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Microwave Drying of Green Bean Slices: Drying Kinetics and Physical Quality

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Abstract

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Several microwave power settings were applied to green beans in order to determine the effect on the drying kinetics along with the rehydration ratio and colour values. In the experiments, several microwave power settings were studied as 180, 360, 600, and 800 W. From the results, it is seen that the level of microwave power affected the drying kinetics, rehydration ratio, and colour of the beans slightly. The nine best known thin-layer drying models that were used in literature were applied to the experimental data and the results showed that Midilli et al. model best fits the experimental data for the drying kinetics of green bean slices. Effective moisture diffusivity was found to be between 1.387×10^{-8} and 3.724×10^{-8} m^2/s. Using modified Arrhenius type equation the activation energy was found as 19.185 kW/kg. The rehydration ratio of samples dried at 800 W was higher than those of samples at other power settings. It was observed that an increase in the microwave power increased the brightness and yellowness, on the contrary, it decreased the greenness of the dried samples.

Keywords: *Phaseolus vulgaris*; effective diffusivity; drying; mathematical modelling; rehydration; colour

List of abbreviations

a, b, c – empirical constants in drying models; D_0 – pre-exponential factor of Arrhenius equation (m^2/s); D_{eff} – effective moisture diffusivity (m^2/s); E_a – activation energy (W/kg); *g, k* – empirical coefficients in drying models (1/s); *K* – slope; *L* – half-thickness of slices (m); *MR* – moisture ratio (dimensionless); M_e – equilibrium moisture content (kg water/kg dry matter – DM); M_0 – initial moisture content (kg water/kg DM); M_t – moisture content at any time (kg water/kg DM); $M_{t+\Delta t}$ – moisture content at $t+\Delta t$ (kg water/kg DM); *N* – number of observations; *n* – positive integer, empirical constant; P – microwave power (W); *P* – probability; *R* – universal gas constant (kJ/(mol.K)); R^2 – coefficient of determination; *RR* – rehydration ratio; *RMSE* – root mean square error; *T* – temperature (°C); *t* – drying time (min, s); W_1 – weight of dried matter (g); W_2 – weight of moisture in the material (g); *z* – number of constants; χ^2 – reduced chi-square

The bean (*Phaseolus vulgaris*), which contains carbohydrates, proteins, dietary fibre (insoluble fibre), vitamins (thiamine, riboflavin, niacin, pyridoxine, and folic acid) as a major amount and minerals of calcium, iron, copper, zinc, phosphorus, potassium, and magnesium as a minor amount and flavonoids, which act as antioxidants and can be found in the hull part of bean, is a gramineous plant that belongs to the family Leguminosae (Ulloa *et al.* 2013). In 2012 the worldwide production of bean was 20 742 857 t and the six major producer countries were China, Indonesia, India, Turkey, Thailand, and Egypt, from higher to lower rank. In Turkey the green bean production was 614 965 t in 2012 on the area of 74 000 ha. In order to extend the storage life of green beans, drying is an important process after harvest because green beans are very sensitive to spoilage due to their high content of moisture.

In the industrial sector the processes that consume time and energy are thermal processes, where one of the thermal process is drying (Secmeler 2003). Microbiological activity, physical and chemical changes during storage that lead to decay and spoilage are prevented by removing enough moisture from food by drying (Doymaz & Ismail 2011; Vijavavenkataraman *et al.* 2012). Without changing the quality of agricultural products, new drying methods are studied to minimize the drying time and energy consumption

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(Secmeler 2003) because major disadvantages of hot air drying of agricultural products are low energy efficiency, quality loss and long drying time during the falling rate period (Boudrioua *et al.* 2003).

Nowadays, the aim of modern drying is come upon by reducing energy consumption and providing high quality with a minimal increase in economic inputs, which has been of increasing attraction to applications in the drying process (Raghavan & Silveira 2001; Kahyaoglu *et al.* 2012; Darvishi *et al.* 2013). For the last 20 years microwave drying has been of interest in the area of water removal from agricultural products, for short drying time that leads to lower energy consumption and better quality of the dried food (Sanga *et al.* 2000). One of the primary advantages in using the microwave heating is that the temperature and moisture gradients are in the same direction, and hence aid each other as opposed to conventional heating where moisture must move out of the material against the gradient of temperature. Thus drying time is shortened due to quick absorption of energy by water molecules, causes rapid evaporation of water, resulting in high drying rates of the food. However, there are some problems with the microwave drying technique. Because of non-uniform heating, the uneven distribution of microwave field can occur. Also, overheating and quality deterioration can take place. To overcome these problems, the microwave drying technique has been combined with other drying methods (Puligundla *et al.* 2013).

Recently, microwave drying has attracted popularity as an alternative method for drying several food products such as fruits, vegetables, and dairy products were also studied. By researchers, cranberries (Yongsawatdigul & Gunasekaran 1996), carrot slices (Lin *et al.* 1998), potatoes (Bouraout *et al.* 1994; Bondaruk *et al.* 2007), grapes (Tulasidas *et al.* 1996), apples (Funebo & Ohlsson 1998; Prothon *et al.* 2001; Bilbao-Sáinz *et al.* 2006), mushrooms (Funebo & Ohlsson 1998; Giri & Prasad 2007), ginseng roots (Ren & Chen 1998), blueberries (Feng *et al.* 1999), pistachios (Kouchakzadeh & Shafeei 2010), tomato pomace (Al-Harahsheh *et al.* 2009), kiwifruits (Maskan 2001), garlic (Sharma & Prasad 2006), spinach (Alibas Ozkan *et al.* 2007), and green peas (Zielinska *et al.* 2013) were studied along by a microwave method. As it is given in the literature studies, there is no data available about microwave drying of green bean. For the contribution to the literature, the drying, rehydration and colour characteristics of green beans in a microwave oven were investigated. Furthermore, the mathematical modelling by using nine thin-layer drying models available in the literature was performed and the values of effective moisture diffusivity and activation energy were calculated.

MATERIAL AND METHODS

Sampling. The fresh green beans (*Phaseolus vulgaris* L.) were obtained from a local grocery store in Istanbul on March 2014. The beans were washed and sliced at an average length and thickness of 2 cm and 0.6 cm, respectively. Then sliced beans were put into low-density polyethylene plastic bags. Packed beans were kept in a refrigerator (Arcelik 1050T; Arcelik, Eskisehir, Turkey) working at a temperature of 4°C. Before experiments the beans were taken out of the refrigerator and waited to equalise with the room temperature. Using the AOAC method (AOAC 1990), the initial moisture content of the beans was determined as 9.89 ± 0.05 kg water/kg dry matter (DM).

Drying procedure. Drying experiments were carried out in a Robert Bosch Hausgerate GmbH (Munich, Germany) model microwave oven which has a maximum output of 800 W working at 2450 MHz. In the microwave drying process, the samples were separated evenly and homogeneously over the entire pan. The drying processes were carried out at microwave powers of 180, 360, 600, and 800 W. The sample mass (approximately 12 ± 0.2 g) was selected during 60 s intervals with a digital balance (Precisa, model XB220A; Precisa Instruments AG, Dietikon, Switzerland) with an accuracy of 0.001 g. Drying was finished when the moisture content of samples was approximately 0.08 kg water/kg dry matter. The dried product was cooled in a desiccator and packed in low-density polyethylene bags that were heat-sealed. The experiments were triplicated and average values of the moisture content were used for drawing the drying curves.

Mathematical modelling. In Table 1, nine thin-layer drying models, which were used on the drying data obtained at different microwave powers, are shown. Using Eq. (1), the sample moisture ratio (MR) was calculated as follows:

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

where: M_t – moisture content (kg water/kg DM) at any specific time; M_0 – initial moisture content; M_e – equilibrium moisture content; t – drying time (min)

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The values of M_e are considered relatively small compared to M_t or M_0, especially for microwave drying. Thus, Eq. (1) can be simplified to $MR = M_t/M_0$ (Balbay & Sahin 2012; Chayjan & Shadidi 2014; Calín-Sánchez *et al.* 2014).

The drying rate *(DR)* was calculated by the following formula:

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

where: $M_{t+\Delta t}$ – moisture content at $t+\Delta t$ (kg water/kg DM); t – time (min)

Determination of effective moisture diffusivity. Fick's second law of diffusion equation, symbolised as a mass-diffusion equation for drying of agricultural products in a falling rate period, is shown in Eq. (3):

$$\frac{\partial M}{\partial t} = \nabla[D_{eff}(\nabla M)] \quad (3)$$

Fick's second law of unsteady state diffusion given in Eq. (3) can be used to determine the moisture ratio in Eq. (4). The solution of diffusion equation for an infinite slab was given by Crank (1975), and uniform initial moisture distribution, negligible external resistance, constant diffusivity, and negligible shrinkage were supposed (Doymaz *et al.* 2015):

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

where: D_{eff} – effective moisture diffusivity (m^2/s); t – time (s); L – half-thickness of samples (m); n – positive integer

For long drying times, only the first term in Eq. (4) is significant and the equation simplifies to:

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (5)$$

Equation (5) can be written in a logarithmic form as follows:

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}\, t}{4L^2}\right) \quad (6)$$

The values of effective moisture diffusivity were determined by plotting experimental drying data in terms of *ln (MR)* versus drying time in Eq. (6). The plot produces a straight line with the slope as follows:

$$\text{Slope} = \left(\frac{\pi^2 D_{eff}}{4L^2}\right) \quad (7)$$

Computation of activation energy. Temperature is not a directly measurable quantity in the microwave oven for a drying process. Hence the activation energy can be calculated by the modified form of Arrhenius equation as given by Dadali *et al.* (2007), where it shows the relationship between the effective moisture diffusivity and the microwave power to sample weight instead of temperature. The equation is given as follows:

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

where: D_0 – pre-exponential factor of Arrhenius equation (m^2/s); E_a – activation energy (W/kg); P – microwave power (W); m – sample weight (kg)

Rehydration experiments. Rehydration is a process of refreshing the dried material in water. Three grams of dried sample were placed in glass beakers containing water (at 23°C) at a ratio of 1: 100 (w/w). At specified time such as 5 h, the samples were then removed from glass beakers, blotted with tissue paper to eliminate excess water on the surface, and weighed. The rehydration ratio (*RR*) was calculated using the following formula:

$$RR = \frac{W_2 - W_1}{W_1} \quad (9)$$

where: W_1 – weight of dried matter (kg); W_2 – weight of moisture in the material (kg); all experiments were conducted in duplicates.

Colour determination. The colour of the fresh and dried green bean samples was recorded by tristimulus colorimetry using a Konica Minolta CR 400 (Minolta, Osaka, Japan). The colour brightness coordinate L^* measures the whiteness value of a colour and ranges from black at 0 to white at 100. The chromaticity coordinate a^* measures red when positive and green when negative, and the chromaticity coordinate b^* measures yellow when positive and blue when negative. Five readings were performed for each sample, and the mean values were calculated.

Statistical analysis. The models in Table 1 were evaluated using the nonlinear regression procedure of Statistica v. 8.0 (StatSoft Inc., Tulsa, USA). The statistical parameters used to determine the model that describes in the best way the variation in the moisture ratio values of dried green beans was the coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE). The lower the χ^2 and RMSE values and the higher the R^2 value, the better the goodness of fit (Falade & Ogunwolu 2014; Vega-Gálvez *et al.* 2014). The χ^2 and RMSE were determined as follows:

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Table 1. Models employed for fitting of experimental data

Models	Equation	Reference
Lewis	$MR = \exp(-kt)$	Hossain *et al.* (2007)
Henderson and Pabis	$MR = a\exp(-kt)$	Chinenye *et al.* (2010)
Logarithmic	$MR = a\exp(-kt) + c$	Akpinar & Bicer (2008)
Verma et al.	$MR = a\exp(-kt) + (1 - a)\exp(-gt)$	Verma *et al.* (1985)
Page	$MR = a\exp(-kt^n)$	Aghbashlo *et al.* (2011)
Midilli et al.	$MR = a\exp(-kt^n) + b_1$	Krishna Murthy & Manohar (2012)
Parabolic	$MR = a + bt + ct^2$	Tunde-Akintunde & Ogunlakin (2013).
Wang and Singh	$MR = 1 + bt + ct^2$	Mujić *et al.* (2014)
Weibull	$MR = \exp\left(-\left(\frac{t}{b}\right)^a\right)$	Corzo *et al.* (2008)

$a, b, c, g, k, k_1, k_2, n$ – empirical constants and coefficients in drying models

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{\exp.i} - MR_{\mathrm{pre}.i})^2}{N - z} \quad (10)$$

$$\mathrm{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{\mathrm{pre}.i} - MR_{\exp.i})^2\right]^{1/2} \quad (11)$$

where: $MR_{\exp,i}$, $MR_{\mathrm{pre},i}$ – experimental and predicted dimensionless moisture ratios, respectively; N – number of observations; z – number of constants

One-way analysis of variance (ANOVA) and multiple comparisons (post-hoc *LSD*) were used to evaluate significant differences in the data at $P < 0.05$ of rehydration and colour results.

RESULTS AND DISCUSSION

Drying curves. Drying curves of green beans during drying by various microwave powers are shown in Figure 1. The initial average moisture content of bean slices was 9.89 kg water/kg DM, which was reduced to 0.08 kg water/kg DM after drying. The obtained drying curves seemed similar to those in the studies that involve fruits and vegetables in the literature. It is apparent that the moisture content decreased steadily with drying time and decreased faster at higher microwave power in all cases. The drying times required to reach the final moisture content of samples were 1320, 600, 540, and 480 s at the microwave power of 180, 360, 600, and 800 W, respectively. The average drying rate of samples increased 2.75 times, as the microwave power increased from 180 W to 800 W. As expected at higher microwave power, the higher heat absorption resulted in higher product temperature, higher mass transfer driving force, faster drying rate and consequently shorter drying time. The results were in agreement with the studies of Abano *et al.* (2012) for tomato slices, Karaaslan and Tuncer (2008) for spinach, and Bal *et al.* (2010) for bamboo shoot slices.

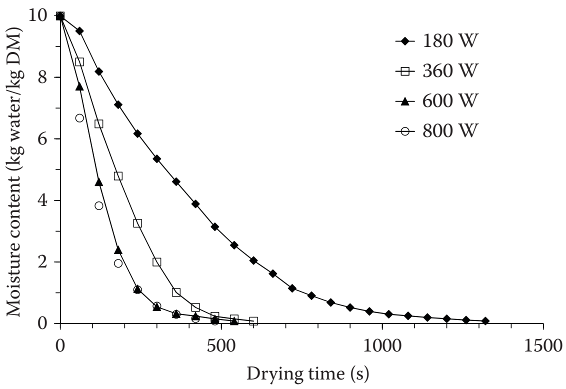

Figure 1. Drying curves of bean slices at different microwave powers

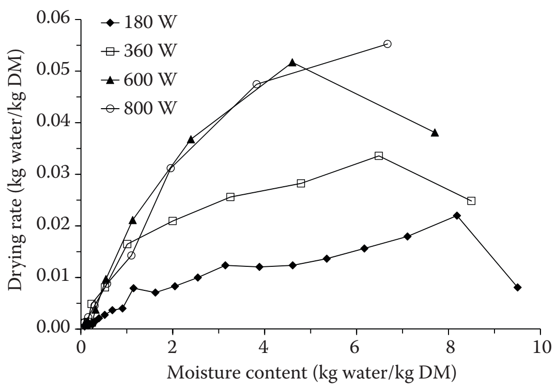

Figure 2. Drying rate curves of green bean slices at different microwave powers

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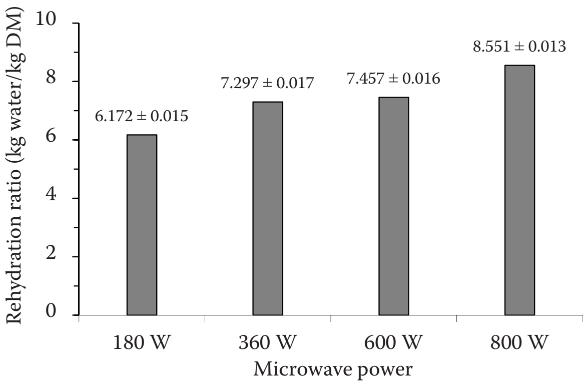

Figure 3. Rehydration ratio values of samples at different microwave powers

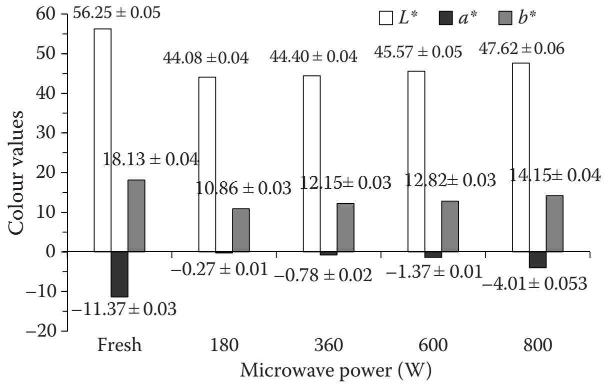

Figure 4. Colour values of samples at different microwave powers

Drying rate. The values of the drying rate of green bean slices were calculated using Eq. (2). Figure 2 depicts the drying rate variation versus the drying time of green bean slices under different microwave power. The constant drying rate period is absent in the microwave drying of bean slices and the drying process took place in the falling rate period. Results of the present study were similar to the previous findings for different foodstuffs (Kayisoglu & Ertekin 2011; Balbay & Sahin 2012; Krishna Murthy & Manohar 2012). From Figure 2, the drying rates increased with the increasing microwave power. This means that the heat and mass transfer at high power is higher and the water loss is rather excessive. During the drying process, drying rates were higher at the beginning of the process, and after that they decreased with a decrease of moisture content in the samples. The reason for a reduction of drying rate might be due to a reduction in the porosity of samples due to shrinkage with advancement, which increased the resistance to water movement leading to a further fall in drying rates (Singh *et al.* 2006; Doymaz *et al.* 2015).

Effective moisture diffusivity. The variation of ln (*MR*) against drying time for bean slices dried at 180, 360, 600, and 800 W is shown in Figure 3. The determined values of the effective moisture diffusivity are shown in Figure 4 and were found to range between 1.387×10^{-8} and 3.724×10^{-8} m^2/s at microwave power of 180–800 W. It can be seen that D_{eff} values increased greatly with increasing microwave power. This can be so because the increase in microwave power caused a rapid rise in the temperature of samples, which in turn increased the vapour pressure. Drying at 800 W has the highest value of effective moisture diffusivity and the lowest value was obtained at 180 W. The calculated effective diffusivity values are within the general range of 10^{-12} to 10^{-8} m^2/s for drying of agricultural products (Zogzas *et al.* 1996). These values are in fact consistent with those in literature, for example 1.26×10^{-9} to 3.32×10^{-9} m/s for hot-air drying of bean slices (Senadeera *et al.*

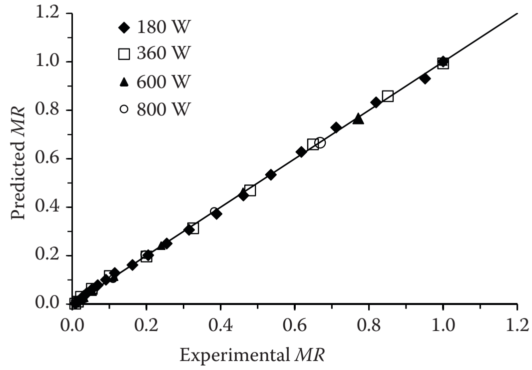

Figure 5. Variation of ln (*MR*) versus drying time for the various microwave powers

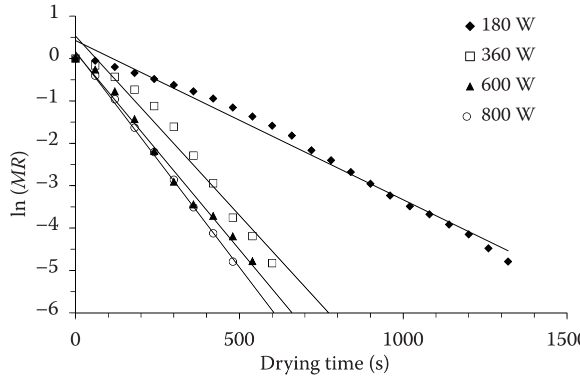

Figure 6. Comparison of experimental and predicted moisture ratio for green bean slices drying using the Midilli et al. model

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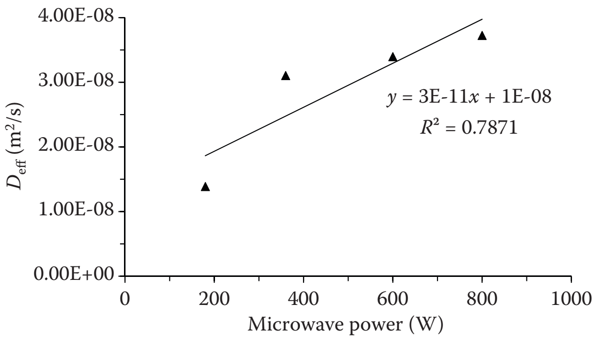

Figure 7. Effective moisture diffusivity versus microwave powers

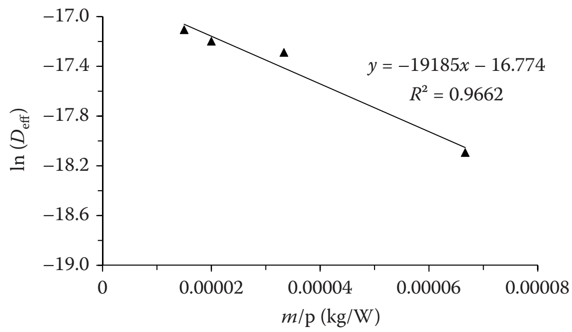

Figure 8. Arrhenius-type relationship between effective moisture diffusivity and microwave powers

2003), 9.3 × 10^{-11} to 1.06 × 10^{-9} m/s for convective drying of Lima bean (Da Silva *et al.* 2009), 0.35 × 10^{-10} to 1.01 × 10^{-10} m/s for hot-air drying of bean slices (Rossello *et al.* 1997), 3.04 × 10^{-9} to 2.64 × 10^{-8} m^2/s for fixed and semi-fluidised drying of faba bean (Chayjan & Shadidi 2014), and 2.8 × 10^{-11} to 8.7 × 10^{-11} m/s for hot-air drying of fresh green bean (Abbasi Souraki & Mowla 2008). The effect of microwave power on effective moisture diffusivity is defined by the following equation:

$$D_{eff} = 3 \times 10^{-11}\,P - 1 \times 10^{-8} \qquad (R^2 = 0.7871) \qquad (12)$$

Activation energy. The activation energy can be determined from the slope of Arrhenius plot, *ln* (D_{eff}) versus *m*/P (Eq. 9). The ln (D_{eff}) as a function of the sample weight/microwave power was plotted in Figure 5. The slope of the line is ($-E_a$) and the intercept equals to ln (D_0). The results show a linear relationship due to Arrhenius type dependence. Eq. (13) shows the effect of sample weight/microwave power on D_{eff} of samples with the following coefficients:

$$D_{eff} = 5.189 \times 10^{-8} \exp\left(-\frac{19185\,m}{P}\right) \qquad (R^2 = 0.9662) \qquad (13)$$

The estimated values of D_0 and E_a from modified Arrhenius type exponential Eq. (13) are 5.189 × 10^{-8} m^2/s and 19.185 kW/kg, respectively.

Rehydration characteristics. One of the quality indicators was the rehydration ability of dried bean slices. The drying process causes some changes in the material structure, and thus influences the renewed absorption of water. Rehydration, as a reverse process to drying, shows the degree of structural damage of the dried material (Kowalski & Szadzińska 2014). The results for the rehydration ratio were calculated from Eq. (9) and plotted against microwave power, as shown in Figure 6. The value of the rehydration ratio was found to increase slightly with an increase in microwave power. The rehydration ratio of samples dried at 800 W was higher than those of samples at the other power settings. It may be due to a short drying time at this power output, which implies that this microwave power causes lower structural damage of the tissue. Thus, the green beans dried at this microwave power retained a higher amount of water than those of dried at the other microwave power settings.

Colour values. Colour change is a quality criterion for assessing the quality of dried products. The results of the colour parameters in fresh beans and obtained from the microwave drying process are presented in Figure 7 for L^*, a^*, and b^*. The chromatic parameters L^*, a^*, and b^* of green beans were L^* 56.250; a^* –11.370; b^* 18.130, respectively. The L^* and b^* values of all dried samples decreased significantly in comparison with the fresh green beans. On the contrary, a^* values increased. The L^* values, which show the lightness of the product, ranged between 56.250 and 44.080. The lowest L^* value was evaluated for a dried product at 180 W because of the Maillard reaction caused by a long drying time. The differences in L^* values between the different settings of drying power were found statistically significant. For microwave drying, the highest $-a^*$ value (less degradation in $-a^*$ value) was observed at 800 W drying. It may be due to a short drying time at this power output, hence the greenness colour of green beans is preserved. The b^* values were found between 18.130 and 14.130 for fresh and dried samples at 800 W, respectively.

Models evaluation and results of statistical analysis. The experimental moisture loss was fitted to nine thin-layer models as shown in Table 1. The best model was selected based on the highest R^2 and the lowest χ^2, and RMSE values. The

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performance of these models is shown in Table 2. The R^2 values ranged from 0.9640 to 0.9998, and χ^2 and RMSE values from 0.000027 to 0.004628 and 0.009083 to 0.213493, respectively. The Midilli et al. model was found to represent the drying kinetics of green bean slices with high R^2 values and low χ^2, and RMSE values for all microwave powers. To validate the selected model, plots of experimental *MR* and predicted *MR* by Midilli et al. model are shown in Figure 8. Obviously, a good agreement was observed between experimental and predicted *MR* values. It means that the data points generally banded around a 45° straight line on the plots. This trend provides extra evidence for the suitability of

Table 2. Statistical results obtained from the selected drying models

Power (W)	Model	R^2	χ^2	RMSE
180	Lewis	0.9755	0.002565	0.213493
	Henderson and Pabis	0.9847	0.001678	0.166435
	Logarithmic	0.9936	0.000740	0.105931
	Verma et al	0.9915	0.000973	0.118646
	Page	0.9989	0.000112	0.038200
	Midilli et al.	0.9990	0.000111	0.038064
	Parabolic	0.9974	0.000293	0.061815
	Wang and Singh	0.9970	0.000323	0.059650
	Weibull	0.9989	0.000112	0.038200
360	Lewis	0.9640	0.004628	0.189898
	Henderson and Pabis	0.9717	0.004044	0.180163
	Logarithmic	0.9893	0.001719	0.106788
	Verma et al	0.9883	0.001869	0.103635
	Page	0.9989	0.000148	0.031874
	Midilli et al	0.9992	0.000141	0.029545
	Parabolic	0.9973	0.000432	0.047971
	Wang and Singh	0.9957	0.000607	0.054961
	Weibull	0.9989	0.000149	0.031874
600	Lewis	0.9754	0.003113	0.126612
	Henderson and Pabis	0.9792	0.002959	0.127468
	Logarithmic	0.9840	0.002277	0.115858
	Verma et al	0.9842	0.002254	0.104087
	Page	0.9987	0.000177	0.031869
	Midilli et al	0.9998	0.000031	0.011365
	Parabolic	0.9853	0.002387	0.114050
	Wang and Singh	0.9853	0.002094	0.113004
	Weibull	0.9991	0.000108	0.024968
800	Lewis	0.9930	0.00732	0.066980
	Henderson and Pabis	0.9939	0.000957	0.065414
	Logarithmic	0.9960	0.000643	0.051382
	Verma et al	0.9966	0.000543	0.041514
	Page	0.9997	0.000033	0.012332
	Midilli et al	0.9998	0.000027	0.009083
	Parabolic	0.9864	0.002196	0.100856
	Wang and Singh	0.9839	0.002229	0.108082
	Weibull	0.9997	0.000032	0.012332

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Table 3. Rehydration ratio (*RR*) and statistical analysis conducted by one-way ANOVA

Power (W)	Mean	Std. error	–95.00%	+95.00%
180	6.172	0.018	6.124	6.221
360	7.297	0.018	7.249	7.346
600	7.457	0.018	7.409	7.506
800	8.551	0.018	8.503	8.600

Table 4. Statistical analysis conducted by one-way ANOVA

Power (W)	Mean	Std. error	–95.00%	+95.00%
L*				
Fresh	56.250	0.049	56.125	56.375
180	44.080	0.049	43.955	44.205
360	44.400	0.049	44.275	44.525
600	45.570	0.049	45.445	45.695
800	47.620	0.049	47.495	47.745
a*				
Fresh	–11.370	0.022	–11.426	–11.314
180	–0.266	0.022	–0.322	–0.210
360	–0.780	0.022	–0.836	–0.724
600	–1.370	0.022	–1.426	–1.314
800	–4.010	0.022	–4.066	–3.954
b*				
Fresh	18.130	0.034	18.042	18.218
180	10.860	0.034	10.772	10.948
360	12.150	0.034	12.062	12.238
600	12.820	0.034	12.732	12.908
800	14.150	0.034	14.062	14.238

the model to forecast the drying characteristics of green bean slices (Doymaz *et al.* 2015).

The rehydration ratio and the results of colour statistical analysis conducted by one-way ANOVA are shown in Table 3 and 4, respectively.

CONCLUSIONS

In this study, the drying characteristics of green beans were investigated in a microwave oven at different microwave powers. The drying process took place in the falling-rate period. The drying time decreased with an increase in the microwave power. The Midilli et al. model gave the best results and showed good agreement with experimental data obtained from the experiments. The effective moisture diffusivity varied between 1.387×10^{-8} and 3.724×10^{-8} m^2/s over the microwave power range. Activation energy was found to be 19.185 kW/kg. It was observed that an increase in the microwave power increased the brightness and yellowness of the dried samples. The greenness of the samples dried at various microwave power settings decreased with increasing the microwave power.

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