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Microwave drying and moisture diffusivity of white mulberry: experimental and mathematical modeling †

Duygu Evin*

Department of Mechanical Engineering, Firat University, Elazig, Turkey

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Abstract

The literature surveyed revealed that drying kinetics of white mulberry under microwave treatment has not been investigated. In present study, both experimental study and mathematical modeling on microwave drying of white mulberry was performed. The microwave drying process which reduced the moisture content of mulberry from 3.76 to 0.25 (g water/g dry matter) was carried out at 90, 180, 360, 600, and 800 W in a modified microwave drying set-up. The effects of microwave drying technique on the moisture ratio and drying rate of white mulberry were investigated experimentally. Both the effects of microwave power level (under the range of 90-800W) and initial sample weight (50-150g) were studied. No constant rate period was observed. Mathematical modeling of thin layer drying kinetics of white mulberry under microwave treatment was also investigated by fitting the experimental drying data to eight thin layer drying models. Among the models proposed, Midilli et al. model precisely represented the microwave drying behavior of white mulberry with the coefficient of determination higher than 0.999 and mean square of deviation (χ^2) and root mean square error (RMSE) lower than $1.1\text{x}10^{-4}$ and $8.9\text{x}10^{-3}$, respectively for all the microwave drying conditions studied. The effective moisture diffusivity (D_{eff}) of white mulberry varied from $0.45\ \text{x}10^{-8}$ to $3.25\text{x}10^{-8}\ m^2s^{-1}$. Both the drying constant (k) and D_{eff} increased with the increase of microwave power level.

Keywords: Microwave drying kinetics; Moisture diffusivity; Mulberry; Thin layer drying models

1. Introduction

The production of white mulberry in 2000 was 68.000 tons in Turkey. Mulberry trees are extensively grown for their leaves as foods for silkworms. Their fruits can be eaten raw or dried or used in mulberry pekmez, juices, paste, marmalade and wine production [1]. White Mulberry has a high level of moisture content at harvest. Because of the short harvesting season and their sensitivity to storage, fresh mulberry fruits should be preserved in some form. Unwashed berries can be kept only several days in a refrigerator in a container. A widely used preservation method for mulberry is drying.

Fruits and vegetables are often dried by sunlight or hot air. Sun and hot air dryings of white mulberry were investigated [2, 3]. However, there are many problems in sun drying such as the slowness of the process, the exposure to environmental contamination, uncertainty of the weather, and the manual labor requirement [1]. On the other hand low-energy efficiency and lengthy time during the falling rate period are major disadvantages of hot air drying of foods, because heat transfer to the inner sections of foods during conventional heating is limited by the low thermal conductivity of food materials in this period [4].

In recent years, microwave drying has gained popularity as an alternative drying method for a wide variety of foods such as banana [4], milk, butter and fresh pasta [5], carrot [6], pumpkin [7, 8], okra [9], tomato pomace [10], peach [11], apple pomace [12], mint leaves [13], chard leaves [14], apple and strawberry [15], leek [16], garlic cloves [17, 18], parsley [19], potato [20, 21], spinach [22] and basil [23]. Drying of a high moist product by hot airflow takes a long time especially during the falling rate period. This is mainly caused by rapid reduction of surface moisture and consequent severe shrinkage. Prolonged exposure to elevated drying may result in substantial degradation of quality attributes. On the other hand, microwave interacts directly with the polar water molecules to generate heat. Thus, microwave drying significantly shortens the drying time and reduces the shrinkage, because in microwave drying, the microwave can easily penetrate the inert dry layers to be absorbed directly by the moisture. The quick energy absorption causes rapid evaporation of water, creating an outward flux of rapidly escaping vapor. In addition to improve the rate of drying, this outward flux can help to reduce the collapse (shrinkage) of tissue structure, which prevails in most

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*Corresponding author. Tel.: +904242370000, Fax.: +904242415526
E-mail address: devin@firat.edu.tr

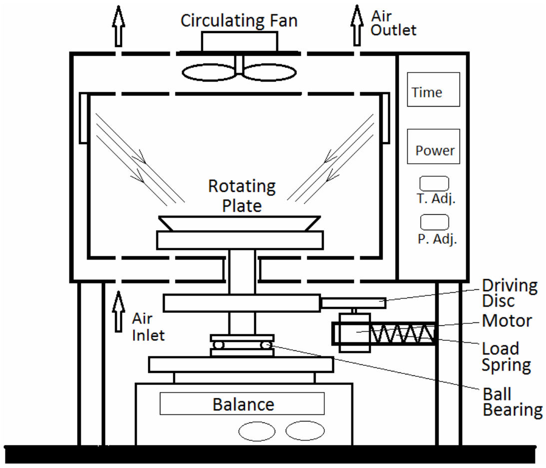

Fig. 1. Schematic illustration of the microwave drying set-up.

conventional air-drying techniques [5-7].

Thin layer drying models are clearly of significant practical value to engineers for the preliminary evaluation of potential microwave drying operations. The correlations are mathematically simple with the characteristic parameters, namely drying constant, providing a combined, but sufficiently informative, measure of the transport properties (moisture diffusivity, thermal diffusivity, heat and mass transfer coefficients). Thin layer drying equations describe the drying phenomena in a unified way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalize drying curves [24].

The literature surveyed revealed that drying kinetics of mulberry under microwave drying conditions has not been documented. Therefore, the main objectives of this study are to: (1) investigate the drying behavior of white mulberry under microwave drying condition (2) discuss the influence of microwave power and initial sample weight on the drying kinetics, (3) model the thin layer drying of white mulberry by fitting mathematical drying models to the experimental microwave drying data, and (4) calculate the effective moisture diffusivities of white mulberry for microwave drying (under the range of 90-800 W).

2. Materials and method

2.1 Experimental apparatus and procedures

The schematic of the experimental microwave drying set-up is given in Fig. 1. A programmable microwave oven (Arcelik MD 564, Turkey) with technical features of 230V, 50 Hz and 2200W, a frequency of 2450 MHz (a wavelength of 12.24 cm) was used for the microwave drying experiments. The dimensions of the microwave cavity were 327x370x207 mm. The microwave oven was operated by a control terminal which could control both microwave power level and emission time. So as to weight the samples without taking out of the oven, a weighting system was integrated to the oven.

A digital balance (Sartorius GP5202, Germany) which has an accuracy of 0.01 and a plastic disc was mounted to the bottom of the microwave oven.

The disc was rotated at 5 rpm on a ball bearing shaft driven by an electrical motor. The presence of the rotating disc was necessary to obtain homogeneous drying and to decrease the level of the reflected microwaves on to the magnetrons. The oven has ventilation holes at the top as well as at the bottom. Air circulation was provided by a fan. Drying experiments were carried out with 90, 180, 360, 600 and 800 W microwave power levels to investigate the effects of microwave power on drying of mulberry. Samples were placed in a single layer on a rotating glass plate in the oven. Moisture loss of the samples was recorded by means of the balance at intervals until no discernible weight change was observed. Rotating was stopped by pulling back the driving disc when recording the weight data.

The moisture content on the dry basis is the weight of moisture present in the product per unit weight of dry matter in the product. For drying experiments, where weight losses are recorded, the instantaneous moisture contents at any given time can be computed according to the following equation [25, 26];

$$M = \left[\frac{(M_o + 1)W_o}{W_t} - 1 \right] \quad (1)$$

where W_o, W_t and M_o are the initial weight of undried product, weight of product at time t and, the initial moisture content, respectively.

Fresh mulberries were harvested by hand at Firat University in Elazig. Berries of uniform size were selected for the drying experiments. The average values of the length and the diameter of the mulberries were 3.1 and 1.5 cm, respectively. The initial moisture content of mulberry was determined by an infrared moisture analyzer (Sartorius MA45, Germany). The initial moisture content was calculated as 3.76 (g water/g dry matter) dry basis as an average of the results obtained.

2.2 Mathematical modeling

Numerous models have been proposed to describe the rate of moisture loss during the thin layer drying of biological materials. In this study, 8 drying models are selected as they represent some of the more commonly adopted ones. The regression analysis was done using the Statistica computer program. The correlation coefficient was one of the primary criteria for selecting the best equation expressing the drying curves of the sample. In addition to R^2, the reduced χ^2 which is the mean square of the deviations between the experimental and calculated values for the models and root mean square error (RMSE) were used to determine the consistency of the fit [24, 27, 28]. These parameters can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{exp,i} - MR_{pre,i})^2}{N - n} \quad (2)$$

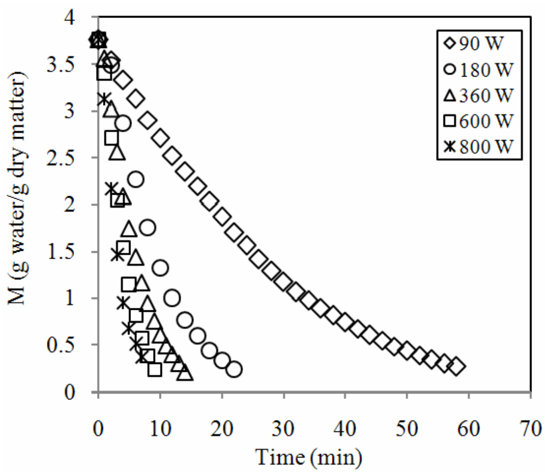

Fig. 2. Variation of moisture content with dying time.

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \quad (3)$$

where $MR_{exp,i}$ is the i[th] moisture content observed experimentally; $MR_{pre,i}$ is the i[th] predicted moisture content; N and n represent the number of observations and constants, respectively. The best model describing the thin layer drying characteristics of mulberry was chosen as the one with the lowest reduced χ^2 and RMSE and the highest R^2.

3. Results and discussion

3.1 Drying curves and mathematical modeling

The microwave drying curve of white mulberry illustrating the variation of moisture content with dying time is given in Fig. 2.

The drying process is characterized by a progressive decrease in moisture content with time. While the moisture content decreases gradually at 90 W, a sharp decrease occurs in the moisture content with the highest microwave power of 800 W.

The microwave drying process which reduced the moisture content of mulberry from 3.76 to 0.25 (g water/g dry matter) took 58-7 min depending on the microwave output power. Drying time was shortened by 88% working at 800 W instead of 90 W. Within a certain microwave power range (90-800 W in this study), increasing output power speeds up the drying process. Similar findings were also reported by several authors for various foods under microwave drying [7, 9, 10].

The variation of drying rate with moisture content which explains the microwave drying behavior of mulberry is given in Fig. 3. Drying rates were calculated as the amount of water removed per unit time per dry solids. As can be seen from the figure, no constant rate period was observed in microwave drying of mulberry for all microwave power levels. Drying process in the range of 90-180 W took place in the falling rate period with the exception of a very short initial warming-up

Table 1. Mathematical models applied to the drying curves of mulberry.

Model no	Model name	Model
1	Newton	MR=exp(-kt)
2	Page	MR=exp(-kt^n)
3	Modified page	MR=exp(-(kt)^n)
4	Henderson and pabis	MR=aexp(-kt)
5	Logarithmic	MR=aexp(-kt)+c
6	Two term	MR=aexp(-k_0t)+bexp(-k_1t)
7	Midilli et al.	MR=aexp(-kt^n)+bt
8	Wang and singh	MR=1+at+bt^2

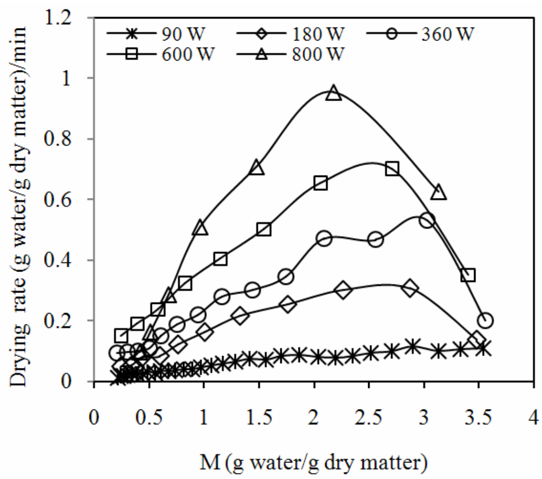

Fig. 3. The effect of microwave power on microwave drying rate of white mulberry.

period. This observation is in agreement with the previous reports on thin layer microwave drying of biological products [11, 12].

Increasing the microwave power substantially increased the drying rate. This indicates that mass transfer within the sample was more rapid during higher microwave power heating because more heat was generated within the sample creating a large vapor pressure difference between the centre and the surface of the product due to the characteristic microwave volumetric heating [10, 11].

Eight thin layer drying models – Newton [29], Page [30], Modified Page [31], Henderson and Pabis [32], Logarithmic [33], Two Term [34], Midilli et al. [24], Wang and Singh [35] – were applied to the drying curves. The regression analyses were done for these thin layer drying models by relating the drying time (t) and dimensionless moisture ratio (MR=M/Mo) for 90, 180, 360, 600 and 800 W. The names, equations and references of the mathematical models applied to the drying curves of mulberry are given in Table 1. The acceptability of the mathematical model is based on the correlation coefficient, root mean square error and the reduced χ^2. The best model describing the thin layer drying characteristics of mulberry was chosen as the one with the lowest reduced χ^2 and RMSE

Table 2. Statistical results of the thin layer drying models for MW drying of white mulberry at 90, 180, 360, 600 and 800 W microwave power (W_o=50 g).

Model	MW Power (W)	Model constants	χ^2	RMSE	R^2
1	90	k=0,038382	0,000832	0,028389	0,99006
	180	k=0,101601	0,003212	0,054262	0,97102
	360	k=0,162456	0,002247	0,045794	0,97807
	600	k=0,229116	0,003615	0,057042	0,96822
	800	k=0,307509	0,002048	0,042335	0,98193
2	90	k=0,010163; n=1,182729	0,000042	0,006332	0,99951
	180	k=0,042360; n=1,372996	0,000209	0,013202	0,99828
	360	k=0,091597; n=1,303933	0,000142	0,011097	0,97871
	600	k=0,124038; n=1,405763	0,000103	0,009090	0,99919
	800	k=0,224099; n=1,257963	0,000600	0,021207	0,99546
3	90	k=0,037835; n=1,182729	0,000042	0,006332	0,99951
	180	k=0,099991; n=1,373005	0,000209	0,013202	0,99828
	360	k=0,159902; n=1,303934	0,000142	0,011097	0,99871
	600	k=0,226566; n=1,405764	0,000103	0,009090	0,99919
	800	k=0,304538; n=1,257963	0,000599	0,021207	0,99546
4	90	a=1,052396; k=0,040498	0,000531	0,022308	0,99386
	180	a=1,087378; k=0,110602	0,002209	0,042905	0,98188
	360	a=1,083796; k=0,176472	0,001340	0,034075	0,98786
	600	a=1,080702; k=0,248181	0,002761	0,046996	0,97843
	800	a=1,049630; k=0,323239	0,001828	0,037024	0,98618
5	90	a=1,137488; k=0,031635; c=-0,11652	0,000094	0,009247	0,99895
	180	a=1,230173; k=0,080159; c=-0,17327	0,001258	0,030712	0,99072
	360	a=1,197007; k=0,133457; c=-0,14315	0,000649	0,022779	0,99457
	600	a=1,332862; k=0,15486; c=-0,2886	0,001066	0,027323	0,99271
	800	a=1,12727; k=0,26998; c=-0,09117	0,001745	0,033028	0,98900
6	90	a=0,526195; k_0=0,040495; b=0,526195; k_1=0,0405	0,000568	0,022308	0,99386
	180	a=0,543689; k_0=0,110602; b=0,543689; k_1=0,110602	0,002761	0,042905	0,98188
	360	a=0,541898; k_0=0,176472; b=0,541898; k_1=0,176472	0,001583	0,034075	0,98786
	600	a=0,540351; k_0=0,248181; b=0,540351; k_1=0,248181	0,003681	0,046996	0,97843
	800	a=0,524815; k_0=0,323239; b=0,524815; k_1=0,323239	0,002742	0,037024	0,98618
7*	90	***a=0,992414; k=0,0213; n=1,162467; b=-0,00033***	***0,000020***	***0,00419***	***0,99978***
	180	***a=1,009931; k=0,039681; n=1,437999; b=0,001795***	***0,000094***	***0,007931***	***0,99938***
	360	***a=1,014072; k=0,094823; n=1,311785; b=0,001294***	***0,000110***	***0,008983***	***0,99916***
	600	***a=1,008072; k=0,126829; n=1,413658; b=0,001422***	***0,000107***	***0,008024***	***0,99937***
	800	***a=1,002946; k=0,210717; n=1,454944; b=0,012479***	***0,000053***	***0,005163***	***0,99973***
8	90	a=-0,02989; b=0,000241	0,000051	0,006923	0,99941
	180	a=-0,07832; b=0,001612	0,001058	0,029696	0,99132
	360	a=-0,12561; b=0,004184	0,000598	0,022773	0,99458
	600	a=-0,17281; b=0,007510	0,000932	0,027311	0,99272
	800	a=-0,24986; b=0,017415	0,000900	0,025982	0,99319

and the highest R^2.

Regression coefficients and standard deviations of the drying models for mulberry during microwave drying process under the microwave power range of 90-800 W are given in Table 2. The modified Page equation differs from the page equation with an exponent 'n' added to the drying constant 'k' which merely gives a drying constant of differing magnitude. All the models demonstrate good agreement with the microwave drying data of mulberry. However, Page, modified Page and the Midilli et al. models have very high R^2 and very low χ^2 and RMSE values.

For all the microwave power levels tested, the model which obtained the closest fit to the microwave drying experimental data was the Midilli et al. model:

$$MR = \alpha\, exp(-kt^n) + bt \tag{4}$$

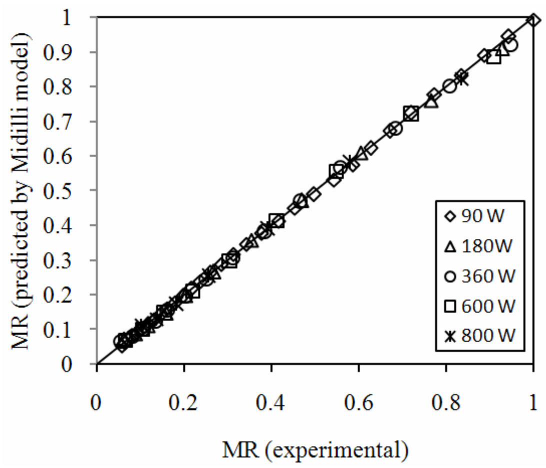

Fig. 4. The comparison of the experimental moisture ratio with the data predicted by the Midilli et al. model.

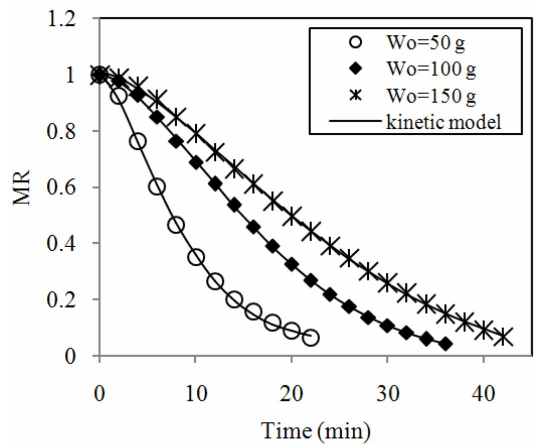

Fig. 5. Moisture ratios versus time for various initial sample weights at 180 W, comparing experimental curve with the predicted one based on the Midilli et al. model.

where t and MR are drying time and moisture ratio, respectively. The estimated parameters of this model (a, dimensionless drying constant; k, drying constant (min^{-1}); b, parameter of the proposed model (min^{-1}) and n, dimensionless drying constant) and values of R^2, RMSE, χ^2 and MBE values are highlighted with the bold italic characters in Table 2. The Midilli et al. model can be considered the most suitable drying model with the highest R^2 and lowest RMSE and χ^2 values for the entire microwave power levels. R^2 values were higher than 0.999 and χ^2 and RMSE values were lower than $1.1x10^{-4}$ and $8.9x10^{-3}$, respectively for the entire microwave drying conditions. The value of the drying rate constant (k) increased with increase in microwave power. Examination of the drying constant (k) in the Midilli et al. model indicates that the relative magnitude of the parameter accurately reflects the drying behavior. Values of drying constants were in the range of 0.02 - 0.21 min^{-1} under the microwave power range of 90-800 W, respectively. The value of the drying rate constant increased with the increase in microwave power. The higher k values verify the elevated moisture removal rates and indicate an enhancement of drying potential [36]. The comparison of the experimental dimensionless moisture content with the data predicted by Midilli et al. model is given in Fig. 4. The model predictions and the drying data are seen generally to be banded around a straight line, which shows that the assumed model is well suited describing the microwave drying behavior of white mulberry.

To exhibit the effect of the initial sample weight, microwave drying is conducted for 50, 100 and 150 g mulberry at a constant microwave power of 180 W. The microwave drying process which reduced the moisture content of mulberry from 3.76 to 0.25 (g water/ g dry matter) took 22- 40 min with the increase of sample amount from 50 to 150 g, respectively. The variation of moisture ratio with time for different amounts of mulberry is shown in Fig. 5. To describe the effect of initial sample weight on the drying kinetics of mulberry at a constant microwave power, eight thin layer drying models given in Table 1 were fitted to the drying curves of mulberry. Among the models proposed, Midilli et al. model again found to be the best model describing the drying kinetics of mulberry at a constant microwave power for the entire initial weight range studied (50-150 g). R^2 values were higher than 0.999 and χ^2 and RMSE values were lower than $9.41x10^{-5}$ and $7.94x10^{-3}$, respectively. Regression coefficients and standard deviations of the drying models during microwave drying process for the initial weights investigated (50, 100 and 150 g) at 180 W are given in Table 3. The regression and the standard deviations of the Midilli et al. model are highlighted with the bold italic characters in the table. Values of drying constants were in the range of 0.039- 0.006 min^{-1} under the initial sample weight of 50-150 g, respectively. The value of the drying rate constant decreased with the increase in initial sample weight. Fitted drying curves based on Midilli et al. model which was found to provide excellent fits to the experimental data for 50, 100 and 150 g initial sample weight at the constant microwave power level of 180 W can be seen in Fig. 5.

3.2 Calculation of the effective moisture diffusivity

The experimental drying data for determination of diffusivity was interpreted by using Fick's second law:

$$\frac{\partial M}{\partial t} = D_{eff} \frac{\partial^2 M}{\partial r^2} . \tag{5}$$

The initial and boundary conditions for cylindrical geometry can be written as follows [37-39]:

$$M = M_0; \quad t = 0, \quad 0 \le r \le R$$
$$\frac{\partial M}{\partial r} = 0; \quad t > 0, \quad r = 0$$
$$M = M_e; \quad t > 0, \quad r = R$$

where M_0 is the initial moisture content (g water /g dry mat-

Table 3. Statistical results of the thin layer drying models for MW drying of 50, 100 and 150 g white mulberry at 180 W.

Model	Mass (g)	Model constants	χ^2	RMSE	R^2
1	50	k=0,101601	0,003212	0,054262	0,97102
	100	k=0,054102	0,007202	0,082601	0,93542
	150	k=0,039124	0,007109	0,082374	0,92879
2	50	k=0,042360; n=1,372996	0,000209	0,013202	0,99828
	100	k=0,008319; n=1,639772	2,90501E-05	0,005098	0,99975
	150	k=0,005002; n=1,651234	8,6993E-05	0,008892	0,99917
3	50	k=0,099991; n=1,373005	0,000209	0,013202	0,99828
	100	k=0,053902; n=1,639992	2,90492E-05	0,005098	0,99975
	150	k=0,040419; n=1,652294	8,69792E-05	0,008892	0,99917
4	50	a=1,087378; k=0,110602	0,002209	0,042905	0,98188
	100	a=1,139766; k=0,062023	0,004586419	0,064060	0,96116
	150	a=1,140462; k=0,045499	0,004269	0,062297	0,95927
5	50	a=1,230173; k=0,080159; c=-0,173277	0,001258	0,030712	0,99072
	100	a=1,705054; k=0,027384; c=-0,63421	0,000996624	0,028970	0,99206
	150	a=2,414522; k=0,013086; c=-1,35238	0,000539965	0,021594	0,99511
6	50	a=0,543689; k_0=0,110602; b=0,543689; k_1=0,110602	0,002761	0,042905	0,98188
	100	a=0,569883; k_0=0,062025 b=0,569883; k_1=0,062020818	0,005198	0,064060	0,96116
	150	a=0,570226; k_0=0,045499 b=0,570236; k_1=0,04549899	0,004743463	0,062298	0,95927
7*	50	***a=1,009931; k=0,039681; n=1,437999; b=0,001795***	***0,000094***	***0,007931***	***0,99938***
	100	***a=1,004857; k=0,009416 n=1,586361; b=-0,000567535***	***1,61971E-05***	***0,003576***	***0,99988***
	150	***a=1,011376; k=0,006723 n=1,52431; b=-0,001531653***	***2,83966E-05***	***0,004820***	***0,99976***
8	50	a=-0,07832; b=0,001612	0,001058	0,029696	0,99132
	100	a=-0,03742; b=0,000267	0,001493572	0,036556	0,98735
	150	a=-0,02548; b=5,66E-05	0,00104884	0,030878	0,98999

ter), M_e is the equilibrium moisture content (g water/g dry matter), t is the drying time (min) and R is the cylinder radius (m).

The solution to Eq. (5) developed by Crank (1975) can be used for various regularly shaped bodies such as rectangular, cylindrical and spherical products, and the form of Eq. (6) can be applicable for particles with cylindrical geometry by assuming uniform initial moisture distribution, constant diffusion coefficient and negligible shrinkage [10, 16, 18, 38]:

$$MR = \frac{4}{\pi^2}\exp\left(-\pi^2 \frac{D_{eff}t}{r^2}\right) \tag{6}$$

where D_{eff} is the effective moisture diffusivity, m^2/s.

This could be further simplified to a straight-line equation as [38]:

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

To calculate the effective moisture diffusivity by using the method of slopes, the logarithm of moisture ratio values, ln(MR), were plotted against drying time (t) according to the experimental data obtained at various microwave output powers. The linearity of the relationship between ln (MR) and drying time is illustrated in Fig. 6.

It was determined that, the effective moisture diffusivity of white mulberry varied from 0.45 to $3.25\text{x}10^{-8}\ m^2s^{-1}$ over the microwave power range studied. Effective moisture diffusivity for mulberry under solar drying was studied by Akbulut and Durmuş (2009). However, no documentary was found about the investigation of the effective moisture diffusivity for mulberry undergoing microwave treatment. It was reported that the effective moisture diffusivity values of white mulberry were in the range of $3.47\text{x}10^{-12}$-$1.46\text{x}10^{-9}\ m^2s^{-1}$ under solar drying [40]. This value range is lower than the effective diffusivity determined for microwave drying which is in the order of (10^{-8}). This finding is in agreement with the investigation on comparasion of microwave and convective drying kinetics of tomato pomace [10] and microwave drying of mint leaves compared with convective drying [13].

Values of Effective diffusivities of mulberry determined under the microwave power range of 90-800 W are given in Table 4. As expected, the values of diffusivities increased with the increase of microwave power due to the increase of temperature and consequently water vapor pressure.

The increase in power resulted in rapid heating of the product, thus increasing the vapor pressure inside the product that made the diffusion of moisture towards the surface faster.

Table 4. Effective diffusivities of white mulberry under the microwave power range of 90-800 W.

Microwave power (W)	90	180	360	600	800
D_{eff} x10^8(m^2/s)	0.456	1.255	1.939	2.909	3.251

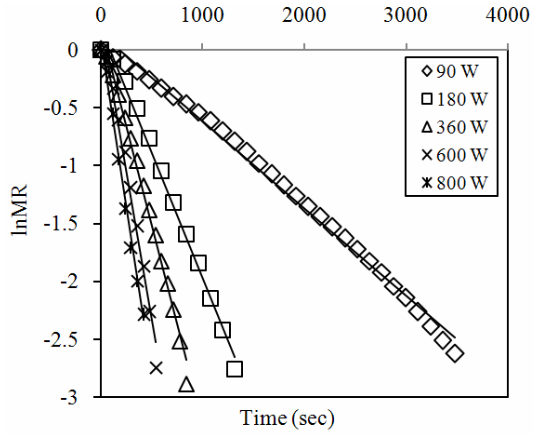

Fig. 6. The logarithm of moisture ratio versus microwave drying time for mulberry.

4. Conclusions

Microwave drying kinetics of white mulberry was investigated. It was observed that drying took place in the falling rate period. The microwave drying process which reduced the moisture content of mulberry from 3.76 to 0.25 (g water/g dry matter) took 58-7 min depending on the microwave output power (90-800 W). Drying time was shortened by 88% working at 800 W instead of 90 W. The microwave drying process which reduced the moisture content of mulberry from 3.76 to 0.25 (g water/g dry matter) took 22-40 min with the increase of sample amount from 50 to 150 g at the constant microwave power level of 180 W, respectively. The Midilli et al. model given by MR = a.exp(-k.t^n) + b.t represented the microwave drying characteristics of white mulberry better than the other frequently used thin layer drying models proposed. For all the conditions studied, R^2 values were higher than 0.999 and χ^2 and RMSE values were lower than 1.1x10^{-4} and 8.9x10^{-3}, respectively. The effective moisture diffusivity of white mulberry varied from 0.45 x10^{-8} to 3.25x10^{-8} m^2s^{-1} over the output power range studied. Both the drying constant (k) and D_{eff} increased with the increase of microwave power level.

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Duygu Evin received her Ph.D degree in Mechanical Engineering from Firat University, Turkey, in 2004. Her research interests include heat and mass transfer, drying and evaporative cooling.