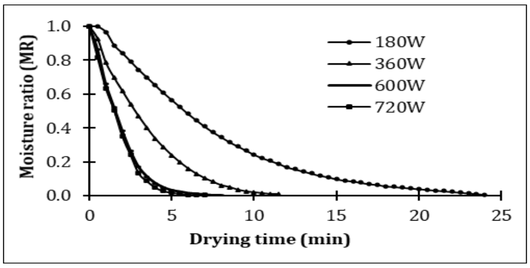

Figure 1. Moisture ratios with time and MWOP.

The effect of MC and drying time on the drying rate at different MWOP levels are presented in Figure 2 and Figure 3, respectively.

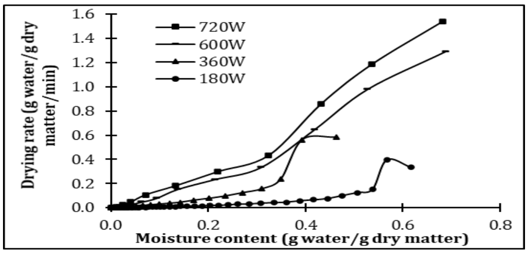

Figure 2. Variation of drying rates with MC for different MWOPs.

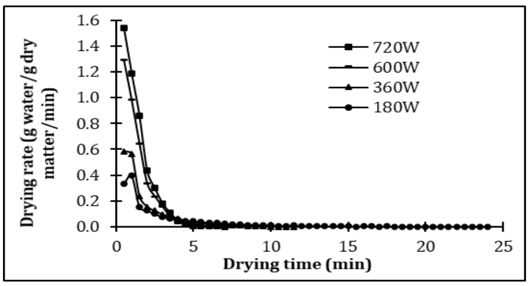

Figure 3. Variation of drying rates with drying time for different MWOPs.

As seen in the graph, the rate of drying decreased with decreasing MC in the period with falling rates, except for a brief period of acceleration at the start of the 180 W and 360 W drying. The critical MC was not found at 600 W and 720 W because of no constant rate period. That means the amount of water transferred to the surface with the help of diffusion and capillary forces through the food material is slower than the amount of water removed from the surface by drying. This expresses that there was no sufficient free water available on the surface of the samples. The reverse of the aforementioned situation is valid for 180 W and 360 W, and along with a constant velocity period is observed, the critical moisture contents are found to be 0.57 and 0.39 g water/g dry matter, respectively. During the initial stages of all drying experiments, there was a higher MW absorption power and a faster drying rate, which is since the leaves have a higher MC. A subsequent reduction in MW absorption and drying rates was caused by moisture loss in the samples [47]. A rise in MWOP brought about in an increment in the heat generated in the sample and consequently an increase in the mass transferred in the sample; thus, the drying rate also increased.

3.2 Mathematical modeling of the microwave thin layer drying data

Nine TLD kinetic models in Table 1 were fitted to all data from experiments to analyze the drying behavior of *EC*Dehnh. leaves. Statistical performance parameters, including R^2, MAPE%, and RMSE, were used to find the best model. The highest R^2, lowest MAPE% and RMSE values determined the better fitting performance. The fitted results of all MWD powers are given in Table 2.

In each case, the performance parameters R^2, MAPE% and RMSE ranged from 0.9870 to 0.9997, 7.090 to 117.4588 and 0.0013 to 0.0442, respectively. Considering performance parameter values, Midilli et al., Page, Diffusion approach, Two-term exponential, and Modified page models fitted well to the results for all experimental data. When these five models were evaluated together, they all had almost the same average R^2 values (0.997) at four MWOP levels, the Midilli et al., Page and Modified Page II models had lower the average MAPE% values (12.0283, 14.3864, and 14.3864, respectively), the average of RMSE of Diffusion approach model was the lowest (0.0074), and the average RMSE values of Midilli et al. And Page models were very close to this value (0.0091 and 0.0094, respectively). Since the b values were minimal in the Midilli et al. model, it has not been evaluated to represent this drying process as a model. In the case of minimal b value, this model is like the Page model since the values are close to 1. Since R^2 is higher when MAPE% and RMSE are lower, Page's mathematical model is the best fit for the data. In this manner, Page's model is the foremost appropriate model to depict the MWD experiments.

In Figure 4(a)-(b), the experimental and ratios of moisture predicted by the Page model are plotted against drying times for MWOP levels of 180, 360, 600, and 800 W, respectively. As can be seen, the Page model estimated values are exceptionally near to the experimental values.

3.3 The effective diffusion coefficient and activation energy

By using Equation 7, the diffusion coefficients (D_{eff}) of *EC*Dehnh. leaves were calculated at different MWOPs. As shown in Figure 5, Ln(MR) is linearly related to t.

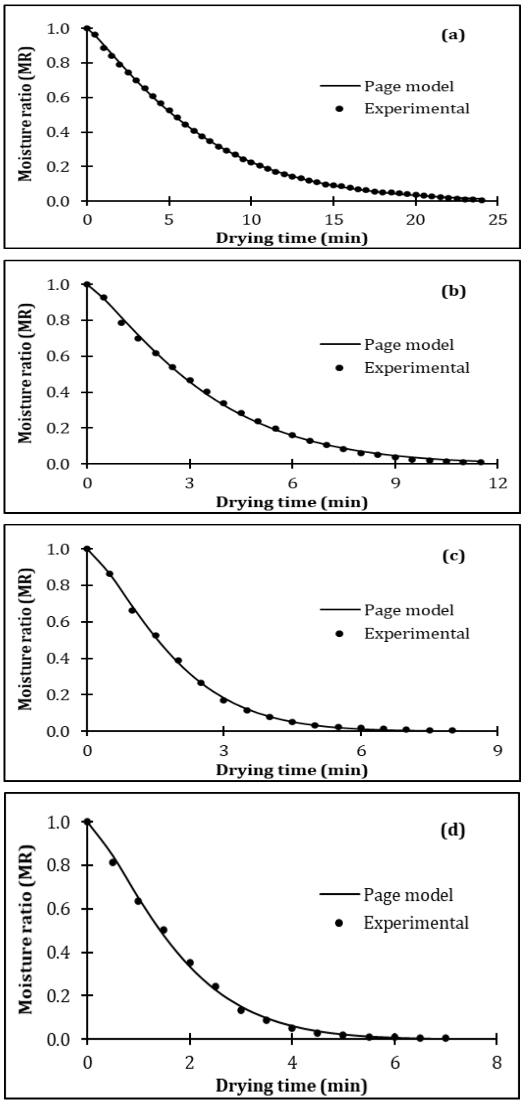

Figure 4. MR variation between experimental and Page model predictions at; (a): 180 W, (b): 360 W, (c): 600 W, (d): 720 W.

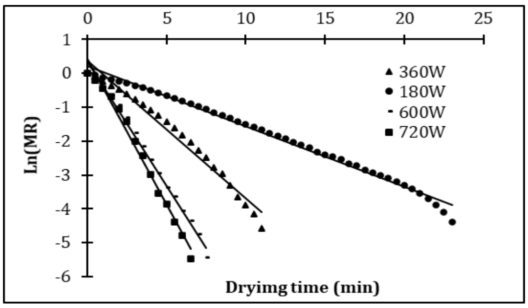

Figure 5. Relation between drying time and Ln (MR) for varied MWOPs.

The results are displayed in Table 3 based on the slopes of the fit lines. Accordingly, D_{eff} increases as MWOP levels increase. With the increase of MWOP level, the D_{eff} increased from 2.36×10^{-11} to 1.145×10^{-10} m^2/s. D_{eff} in 720 W was fivefold higher than 180 W. The D_{eff} values gotten within the present work are in the range of suggested for plant materials (10^{-11} to 10^{-6} m^2/s) and, so it seems reasonable.

Table 2. Coefficients and model performance values of each applied model for each MWOP.

Model No.	P (W)	Model constants							R^2	MAPE (%)	RMSE
		k	a	n	b	c	g	h			
1	180	0.1439							0.9978	46.0954	0.0258
	360	0.2828							0.9953	66.8777	0.0352
	600	0.5178							0.9903	98.9585	0.0433
	720	0.5631							0.9893	136.7986	0.0442
2	180	0.0972	0.9957	1.1825	$7*10^{-12}$				0.9997	11.4038	0.0047
	360	0.1936	0.9894	1.2528	$2*10^{-11}$				0.9988	16.5640	0.0108
	600	0.3797	0.9984	1.3708	0.0005				0.9995	9.0046	0.0071
	720	0.4128	0.9843	1.3742	$2*10^{-10}$				0.9982	11.1406	0.0137
3	180	0.0991		1.1753					0.9997	11.5798	0.0047
	360	0.2014		1.2334					0.9988	18.0214	0.0111
	600	0.3821		1.3584					0.9995	15.3555	0.0073
	720	0.4303		1.3422					0.9981	12.5890	0.0143
4	180	0.2342	500.3871		1.0012				0.9998	11.4638	0.0044
	360	0.4836	505.1701		1.0013				0.9927	20.2276	0.0013
	600	0.9822	506.7887		1.0017				0.9993	7.9040	0.0081
	720	1.0325	503.4081		1.0016				0.9977	24.8549	0.0159
5	180	0.1524	1.0615						0.9964	35.6460	0.0189
	360	0.2999	1.0642						0.9927	55.4824	0.0290
	600	0.5515	1.0740						0.9883	78.7028	0.0368
	720	0.5924	1.0597						0.9870	117.4588	0.0399
6	180	0.1524	0.3537		0.3538	0.3540	0.1524	0.1524	0.9964	35.6460	0.0189
	360	0.2999	0.3550		0.3526	0.3566	0.2999	0.2999	0.9927	55.4824	0.0290
	600	0.5515	0.3568		0.3282	0.3891	0.5515	0.5515	0.9883	78.7028	0.0368
	720	0.5924	0.3550		0.3565	0.3481	0.5924	0.5924	0.9870	117.4588	0.0399
7	180	0.1916	1.7148						0.9998	12.7108	0.0046
	360	0.3882	1.7748						0.9985	24.7149	0.0127
	600	0.7643	1.9212						0.9991	9.1643	0.0096
	720	0.8079	1.8744						0.9972	37.6941	0.0180
8	180	0.1524	1.0615			$3*10^{-9}$			0.9964	35.6460	0.0189
	360	0.2999	1.0642			$2*10^{-9}$			0.9927	55.4824	0.0290
	600	0.5515	1.0740			$9*10^{-11}$			0.9883	78.7028	0.0368
	720	0.5924	1.0597			$4*10^{-10}$			0.9870	117.4588	0.0399
9	180	0.1399		1.1753					0.9997	11.5798	0.0047
	360	0.2727		1.2334					0.9988	18.0214	0.0111
	600	0.4925		1.3584					0.9995	15.3555	0.0073
	720	0.5335		1.3422					0.9981	12.5890	0.0143

MR: Moisture ratio. a, b, c, g, h: Coefficients. N: Microwave drying exponent specific to each equation. k: Drying coefficient specific to each equation. t: Time.

Table 3. Effective diffusion coefficient of *EC*Dehnh. leaves at various MWP levels.

P (W)	$D_{eff} * 10^{11} (m^2/s)$	R^2
180	2.36	0.9903
360	5.38	0.9759
600	9.69	0.9931
720	11.45	0.9869

Increased microwave output power caused faster movement of water molecules inside the sample and led to faster diffusion of moisture towards the surface. The same trend was observed in the studies performed on the microwave drying of various leaves [4],[12],[22].

Activation energy is the minimum energy required to initiate moisture diffusion from a product. Based on the slope of the graph shown in Figure 6, the E_a value was calculated to be 7.4225 W/g. As compared the present result with other plant materials, the higher E_a means lower moisture diffusivity [2]. In the literature, the activation energy values for some microwave dried leafy plant materials were calculated as 8.28, 11.41, 12.28 W/g [48].

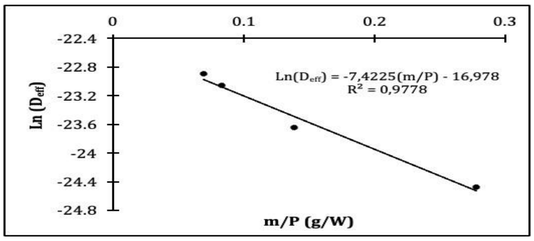

Figure 6. Ln(D_{eff}) and the sample amount/power level relationship.

3.4 Specific energy consumption (SEC)

To achieve the desired final product features, effective use of energy is one of the main goals during the drying process [48]. So, it is inevitable to look at the energy aspects of microwave drying of *EC*Dehnh. leaves. The calculated SEC values at different operating MWOPs are presented in Figure 7. Observation showed that the SEC changed as the MWOP increased. SEC (9.93 kWh/kg) at 360 W MWOP was the maximum, while SEC (8.56 kWh/kg) at 800 W MWOP was the minimum. During the MWD process, MWs increase products' temperature and lead to better-removing moisture. Therefore, energy consumption was reduced as a result of this situation. Similar reports have been published by other researchers [1],[3],[22], [46].

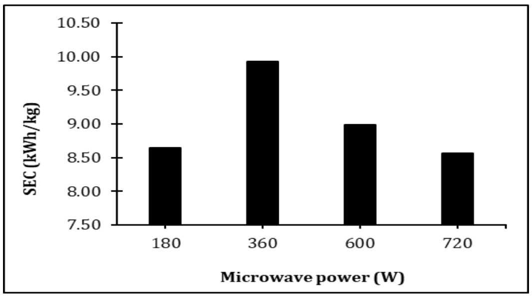

Figure 7. MW energy consumption for drying *EC*Dehnh. Leaves.

3.5 Effective of microwave power on the EO yield

The drying handle can affect the yield of EOs in plant materials and generally depends on the drying time and drying temperature [49]. As a result of the present study, yellow, clear, EOs were extracted from *EC*Dehnh. leaves dried at various MWOP levels. Figure 8 shows how much EO is yielded by drying the leaves using different MWOPs. In a comparison of the results, 720 W produced the lowest EO yield (0.90 mL/100 g dry matter) when dried samples were tested. An increment in the MWOP was concluded with a slightly decreasing EO yield. The destruction forces of heat can increase during drying, which may explain this situation. These results agree with the studies of other researchers working on similar subjects [4],[15],[34],[35].

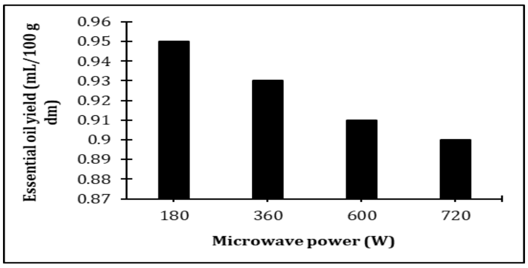

Figure 8. Essential oil yields of *EC*Dehnh. by different MWOP.

4 Conclusions

*EC*Dehnh. leaves were dried using the MWD method in the current study. The drying behavior of the leaves was evaluated in a MW oven with four varied MWOP levels (180, 360, 600, and 720 W). A significant impact of higher power levels was seen on the drying rate. Out of the nine different models applied, Page's model was proved to be the best TLD model with the most appropriate model performance values. D_{eff} values varied from 2.36×10^{-11} to $11.45\times10^{-11} m^2/s$. E_a was determined to be 7.4225 W/g using an Arrhenius-type relationship. This activation energy will be the main basic consideration for design of any drying system and calculation of required drying energy.

SEC was found to be between 8.56 and 9.93 kWh/kg. It was found that the lowest value was obtained at the highest MWOP among applied. The MW oven appears to be an effective method for drying *EC*Dehnh. leaves to get EOs. The oil yields in low MWOP levels were higher than those in high MWOP levels. Overall, MWD is more efficient than conventional drying methods as it reduces the time required for drying and results in a good yield of EOs from dried Eucalyptus leaves. Since any microwave oven exhibits specific power distribution, the results obtained are limited to those obtained using only the domestic microwave oven. The results of this study are prioritized to be applied in practice by designing a pilot or industrial conveyor type microwave oven.

5 Nomenclature

D_0	:	Pre-exponential factor (m^2/min),
D_{eff}	:	Effective diffusion coefficient (m^2/min),
DR	:	Drying rate (kg water/kg dry matter/min),
E_a	:	Activation energy (W/g),
*EC*Dehnh.	:	*Eucalyptus camaldulensis* Dehnh.,
EO	:	Essential oil
L	:	Thin-layer half-thickness (m),
m	:	Raw sample mass (g),
M_0	:	Initial moisture content (kg water/kg dry matter),
MAPE%	:	Mean absolute percentage error,
MC	:	Moisture content (kg water/kg dry matter),
M_e	:	Equilibrium moisture content (kg water/kg dry matter),
MR	:	Moisture ratio,
M_t and M_{t+dt}	:	Moisture content at t and t+dt (kg water/kg dry matter),

MW	:	Microwave,
mw	:	Mass of water evaporated (kg),
MWD	:	Microwave drying,
MWOPs	:	Microwave output powers (W),
MWP	:	Microwave power (W),
P	:	Operating MWOP (W),
R^2	:	Coefficient of determination,
RMSE	:	Root mean square error,
SEC	:	Specific energy consumption (kWh/kg),
SQP	:	Sequential Quadratic Programming,
t	:	Drying time (min),
TLD	:	Thin layer drying.

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7 Author contribution statements

In this study, Behlül Ertuğrul ŞENGÜL contributed to the performing experiments, collecting data, arrangement of references and Emir TOSUN contributed to the formation of the idea, literature review, supplying the materials used, performing experiments, assessment of obtained results, writing, spelling.

8 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared. There is no conflict of interest with any person/institution in the article prepared.

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