FULL LENGTH ARTICLE

Study of the drying kinetics of pepper

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Abstract The present study investigated the influence of microwave power on the drying kinetics, energy consumption and drying efficiency of green pepper during microwave drying at 180, 240, 300, 360, 420, 480 and 540 W. Seven mathematical models for describing the thin-layer drying behaviour of pepper samples were investigated. The models were compared based on their R^2, RMSE and χ^2 values between experimental and predicted moisture ratios. By increasing the microwave output powers (180–540 W), the drying time decreased from 9 to 2.5 min. The drying process took place in the falling rate period. The results show that the Midilli model is the most appropriate model for drying behaviour of thin layer pepper samples. A third order polynomial relationship was found to correlate the effective moisture diffusivity with moisture content. The effective moisture diffusivity increased with decrease in moisture content of pepper samples. The average effective diffusivity varied from 8.315×10^{-8} to 2.363×10^{-7} m^2/s, over the microwave power range studied, with an energy activation of 14.19 W/g. Energy efficiency increased with increase in microwave power and moisture content. The least specific energy consumption (4.99 MJ/kg water) was at the microwave power of 240 W and the highest (6.80 MJ/kg water) was at 180 W.

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1. Introduction

Dehydration is an important preservation process which reduces water activity through the decrease of water content,

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avoiding potential deterioration and contamination during long storage periods. Other important objectives of food dehydration are weight and volume reduction, intended to decrease transportation and storage costs (Celma et al., 2009; Sarimeseli, 2011; Figiel, 2010; Vega et al., 2007; Wang et al., 2007).

Fresh peppers may be stored for up to 3 weeks in cool, moist conditions (45–50 °F and 85–90 percent relative humidity) (ISU, 2009). Peppers are commonly dried for spice production. The dried spice is used in food mixtures, salad dressings, instant soups, frozen pizzas and many other convenience foods. Peppers are also a source of minerals such

as calcium, phosphorous, potassium and iron (Faustino et al., 2007).

According to local producers, sun dehydration of pepper requires about seven consecutive days, and the fruits suffer undesirable fermentation, with consequent reduction in the sales (Soysal et al., 2009). This process is slow, requires a deal of care, and thus is not feasible once the actual quality of product is not competitive.

Hot-air drying has been to date the most common drying method employed for pepper (Vega et al., 2007; Ade-Omowaye et al., 2002; Tunde-Akintunde et al., 2005). But air drying has drawbacks of both long drying time required and poor quality (Chou and Chua, 2001; Soysal et al., 2006; Therdthai and Zhou, 2009). The desire to eliminate this problem, to prevent significant quality deterioration, as well as to achieve fast and effective thermal processing has resulted in the increasing use of microwaves for pepper drying. Microwave drying is more rapid, more uniform and more highly energy efficient compared to conventional hot air drying and infrared drying (Sarimeseli, 2011; Soysal et al., 2006; Duan et al., 2003; Al-Harahsheh et al., 2009). In a microwave drying system, the microwave energy has an internal heat generative capacity and can easily penetrate the interior layers to directly absorb the moisture in the sample. The quick energy absorption causes rapid evaporation of water, creating an outward flux of rapidly escaping vapour, thus, both thermal gradient and moisture gradient are in the same direction (Dadali et al., 2007; Soysal et al., 2006; Wang et al., 2007).

Various mathematical models describing the drying mechanism have been suggested for the optimisation of the process and the design of effective dryers. Also, the prediction of drying rates for thin layer drying and moisture diffusion parameters of vegetables and fruits are important components of microwave drying simulation models and are essential for an efficient moisture transfer analysis (Da Silva et al., 2009; Vega et al., 2007; Sharma and Prasad, 2004; Sharma et al., 2005).

Therefore, the aim of this research was the study and the modelling of the drying kinetics of mass transfer, energy consumption and drying efficiency during the microwave drying process of pepper, and the analysis of the influence of microwave power on the kinetic constants of the proposed models.

2. Materials and methods

2.1. Materials

Fresh green peppers were harvested from a green house in the Ilam province of Iran, in September 2009 and were stored in the refrigerator at temperature of 4 °C until the experiments were carried out. Before the experiments, the samples were removed from the refrigerator and allowed to reach room temperature (about 18 °C). The green peppers (average dimensions of 0.7 ± 0.1 cm diameter and 6 ± 1 cm length) were washed and halved. After removing the seed samples, they were cut to the length of 2 cm. The green pepper had an initial moisture content of 73.33% (wet basis), which was determined by drying in a convective oven at 103 ± 1 °C until the weight did not change any more (Kashani Nejad et al., 2002).

2.2. Drying equipment and method

Drying treatment was performed in a domestic digital microwave oven (model MG-607 900 W, LG, Korea) with technical features of 230 V, 50 Hz and 2650 W, at the frequency of 2450 MHz. The microwave power was regulated by a control terminal which could control both microwave power level and emission time. Drying trial was carried out at seven different microwave generation powers: 180, 240, 300, 360, 420, 480 and 540 W. The area on which microwave drying is carried out was $530 \times 500 \times 322$ mm in size, and consisted of a rotating glass plate with 300 mm diameter at the base of the oven. The adjustment of microwave output power and processing time was done with the aid of a digital control facility located on the microwave oven. During drying experiments, each sample was put on the rotating glass of microwave and placed at the centre of the oven. Moisture loss was periodically measured by taking out the rotating glass and weighing on the digital balance with a precision of 0.01 g. Three replications of each experiment were performed according to a preset microwave output power and time schedule, and the data given were an average of these results. The microwave power was applied until the weight of the sample reduced to a level corresponding to moisture content of about 0.1 kg water/kg dry base. All weighing processes were completed in less than 10 s during the drying process.

2.3. Mathematical modelling

For the investigation of drying characteristics of green pepper, it is important to model the drying behaviour effectively. In this study, the experimental drying data of green pepper at different microwave powers were fitted into seven commonly used thin-layer drying models, listed in Table 1.

Moisture ratio of samples during drying is generally calculated by the following equation:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

where M_t, M_0 and M_e are moisture content at any time of drying (kg water/kg dm), initial moisture content (kg water/kg dm) and equilibrium moisture content (kg water/kg dm), respectively. The values of M_e are relatively small compared to M_t and M_0 for long drying times and accordingly one can write (Evin, 2011; Soysal et al., 2006):

$$MR = \frac{M_t}{M_0} \quad (2)$$

2.4. Correlation coefficients and error analysis

The ability of the tested mathematical model to represent the experimental data was evaluated through the correlation coefficient (R^2), the reduced (χ^2) and the root mean square error (RMSE) parameters. The higher the R^2 and lower the χ^2 and RMSE values, the better is the fitting procedure (Wang et al., 2007; Ozbek and Dadali, 2007). These parameters are defined as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N} \left(MR_{pre,i} - MR_{exp,i}\right)^2}{N - z} \quad (3)$$

Table 1   Mathematical models given by various authors for the drying curves.

Model name	Model	References
Lewis	$MR = \exp(-kt)$	Doymaz and Ismail (2011)
Page	$MR = \exp(-kt^n)$	Jangam et al. (2008)
Henderson and Pabis	$MR = a\exp(-kt)$	Figiel (2010)
Logarithmic	$MR = a\exp(-kt) + b$	Kingsly et al. (2007)
Wang and Singh	$MR = 1 + bt + at^2$	Wang et al. (2007)
Midilli et al.	$MR = a\exp(-kt^n) + bt$	Midilli et al. (2002)
Modified Page	$MR = \exp(-(kt)^n)$	Arslan and Ozcan (2010a,b)

where k is the drying constant and a, b, n are equation constants.

$$RMSE = \left(\frac{\sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2}{N} \right)^{0.5} \quad (4)$$

where $MR_{exp,i}$ and $MR_{pred,i}$ are the ith experimental and predicted moisture ratio, respectively, N is the number of observations and z is the number of parameters. In this study, the nonlinear or linear regression analysis was performed using the IMB SPSS statistics 19.

2.5. Drying rate

The drying rate of samples was calculated using Eq. (5):

$$DR = \frac{M_{t+\Delta t} - M_t}{\Delta t} \quad (5)$$

where $M_{t+\Delta t}$ is moisture content at $t + \Delta t$ (kg water/kg dm), t is time (min) and DR is the drying rate (kg water/kg dm min).

2.6. Moisture diffusivity

Fick's second equation of diffusion was used to calculate the effective diffusivity, considering a constant moisture diffusivity, infinite slab geometry and uniform initial moisture distribution:

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\frac{(2n+1)^2 \pi^2}{4L^2} D_{eff} t \right) \quad (6)$$

where D_{eff} is the effective diffusivity (m²/s) and L is the thickness (here half) of layer (m). The Eq. (6) can be simplified by taking the first term of Eq. (7):

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

Eq. (7) is evaluated numerically for Fourier number, $F_0 = D_{eff} \times t/4L^2$, for diffusion and can be rewritten as Eq. (8) (Sharma and Prasad, 2004; Sharma et al., 2005):

$$MR = \frac{8}{\pi^2} \exp(-\pi^2 F_0) \quad (8)$$

Thus:

$$F_0 = -0.101\ln(MR) - 0.0213 \quad (9)$$

The effective moisture diffusivity was calculated using Eq. (10) as:

$$D_{eff} = \frac{F_0}{\left(\frac{t}{4L^2} \right)} \quad (10)$$

2.7. Activation energy

Inasmuch as temperature is not precisely measurable inside the microwave drier, the activation energy is found as modified from the revised Arrhenius equation. In a first method it is assumed as related to the drying kinetic constant rate (k) and the ratio of microwave output power to sample weight (m/P) instead of to air temperature. Then Eq. (11) can be effectively used (Ozbek and Dadali, 2007) as follows:

$$k = k_0 \exp\left(-\frac{E_a m}{P} \right) \quad (11)$$

In the second method, the correlation between effective diffusion coefficient and (m/P) is used for calculation of the activation energy.

$$D_{eff} = D_0 \exp\left(-\frac{E_a m}{P} \right) \quad (12)$$

where k is the drying rate constant obtained by using the best model (1/min), k_0 is the pre-exponential constant (1/min), E_a is the activation energy (W/g), m is the mass of raw sample (g), and D_0 is the pre-exponential factor (m²/s).

2.8. Energy efficiency of microwave drying

The microwave drying efficiency was calculated as the ratio of heat energy utilised for evaporating water from the sample to the heat supplied by the microwave oven (Soysal et al., 2006; Mousa and Farid, 2002).

$$\mu = \frac{m_w \lambda_w}{Pt} \times 100 \quad (13)$$

where μ is the microwave drying efficiency (%); m_w is the mass of evaporated water (kg); λ_w is the latent heat of vapourisation of water (J/kg); P is the average microwave power (W); and t is the time interval (s).

The energy consumed for drying a kilogram of sample is calculated using Eq. (14) (Varith et al., 2007; Soysal, 2004; Sarimeseli, 2011):

$$E_s = \frac{Pt \times 10^{-6}}{m_w} \quad (14)$$

where E_s is the specific energy consumption to evaporate a unit mass of water from the product (MJ/kg water). The average microwave energy efficiency values were calculated as the averaged energy consumption for water evaporation divided by the supplied microwave energy in the, total power-on time (Soysal et al., 2006).
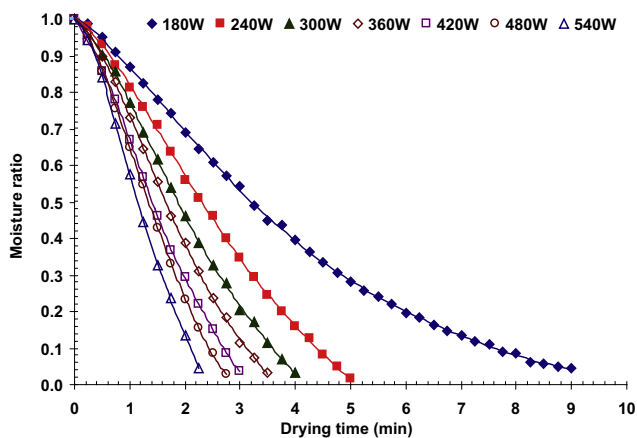
3. Results and discussion

3.1. Fitting of drying curves

Fig. 1 shows the change in moisture ratio of pepper samples with time by microwave drying. It is clear that the moisture ratio decreases continuously with drying time. On the other hand, mass transfer within the sample was more rapid during higher microwave power heating because more heat was generated within the sample creating a large vapour pressure difference between the centre and the surface of the product due to characteristic microwave volumetric heating. The drying times obtained in this present study were extremely low compared to the results obtained in the previous studies given in the literature. Doymaz and Ismail (2010) in his work concluded that during convective drying of green bell pepper, drying time of 520 min would be most suitable for the convective drying of green bell pepper. The results obtained in this present work showed that as compared to convective dryer; the drying time can be shortened by 208-fold by working at 540 W. Besides this, by performing microwave drying at 540 W instead of hot air drying of red pepper samples at 55–70 °C with air velocity of 1.5 m/s as reported by Akpinar et al. (2003), the drying time can be shortened by about 48–128-fold, respectively.

The statistical results from models are summarised in Table 2. The values of mentioned tests were in the range of 0.780–0.999 for R^2, 0.00002–0.05674 for χ^2, and 0.00375–0.21745 for RMSE. Based on the criteria of the highest R^2 and the lowest RMSE, and χ^2, the model of Midilli was selected as the most suitable model to represent the thin-layer drying behaviour of pepper samples. Fig. 2 compares experimental data with those predicted with the Midilli model for pepper samples at 180, 240, 300, 360, 420, 480 and 540 W. The prediction using the model showed MR values banded along the straight line, which showed the suitability of these models in describing drying characteristics of pepper.

To account the effect of the microwave power on the Midilli model, the constants k, a, b and n were regressed against those of drying microwave powers using regression analysis. Based on the regression analysis, the accepted model and their constants are as follows:

$$MR(t, P) = a \, \exp(-k \, t^n) + bt$$
$$k = 0.0847 \, \exp(0.0031P) \quad R^2 = 0.979 \tag{15}$$
$$n = 3 \times 10^{-8} P^3 - 3 \times 10^{-5} P^2 + 0.0136P - 0.2157 \quad R^2 = 0.978 \tag{16}$$
$$b = 8 \times 10^{-8} P^2 - 0.0019P + 0.0218 \quad R^2 = 0.930 \tag{17}$$
$$a = 3 \times 10^{-7} P^2 - 0.0003P + 1.0474 \quad R^2 = 0.929 \tag{18}$$

3.2. Drying rate

As seen in Fig. 3, all curves have two stages. The drying rate rapidly increases and then slowly decreases as drying progresses. In general, it is observed that drying rate reduces with time or with the reduction of moisture content. As mentioned earlier, the product's moisture content reduces over time. The drying process took place in the falling rate period. Similar results have been observed in the drying of different fruits and vegetables: kiwifruit (Femenia et al., 2009); hazelnut (Uysal et al., 2009); carrot pomace (Kumar et al., 2011); amelia mango (Dissa et al., 2009); pineapple, mango, guava and papaya (Marques et al., 2009) and apple pomace (Wang et al., 2007). Lahsasni et al. (2004) reported that the drying during the falling rate period is so governed by water diffusion in the solid.

The moisture content of the material was very high during the initial phase of the drying which resulted in a higher absorption of microwave power and higher drying rates due to the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave power and resulted in a fall in the drying rate. Higher drying rates were obtained at higher microwave output powers. Thus, the microwave output power had a crucial effect on the drying rate. Similar findings were reported in previous studies (Wang et al., 2007; Soysal et al., 2006; Therdthai and Zhou, 2009).

3.3. Effective moisture diffusivity

Variation in effective moisture diffusivity of samples with moisture content at different microwave power levels is shown in Fig. 4. The effective moisture diffusivity increased with decrease in moisture content. However, the moisture diffusivity further was higher at any level of moisture content at a higher microwave power level, resulting in a shorter drying time. This may indicate that as the moisture content decreased, the permeability to vapour increased, provided the pore structure remained open. The temperature of the product rises rapidly in the initial stages of drying, due to more absorption of microwave heat, as the product has a high loss factor at higher moisture content. This increases the water vapour pressure inside the pores and results in pressure induced opening of pores. In the first stage of drying, liquid diffusion of moisture could be the main mechanism of moisture transport. As drying progressed further, vapour diffusion could have been the dominant mode of moisture diffusion in the latter part of drying. Sharma and Prasad (2004) and Sharma et al. (2005) also reported a similar trend in the variation in the moisture diffusivity with moisture content.

A third order polynomial relationship was found to correlate the effective moisture diffusivity with corresponding moisture content of samples and is given by Eq. (19)

$$D_{eff} = (A + BM + CM^2 + DM^3) \times 10^{-8} \tag{19}$$

Figure 1 Relationship between the moisture ratio and the drying time at different microwave powers.

Table 2 Values of the drying constants and coefficients of different models determined through regression method for all microwave power values.

Model	P (W)	Constants and coefficients	R^2	χ^2	RMSE
Newton	180	$k = 0.2917$	0.944	0.00644	0.07917
	240	$k = 0.5022$	0.780	0.02171	0.14380
	300	$k = 0.5847$	0.829	0.01875	0.13248
	360	$k = 0.6821$	0.827	0.02132	0.14107
	420	$k = 0.7758$	0.837	0.01854	0.13080
	480	$k = 0.8029$	0.879	0.01883	0.13138
	540	$k = 0.9595$	0.816	0.02201	0.14076
Henderson and Pabis	180	$a = 1.3543; k = 0.3416$	0.972	0.00829	0.08854
	240	$a = 1.6931; k = 0.6563$	0.844	0.04803	0.20847
	300	$a = 1.5639; k = 0.7473$	0.885	0.03574	0.17759
	360	$a = 1.5992; k = 0.8764$	0.887	0.04248	0.19186
	420	$a = 1.5298; k = 0.9799$	0.891	0.03723	0.17748
	480	$a = 1.6405; k = 1.1370$	0.8652	0.05674	0.21745
	540	$a = 1.5147; k = 1.2217$	0.873	0.04373	0.18704
Logarithmic	180	$a = 1.315; k = 0.172; b = -0.258$	0.997	0.00028	0.01610
	240	$a = 2.067; k = 0.142; b = -1.00$	0.996	0.00052	0.02109
	300	$a = 3.192; k = 0.098; b = -2.149$	0.996	0.00052	0.02070
	360	$a = 3.441; k = 0.104; b = -2.393$	0.995	0.00699	0.07478
	420	$a = 3.250; k = 0.126; b = -2.213$	0.996	0.00056	0.02069
	480	$a = 4.049; k = 0.109; b = -3.00$	0.995	0.00070	0.02291
	540	$a = 4.949; k = 0.102; b = -3.90$	0.995	0.00084	0.02418
Modified Page	180	$k = 0.238; n = 1.378$	0.999	0.00005	0.00686
	240	$k = 0.357; n = 1.699$	0.996	0.00048	0.02078
	300	$k = 0.437; n = 1.707$	0.997	0.00037	0.01814
	360	$k = 0.499; n = 1.761$	0.997	0.00030	0.01621
	420	$k = 0.580; n = 1.699$	0.997	0.00036	0.01755
	480	$k = 0.624; n = 1.811$	0.996	0.00048	0.01999
	540	$k = 0.723; n = 1.820$	0.997	0.00037	0.01719
Midilli	180	$a = 1.014; k = 0.152; b = -0.004; n = 1.284$	0.999	0.00003	0.00478
	240	$a = 1.003; k = 0.164; b = -0.032; n = 1.463$	0.999	0.00003	0.00527
	300	$a = 0.997; k = 0.221; b = -0.030; n = 1.540$	0.999	0.00005	0.00597
	360	$a = 1.001; k = 0.267; b = -0.032; n = 1.585$	0.999	0.00002	0.00375
	420	$a = 0.997; k = 0.342; b = -0.040; n = 1.529$	0.999	0.00004	0.00538
	480	$a = 1.003; k = 0.356; b = -0.0531 n = 1.590$	0.999	0.00004	0.00540
	540	$a = 1.003; k = 0.449; b = -0.060; n = 1.623$	0.999	0.00006	0.00580
Wang and Singh	180	$a = 0.0082, b = -0.1809$	0.996	0.00037	0.01867
	240	$a = 0.0038, b = -0.2221$	0.994	0.00062	0.02364
	300	$a = 0.0050; b = -0.2703$	0.993	0.00077	0.02601
	360	$a = 0.0042; b = -0.3031$	0.992	0.00098	0.02601
	420	$a = 0.0101; b = -0.3615$	0.994	0.00073	0.02493
	480	$a = -0.0011; b = -0.3644$	0.993	0.00097	0.02823
	540	$a = -0.0139; b = -0.4050$	0.992	0.00098	0.02800
Page	180	$k = 0.139; n = 1.378$	0.999	0.00005	0.00682
	240	$k = 0.174; n = 1.699$	0.996	0.00048	0.02079
	300	$k = 0.243; n = 1.707$	0.997	0.00034	0.01737
	360	$k = 0.294; n = 1.761$	0.997	0.00030	0.01621
	420	$k = 0.397; n = 1.699$	0.997	0.00036	0.01755
	480	$k = 0.425; n = 1.811$	0.996	0.00048	0.01999
	540	$k = 0.554; n = 1.820$	0.998	0.00037	0.01719

where A, B, C, D are the constants of regression, and M is the moisture content (d.b.)

Regression constants for microwave drying of pepper samples under different powers are presented in Table 3. The high values of R^2 are indicative of good fitness of empirical relationship to represent the variation in effective moisture diffusivity with moisture content of samples.

The average effective moisture diffusivity was calculated by taking the arithmetic mean of the effective moisture diffusivities that were estimated at various levels of moisture contents during the course of drying, as shown in Fig. 5. Average values of effective diffusivity for different microwave power are presented in Table 4. The D_{eff} values of the samples were within the general ranges of 10^{-9}–10^{-11} m^2/s for biological materials
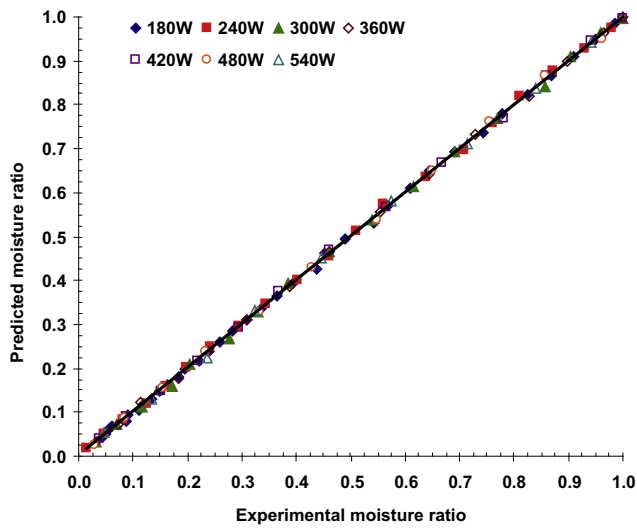
Figure 2 Comparison of experimental moisture ratio with predicted moisture ratio from the Midilli model for pepper.
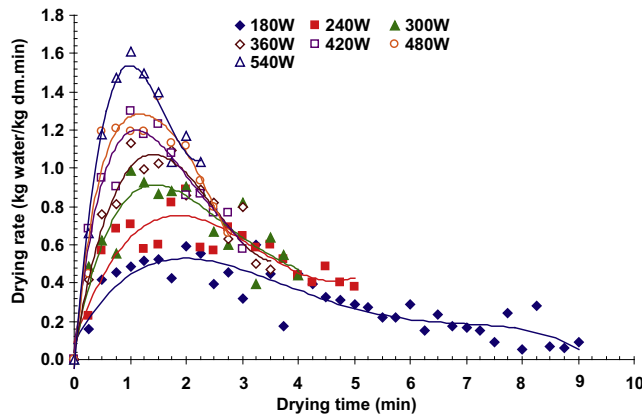

Figure 3 Relationship between the drying rate and the drying time at different microwave powers.
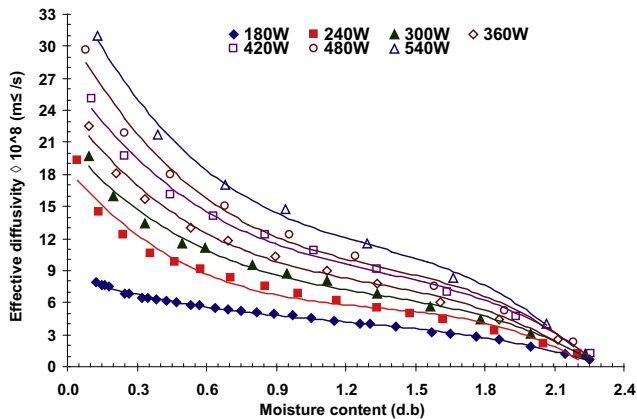

Figure 4 Variation in effective moisture diffusivity with moisture content at different microwave powers.

(Wang et al. 2007; Kumar et al., 2011). The values of D_{eff} are comparable with the reported values of $5.10–8.32 \times 10^{-10}$ m^2/s

Table 3 Regression coefficients of effective moisture diffusivity for different microwave powers.

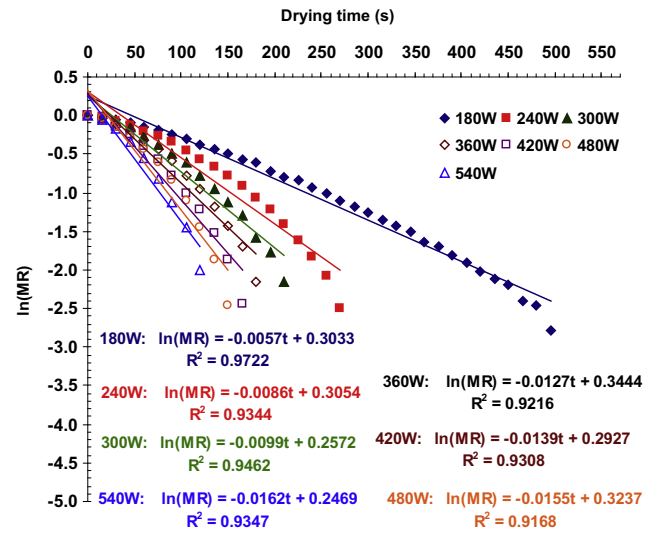| P (W)	A	B	C	D	R^2
540	31.476	−43.236	28.011	−7.046	0.995
480	1.3081	−38.968	24.905	−6.075	0.991
420	27.205	−31.012	19.317	−4.566	0.994
360	24.087	−28.892	18.815	−4.755	0.992
300	20.848	−24.575	15.669	−3.889	0.991
240	18.564	−25.490	17.731	−4.468	0.977
180	8.5051	−6.997	4.305	−1.226	0.997

Figure 5 Variation in ln (MR) and drying time for pepper samples dried at different microwave powers.

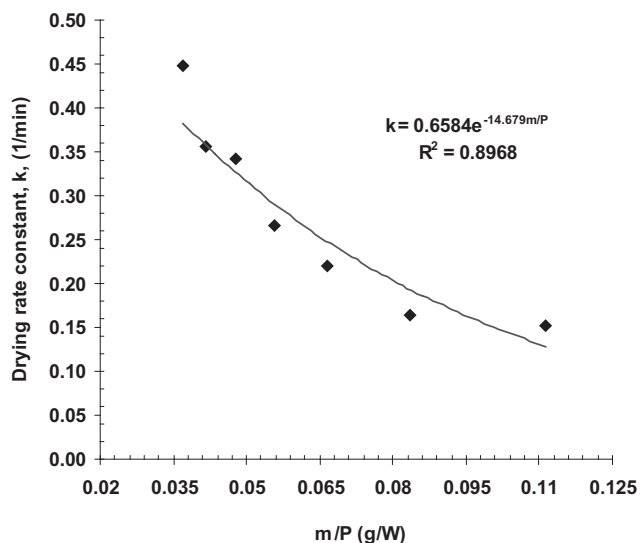**Table 4** Result of average effective diffusivity of pepper with different microwave power levels.

P (W)	Average effective diffusivity (m^2/s)
540	2.363×10^{-7}
480	2.261×10^{-7}
420	2.028×10^{-7}
360	1.853×10^{-7}
300	1.444×10^{-7}
240	1.255×10^{-7}
180	8.315×10^{-8}

mentioned for red pepper (Di Scala and Crapist, 2008), $3.72–9.96 \times 10^{-10}$ m^2/s for Jaranda variety red pepper (Sanjuán et al., 2003); $0.360–2.01 \times 10^{-10}$ m^2/s for green peppers (Ertekin, 2002); 0.705 and 2.618×10^{-9} m^2/s for green bell pepper (Doymaz and Ismail, 2010); $2.25–2.74 \times 10^{-8}$ m^2/s for red pepper (Doymaz and Pala, 2002) and 0.31 and 87.39×10^{-9} m^2/s for red bell pepper (Arslan and Ozcan, 2010,2011). The differences between the results can be explained by effect of type, composition, and tissue characteristics of the peppers and the proposed model used for calculation.
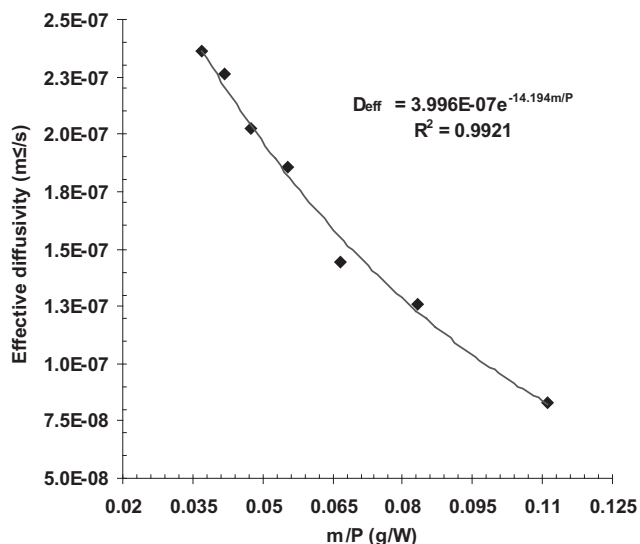
3.4. Activation energy

Activation energy can be calculated from the (K–m/P) curve (Fig. 6) and Eq. (11). Based on statistical analysis and Page's model coefficients, k_0 and E_a values were estimated as 0.6584 (1/min) and 14.67 (W/g).

Another method for calculation of activation energy is the calculation of the coefficients for Eq. (12) from (D_{eff}) versus (m/P) curve (Fig. 7), which would yield activation energy and D_0 values of 3.996×10^{-7} m^2/s and 14.194 W/g. The values of activation energy are comparable with the reported values of 5.54 W/g mentioned for okra (Dadali et al., 2007), 13.6 W/g for pandanus leaves (Rayaguru and Routray, 2011), 12.284 for mint leaves (Ozbek and Dadali, 2007),

16.675 W/g and 24.222 W/g for sweet and sour pomegranate, respectively (Minaei et al., 2012).

3.5. Energy efficiency and consumption

The variation of energy efficiency with moisture content and drying time is shown in Figs. 8 and 9. The energy efficiency was very high during the initial phase of the drying which resulted in a higher absorption of microwave power. Following moisture reduction, the energy absorbed by the product decreased and reflected power increased (Mousa and Farid, 2002; Soysal et al., 2006). For this reason, it was observed that as the microwave power increased the energy losses increased, in other words energy efficiency values decreased. Similar trends were also observed by Soysal et al. (2006) for microwave drying of parsley. The best result with regard to energy efficiency was obtained from 240 W microwave power levels among all microwave power.

The average energy needed for drying 1 kg of samples can be seen from Fig. 10. The values ranged from 4.99 to 6.80 MJ/kg water. Also, the average drying efficiencies were calculated as 33.18, 45.20, 43.95, 41.59, 42.96, 41.35 and

Figure 6 The relationship between the values of k versus sample amount/power.
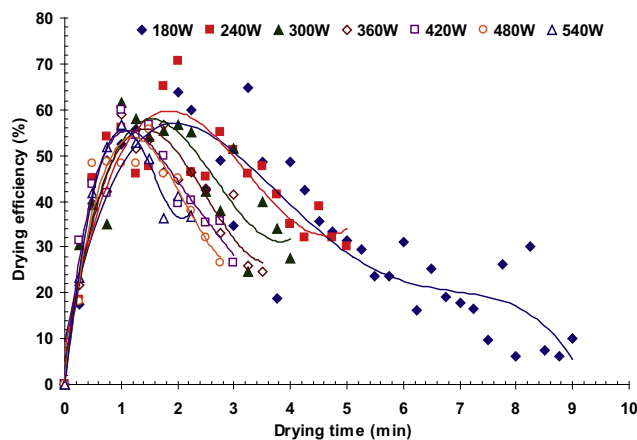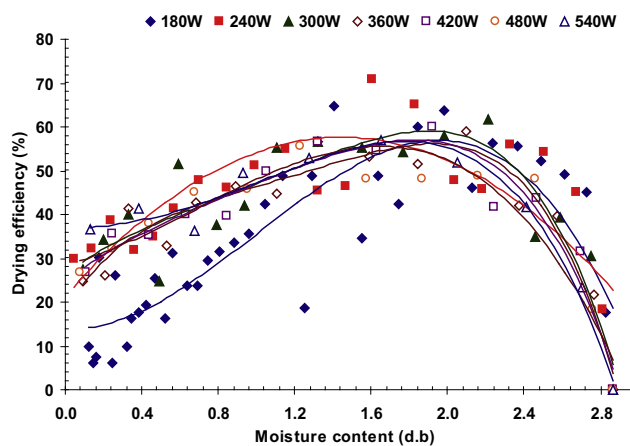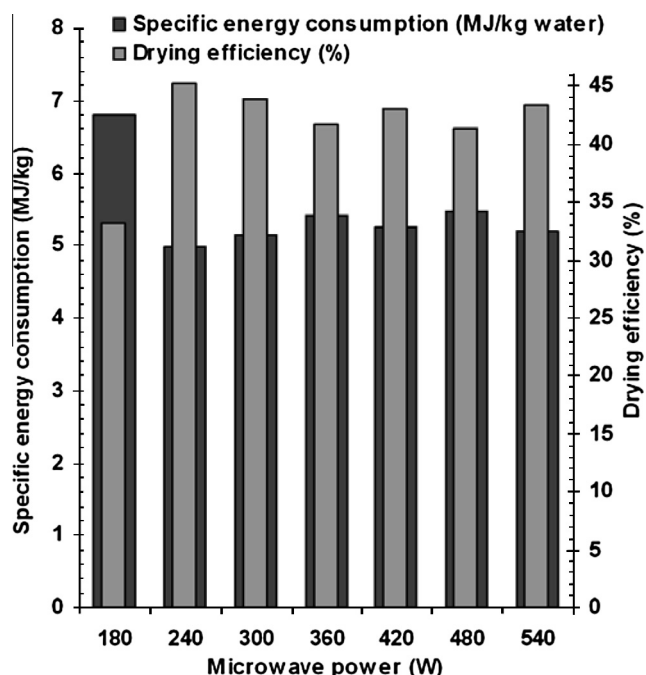

Figure 8 Variation in drying efficiency with drying time at different microwave powers.

Figure 7 The relationship between the values of D_{eff} versus sample amount/power.

Figure 9 Variation in drying efficiency with moisture content at different microwave powers.

Figure 10 Average specific energy consumption and drying efficiency of pepper at different microwave powers.

43.38% for the microwave power levels of 180, 240, 300, 360, 420, 480 and 540 W., respectively (Fig. 10). The minimum specific energy consumption (4.99 MJ/kg) and maximum drying efficiency (45.20%) are obtained at microwave power of 240 W.

4. Conclusions

The seven thin layer models were used to describe the microwave drying kinetics of the pepper slices. The Midilli model provided the best fit. By increasing the microwave power level, the effective moisture diffusivity and drying rate were increased. Therefore, drying time could be reduced. A third order polynomial relationship existed between effective moisture diffusivity and the moisture content of pepper slices. The effective moisture diffusivity increased with decrease in moisture content of pepper samples. The average effective diffusivity varied from 8.315×10^{-8}–$2.363 \times 10^{-7}\,\mathrm{m^2/s}$ in the microwave power range of 180–540 W. The activation energy was found to be 14.194 W/g. Specific energy consumption and drying efficiency in microwave drying of pepper slices ranged between 4.99 and 6.80 MJ/kg water and 33.18–45.20%, respectively. We concluded that 240 W is the optimum microwave power level in the microwave drying of pepper slice with respect to energy consumption (4.99 MJ/kg water) and drying efficiency (45.20%).

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