DRYING KINETICS AND CHANGES IN COLOR PARAMETERS WHEN DRYING GREEN PEA (*Pisum Sativum l.*) IN MICROWAVE

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***Abstract*— This research was conducted to determine the drying kinetics and color parameters changes of green peas when microwave drying at different microwave powers. For drying, 6 drying kinetics models were applied. The values of L*, a*, b*, C* and H^o were measured to determine the effect of the microwave drying on the color parameters. The most suitable model was the parabolic model in microwave drying of green peas. Effective diffusion coefficients changed between 2.50x10^{-9} m^{2}s^{-1} and 8.16x10^{-9} m^{2}s^{-1}. The activation energy was found as 1279.7 W/g. L*, a* and b* color parameters were significantly influenced by microwave drying, while C* and H^o values were not the much affected.**

***Keywords*–Activation energy, drying models, drying rate, effective diffusion, microwave drying, rehydration**

I. INTRODUCTION

Agricultural crops continue their respiratory activities after they are harvested. For this reason, they are quickly spoiled and cannot be stored for a long time. There are many ways in which products can be stored for a long time after they have been harvested. One of these methods is the drying of the products. Drying can be defined as a process of moisture removal of products by heat and mass transfer. It is also a classical method of food preservation, which provides longer shelf-life, lighter weight for transportation and smaller space for storage (Ertekin and Yaldız, 2004). Drying method has been applied with the help of solar energy since the first ages. However, this method is not preferred widely today due to the fact that the products are exposed to dust, insects, and microorganisms, as well as the drying time, is long (Alibas *et al.*, 2007). Many drying methods such as hot air drying, vacuum drying, freeze drying are used for drying products. These methods have positive or negative aspects compared to each other. The drying method chosen should preserve as much as possible the biological qualities of the product after drying (Motevali *et al.*, 2011). Especially in hot air drying method, the loss of nutritional value of the product and energy consumption is high. The microwave drying method, which has been used in recent years, is a less costly method than other methods (Changrue and Raghavan, 2006). In this method, the dipole heating causes the water to move towards the surface of the product and to evaporate. In the microwave drying method, a higher drying rate is achieved (Sharma and Prasad, 2004; Li *et al.*, 2010). For whatever drying method is applied, mathematical models that define the drying mechanism need to be used for designing the proper dryer and for optimizing the drying process. With these mathematical models alternative drying methods can be developed.

Color properties are as important as quality attributes for dried products and should be as similar as possible to the color properties of fresh food to increase acceptability. Color changes during drying process have great importance from economic viewpoint (Moreira *et al.*, 2008).

The green pea (*Pisum sativum l.*) used as material in this research is one of the important plants of the leguminous family and has an important place in human nutrition. Green peas are a protein-rich and valuable plant and consumed fresh, canned and dried as well. In addition to its 25% protein, it is also rich in A, B and D vitamins (Alan and Nevzat, 1984). The moisture content (db) of fresh peas varies between 2.3 and 4.0 and therefore it is difficult to store them for a long time. In recent years, the consumption of dried green peas has become more common (Pardeshi *et al.*, 2009).

High microwave powers were used in previous studies on microwave drying of peas (Heybeli *et al.*, 2013, at 500-750 W; Doymaz *et al.*, 2015 at 180-800 W; Chahbani *et al.*, 2018, at 300-450 W). In this research, lower output powers were used to see the difference in product drying times and color properties than previous studies. Green peas were dried at three different power outputs (90 W, 180 W and 360 W) in microwave and the optimal kinetic model for drying was investigated. The change in the color parameters of the green pea after the drying process was also investigated.

II. METHODS

A. Plant material

Green peas used in drying experiments have been taken from the market from local producers and separated from their shells. Green pea samples were stored in the refrigerator (+4 °C) until used in drying experiments (Kocayigit, 2010).

B. Microwave drying process

The initial moisture content of the green pea samples to be dried was determined with AOAC (1990) method as average 3.098 kg-water/kg-dry matter. During the preliminary drying tests, drying times extended at microwave powers below 90 W, and it was difficult to remove the moisture in the inner parts of the product.

Table 1. Kinetic Models applied for fitting of experimental drying data

Model Name	Equation	References
(1) Newton	$MR = exp(-kt)$	Ayensu,1997; Tiris *et al.*, 1994
(2) Page	$MR = exp(-kt^n)$	Park *et al.*, 2002; Sun and Woods, 1994
(3) Henderson&Pabis	$MR = a\ exp(-kt)$	Chhinnan, 1984; Rahman *et al.*, 1997
(4) Logarithmic	$MR = a\ exp(-kt) + c$	Doymaz, 2004; Lahsasni *et al.*, 2004
(5) Midilli	$MR = a\ exp(-kt^n) + bt$	Midilli *et al.*, 2002; Ertekin and Yaldiz, 2004
(6) Wangh and Singh	$MR = 1 + at + bt^2$	Wang and Singh, 1978
(7) Parabolic	$MR = a + bt + ct^2$	Chabbani *et al.*, 2018

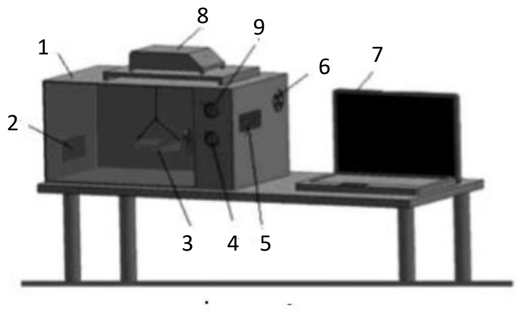

Figure 1. Microwave dryer (1:Microwave oven 2: Ventilation hole 3: Tray 4: Timer 5: Magnetron 6: Fan 7: Computer 8: Power switch 9: Scale

Above 360 W microwave powers, it was observed that physical distortions occurred on the surface of the product. For this reason, drying experiments were carried out at 90 W, 180 W and 360 W powers**.** Microwave drying applications were performed using a microwave oven (with Beko brand, 2450 MHz frequency, maximum 800 W power and 19 lt inner space), as seen in Fig. 1. Electronic balance (AND brand) was used to measure the weight losses during microwave drying, continuously using interface programs, such as hot air dryer (Celen *et al*., 2016).

The pea samples of 100 g each drying experiment have been dried in a pan attached with a rope to the digital precision scale on the microwave oven which sent the measurement data to the computer in order to be recorded in an excel file with 10 s intervals. The drying process has been continued until the green pea samples reached 29-30% of their initial mass (Sahin *et al*., 2018).

C. Drying kinetics modelling

There are many models related to drying kinetics in the literature. These models are semi-theoretical, theoretical and empirical models. Kinetic models used in this study are given in Table 1. The dimensionless moisture ratio (MR) used in these models is given in the following equation (Chahbani *et al*., 2018):

$$MR = \frac{X_t - X_{eq}}{X_0 - X_{eq}} \tag{1}$$

where: X_t-moisture content of the sample at any time; X_{eq}-equilibrium moisture content; X_0-Initial moisture content (kg-water/kg-dry matter) of the sample.

Since the X_{eq} value is quite small compared to the value X_t, the Eq. 1 can be written as (Doymaz *et al.*, 2015; Midilli and Kucuk, 2003):

$$MR = \frac{X_t}{X_0} \tag{2}$$

Drying rate was calculated as follow (Alibas, 2012):

$$DR = \frac{X_t - X_{t+dt}}{dt} \tag{3}$$

where: DR- Drying rate (kg-water/kg-dry matter.s); X_{t+dt}- moisture content at $t + dt$ (kg-water/kg-dry matter); t- time (s).

The non-linear regression procedure is used in order to estimate the empirical coefficients of these models. The determination coefficient (R^2), the root mean square error (RMSE) and the reduced chi-square (χ^2) values were used to understand the fit of the experimental data with the models (Diamente and Munro, 1991; Yaldiz *et al.*, 2001). The model with the lowest values of χ^2 and RMSE of the drying models and the highest value of R^2 was selected as the most suitable model (Ertekin and Menges, 2006).

D. Determination of effective moisture diffusivity and activation energy.

The theoretical model, which has found extensive research in thin-layer drying of various foods, is the solution to Fick's second law (Hutchinson and Otten, 1983; Madhiyanon *et al.*, 2009):

$$\frac{\partial X}{\partial t} = \nabla.\left(D_{eff}.\nabla X\right) \tag{4}$$

Equation 4 can be solved by taking the diffusion coefficient constant and simplifying with appropriate boundary conditions and the following equation can be written for spherical coordinates:

$$MR = \frac{X_t - X_e}{X_0 - X_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}exp\left(-\frac{\pi^2 n^2 D_{eff} t}{r^2}\right) \tag{5}$$

For long drying times the first terms of Eq. 5 are used for solution (Madamba, 2003):

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

where: D_{eff}- effective diffusion coefficient ($m^2.s^{-1}$); r- average radius of sample (m); t- time (s).

Effective diffusivity values were calculated by the slope of the graph of experimental ln (MR) values as a function of drying times:

$$Slope = \frac{\pi^2 D_{eff}}{r^2} \tag{7}$$

The modified Arrhenius equation has been utilized to determine the activation energy (Fu *et al.*, 2017):

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

where: D_o- pre-exponential factor of Arrhenius equation (m^2.s^{-1}); E_a- Activation energy (W.g^{-1}); m- Average mass of sample (g); P- Microwave output power (W).

The slope of the graph of lnD_{eff} versus m/P is the activation energy.

E. Determination of color parameters of dried products

L^*, a^*, b^*, C^* and H^0 indicate brightness, redness-greenness, yellowness-blueness, color intensity (Chroma), hue angle, respectively. Negative a^* indicates green, and higher positive a^* indicates red color. Higher positive b^* indicates more yellow color.

The Chroma (C^*) value indicates the color intensity or saturation, which is calculated as below:

$$C^* = (a^{*2} + b^{*2})^{0.5} \quad (9)$$

Hue angle (H^o) indicates sample color when a^* 0 and b^*> 0, which is calculated as below:

$$H^o = \tan^{-1}(a^*/b^*) \quad (10)$$

If a^*<0 and b^*>0, Hue angle (H^o) calculated as below:

$$H^o = \tan^{-1}(a^*/b^*) + 180^o \quad (11)$$

For each application, on surfaces of ten randomly selected green pea samples were measured color parameters (L^*, a^*, b^*, C^* and H^o) at three different points in order to compare before and after drying (Chabbani *et al*., 2018; Alibas, 2007).

Color measurements were made with the Minolta CR 400 color meter. This instrument uses a spectral response for a CIE 1931 2^o observer and illuminant C (Konica Minolta, 2002).

III. RESULTS

A. Drying kinetics models

The decreasing in moisture content of the green pea at 90 W, 180 W and 360 W microwave power outputs are shown Fig. 2. As seen from Fig.2, at 360 W microwave power, the product lost moisture in a shorter time. In the initial stages of drying at 90 W and 180 W microwave powers, the reduction in moisture content was close to each other. The drying time required for drying has been 63, 50 and 19 min at 90, 180 and 360 W microwave power, respectively. Heybeli *et al*. (2013) stated that drying time changed between 10 and 13 minutes at 500-750 W microwave powers. The drying time at 360 W were close these values. As the microwave power increases, the drying time decreases rapidly, but its effects on the quality of the product need to be investigated. Similar results were found for green peas (Chahbani *et al.*, 2018), green beans (Doymaz *et al.*, 2015), carrots (Fu *et al.*, 2017).

Drying rates (DR) at different microwave rates were given in Fig. 3. At the 360 W microwave power, drying rate is considerably higher than others. One reason why the drying time and drying rate in 360 W microwave power are different from the others is the difference in power. Since the difference between 90 W and 180 W powers is less, the drying time and drying rate are closer to each other at these powers.

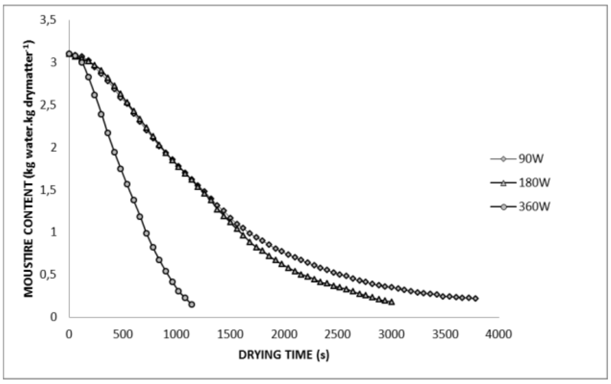

Figure 2. Changes of experimental moisture content versus Drying Time

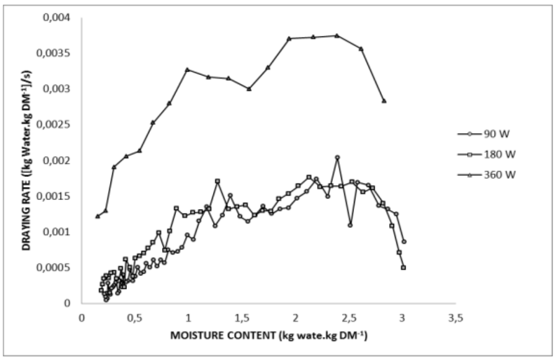

Figure 3. The graph of experimental moisture content versus Drying Rate

Statistical results calculated from selected 7 drying models are shown Table 2. The lowest RMSE and highest R^2 values were found in the Parabolic Model (7). While RMSE was changed between 0.0399 and 0.0974 for all examined models, this value changed between 0.0158 and 0.0271 for Parabolic Model at 3 different microwave powers. The closest values to this model are found in Logarithmic Model (4). Both models can be used to describe the drying kinetics of the green pea, but the Parabolic model was preferred in this study. This model represented the experimental values satisfactorily. Chahbani *et al.* (2018) also reported that parabolic model is the most suitable model for microwave drying pea. The drying constants a, b, and c of the parabolic model are given in Table 3. At 360 W microwave power the coefficients b and c are quite large compared to others. This is due to the high drying rate at this microwave power.

The predicted moisture with the parabolic model and experimental moisture changes are given in Fig. 4 as a function of time.

B. Effective moisture diffusivity and activation energy.

Effective diffusion coefficients at 90 W, 180 W and 360 W microwave output power are shown in Table 4. The effective diffusion coefficient (*D_{eff}*) increased as microwave power increased. This is an expected situation according to Eq. 8. Fu *et al.* (2017) and Chahbani *et al.* (2018) in their research about microwave drying also

Table 2. Statistical results calculated from selected drying models

Model No	P (W)	RMSE	χ^2	R^2
	90	0.0494	2.480x10^{-3}	0.973
1	180	0.0740	5.588x10^{-3}	0.944
	360	0.0974	9.992x10^{-3}	0.910
	90	0.0393	1.598x10^{-3}	0.983
2	180	0.0535	2.974x10^{-3}	0.971
	360	0.0634	4.465x10^{-3}	0.962
	90	0.0296	9.020x10^{-4}	0.990
3	180	0.0505	2.659x10^{-3}	0.974
	360	0.0753	6.302x10^{-3}	0.946
	90	0.0249	6.488x10^{-4}	0.993
4	180	0.0313	1.044x10^{-3}	0.990
	360	0.0307	1.107x10^{-3}	0.991
	90	0.0276	8.153x10^{-4}	0.992
5	180	0.0333	1.203x10^{-3}	0.989
	360	0.0318	1.263x10^{-3}	0.990
	90	0.0277	7.930x10^{-4}	0.991
6	180	**0.0399**	1.653x10^{-3}	0.984
	360	0.0388	1.672x10^{-3}	0.986
	90	0.0158	2,648x10^{-4}	0.997
7	180	0.0241	6.149x10^{-4}	0.994
	360	0.0271	8.626x10^{-4}	0.993

Table 3. Drying constants of the Parabolic Model

P (W)	a	b	c
90	1.0661	-5.70x10^{-4}	8.27x10^{-8}
180	1.0917	-6.15x10^{-4}	8.95x10^{-8}
360	1.0757	-1.17x10^{-3}	2.06x10^{-7}

Table 4. Effective diffusion coefficients

P (W)	D_{eff} (m^2.s^{-1})	Slope (x10^{-4})	R^2
90	2.50x10^{-9}	7.726	0.997
180	3.15x10^{-9}	9.725	0.983
360	8.16x10^{-9}	25.22	0.927

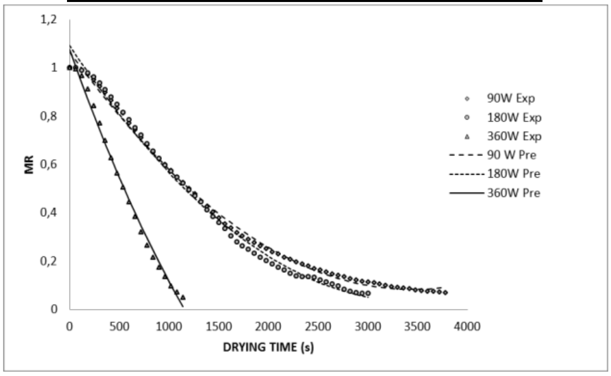

Figure 4. Time-dependent variation of estimated and experimental moisture rates in the parabolic model.

stated that D_{eff} increased when microwave output power increase.

The pre-exponential factor (D_o) and the activation energy (E_a) were calculated by slope the Arrhenius plot of lnD_{eff} as a function of the sample mass/microwave power. These values were 9.218x10^{-9} m^2.s^{-1} and 1279.7 W.g^{-1} respectively. It is possible to express the effective diffusion coefficient as a function of m/P in the following equation:

$$D_{eff} = 9.218x10^{-9}exp\left(1297.7\frac{m}{P}\right) \qquad (12)$$

Chabbani *et al.* (2018) were found these values 4.32x10^{-9} m^2.s^{-1} and 1380.0 W.g^{-1} at 100-300 W microwave power for green pea, respectively. Doymaz et al. (2015) found these values as 5.189x10^{-8} m^2.s^{-1} and 19185 W.g^{-1}, respectively, in a study of drying the green bean in microwave. It is seen that the activation energy is higher in the green bean than in the green pea.

C. Changes in color parameters

Color parameters of dried green peas have been given with the Duncan's multiple range tests (P<0.05) in Table 5. Brightness (L^*) of samples were significantly different in all microwave output powers than fresh product and decreased significantly after drying. However, there was no significant difference in Brightness (L^*) between microwave output powers. Heybeli *et al.* (2013) stated that the Lightness values of the pea samples (L^*) were not affected by microwave power. Kocyigit (2010) stated that there was a decrease in the (L^*) value of green pea samples that were dried at different temperatures according to the fresh green pea. In dried products, there was a color change from green to yellow. After drying, a^* values were significantly different from fresh green peas in all power outputs. At 90 W and 360 W power outputs, b^* values were different from b^* values of fresh peas. At 180 W output power, b^* value was in the same group with fresh peas (Table 5). Heybeli *et al.* (2013) found that the effect of microwave power on the a^* value which gives the green ratio was statistically significant (P<0.05). Chahbani *et al.* (2018) and Alibas (2012) also stated that the values of a^* and b^* decrease as microwave output increases. High contents of sugars, proteins, and chlorophyll in green peas caused color changes of them after drying in the microwave (Zielinska *et al.*, 2013; Dadali, 2007). In Chroma (C^*) parameters, fresh green pea, 90 W and 360 W microwave output powers were in the same group statistically. These parameters did not change significantly after drying except 180 W microwave output power (Table 5). Heybeli *et al.* (2013) also found that the dried peas were close to fresh pea samples without any change in the Chroma. As seen in Table 5, Hue angles (H^o) were significantly different in all microwave powers and decreased after drying.

Table 5. Color parameters of fresh and dried green peas

	L*	a*	b*	C*	H^o
Fresh	55,79$^{\mathbf{b}}$±0,98	-17,59$^{\mathbf{a}}$±0,32	42,18$^{\mathbf{a}}$±0,87	49,68$^{\mathbf{b}}$±0,92	110,8$^{\mathbf{b}}$±0,48
90W	42,80$^{\mathbf{a}}$±1,44	-12,44$^{\mathbf{b}}$±0,56	48,85$^{\mathbf{b}}$±2,71	50,43$^{\mathbf{b}}$±2,72	104,5$^{\mathbf{a}}$±0,85
180W	43,53$^{\mathbf{a}}$±0,75	-10,87$^{\mathbf{c}}$±0,60	41,76$^{\mathbf{a}}$±1,64	43,56$^{\mathbf{a}}$±1,70	105,1$^{\mathbf{a}}$±0,41
360W	42,78$^{\mathbf{a}}$±1,04	-13,72$^{\mathbf{b}}$±0,49	50,72$^{\mathbf{b}}$±2,43	52,54$^{\mathbf{b}}$±2,45	105,2$^{\mathbf{a}}$±0,48

IV. CONCLUSIONS

In this study, peas were dried at 3 different microwave power (90 W, 180 W and 360 W) without any pretreatment. The drying time at 360 W microwave power was less than the other two microwave power. The drying rate increased (DR) with microwave power, but was higher than the others at 360 W power. The Parabolic Model has been the most suitable model between applied drying models for drying green peas with microwave. Effective diffusion coefficients were also affected by the microwave power and increased with increasing microwave power. The color parameters Brightness (L^*), redness-greenness (a^*) and Hue angle (H^o) were influenced by the microwave output power and were different significantly from the fresh product at all microwave power outputs. As a result of the drying process, while the L^* and H^o values decreased, a^* value increased. The yellowness-blueness (b^*) at 90 W and 360 W increased significantly after drying. The Chroma (C^*) of the dried samples and fresh green peas showed no statistical difference among them, except for the 180 W sample. In this study, instead of high microwave output powers as in previous studies, it can be suggested to use 360W microwave output power, which is closer to drying time and rate at high microwave powers.

REFERENCES

Alan, M. and Nevzat A. (1984) *Bezelye El Kitabı*. Ege Bölge Zirai Araştırma Enstitüsü Yayınları No: 37, Menemen –İzmir.

Alibas, I. (2007) "Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying," *Biosystems Engineering*, **96**, 495-502.

Alibas, I., Akbudak B. and Akbudak N. (2007) "Microwave drying characteristics of spinach," *Journal of Food Engineering*, **78**, 577-583.

Alibas, I. (2012) "Microwave Drying of Grapevine (Vitis vinifera L.) Leaves and Determination of Some Quality Parameters," *Journal of Agricultural Sciences*, **18**, 43-53.

AOAC (1990) *Official Methods of Analysis*, 15th Edition, Association of Official Analytical Chemists, Washington DC.

Ayensu, A. (1997) "Dehydration of food crops using a solar dryer with convective heat flow," *Solar Energy*, **59**, 121–126.

Celen, S., Aktas T., Karabeyoglu S.S. and Akyildiz A. (2016) "Drying behavior of prina (crude olive cake) using different type of dryers," *Drying Technology*, **34**, 843-853.

Chahbani, A., Fakhfakh N., Balti M.A., Mabrouk M., El-Hatmi H., Zouari N. and Kechaou N. (2018) "Microwave drying effects on drying kinetics, bioactive compounds and antioxidant activity of green peas (Pisum sativum L.)," *Food Bioscience*, **25**, 32–38.

Changrue, V. and Raghavan V.G.S. (2006) "Microwave drying of fruits and vegetables," *Stewart Postharvest Review*, **2**, 1–7.

Chhinnan, M.S. (1984) "Evaluation of selected mathematical models for describing thin-layer drying of in-shell pecans," *Transactions of the ASAE*, **27**, 610–615.

Dadali, G. (2007) *Drying of okra and spinach using microwave technique, investigation and modeling of tissue and color Properties*, Master Thesis, Department of Chemical Engineering, Graduate School of Natural and Applied Sciences, Yildiz Technical University.

Diamente, L.M. and Mnro P.A. (1991) "Mathematical modeling of hot air drying of sweet potato slices," *International Journal of Food Science and Technology*, **26**, 99-105.

Doymaz, I. (2004) "Effect of drying treatment on air drying of plums," *Journal of Food Engin*eering, **64**, 465–470.

Doymaz, I., Kipcak A.S. and Piskin S. (2015) "Microwave drying of green bean slices: Drying kinetics and physical quality," *Czech Journal of Food Sciences*, **33**, 367–376.

Ertekin, C. and Menges H.O. (2006) "Mathematical modeling of thin layer drying of Golden apples," *Journal of Food Engineering*, **77**, 119–125.

Ertekin, C. and Yaldız O. (2004) "Drying of Eggplant and Selection of a Suitable Thin Layer Drying Model," *Journal of Food Engineering*, **63**, 349–359.

Fu, B.A., Chen M.Q. and Song J.J. (2017) "Investigation on the microwave drying kinetics and pumping phenomenon of lignite spheres," *Applied Thermal Engineering*, **124**, 371–380.

Heybeli, N., Ertekin C. and Dikici G. (2013) "Drying of Peas with a Heated Air Supported Microwave Dryer," *28th National Agricultural Mechanization Congress*, 4-6 September, KONYA, 262-268.

Hutchinson, D. and Otten L. (1983) "Thin Layer Air Drying of Soybeans and White Beans," *Journal of Food Technology*, **18**, 507-522.

Kocayigit, F. (2010) *Investigation of drying characteristics of some vegetables,* Master Thesis, Department of Chemical Engineering Graduate School of Natural and Applied Sciences, Yildiz Technical University.

Konica Minolta. (2002) *Chroma Meter Konica Minolta Cr-400/410*, Instruction Manual. 160. Retrieved fromhttp://sensing.konicaminolta.com.mx/products /cr-410-chroma-meter-difference-with colorimeter/support/cr-400-410_instruction_eng.pdf

Lahsasni, S., Kouhila M., Mahrouz M. and Jaouhari J.T. (2004) "Drying kinetics of prickly pear fruit (Opuntica ficus indica)," *Journal of Food Engineering*, **61**,173–179.

Li, Z., Raghavan G.S.V. and Orsat V. (2010) "Optimal power control strategies in microwave drying," *Journal of Food Engineering*, **99**, 263–268.

Madamba, P.S. (2003) "Thin Layer Drying Models for Osmotically Pre-dried Young Coconut," *Drying Technology*, **9**, 1759-1780.

Madhiyanon, T., Phila A. and Soponronnarit S. (2009) "Models of Fluidized Bed Drying for Thin-Layer Chopped Coconut," *Applied Thermal Engineering*, **29**, 2849-2854.

Midilli, A. and Kucuk H. (2003) "Mathematical modeling of thin layer drying of pistachio by using solar energy," *Energy Conversion and Management*, **44**, 1111–1122.

Midilli, A., Kucuk H. and Yapar Z. (2002) "A new model for single layer drying," *Drying Technology*, **20**, 1503–1513

Moreira, R., Chenlo F., Chaguri L. and Fernandes C. (2008) "Water absorption, texture, and color kinetics of air-dried chestnuts during rehydration," *Journal of Food Engineering*, **86**, 584-594.

Motevali, A., Minaei S. and Khoshtagaza M.H. (2011) "Evaluation of energy consumption in different drying methods," *Energy Conversion and Management*, **52**, 1192–1199.

Pardeshi, I.L., Arora S. and Borker P.A. (2009) "Thin-Layer Drying of Green Peas and Selection of a Suitable Thin-Layer Drying Model," *Drying Technology*, **27**, 288-295.

Park, K.S., Vohnikova Z. and Brod F.P.R. (2002) "Evaluation of drying parameters and desorption isotherms of garden mint leaves (Mentha crispa L.)," *Journal of Food Engineering*, **51**, 193–199.

Rahman, M.S., Perera C.O. and Thebaud C. (1997) "Desorption isotherm and heat pump drying kinetics of peas," *Food Research International*, **30**, 485–491.

Sahin, F.H., Acikgoz F.E., Deveci M., Ellialtioglu S.S. and Aktas, T. (2018) "Effects of hot air and microwave drying techniques on drying characteristics and some quality parameters of *Tropaeolum Majus* L.," *Advances in Food Sciences*, **40**, 101-110.

Sharma, G. and Prasad S. (2004) "Effective moisture diffusivity of garlic gloves undergoing microwave convective drying," *Journal of Food Engineering*, **65**, 609-617.

Sun, D.W. and Woods J.L. (1994) "Low temperature moisture transfer characteristics of wheat in thin layers," *Transactions of the ASAE*, **37**, 1919–1926.

Tiris, C., Ozbalta N., Tiris M. and Dincer I. (1994) "Experimental testing of a new solar dryer," *International Journal of Energy Research*, **18**, 483–490.

Wang, C.Y. and Singh, R.P. (1978) "A single layer drying equation for rough rice," *ASAE Paper No: 78-3001, ASAE*, St. Joseph, MI.

Yaldiz, O., Ertekin C. and Uzun H.I. (2001) "Mathematical modeling of thin layer solar drying of Sultana grapes," *Energy*, **26**, 457–465.

Zielinska, M., Zapotoczny P., Alves-Filho O., Eikevik T.M. and Blaszczak W. (2013) "A multi-stage combined heat pump and microwave vacuum drying of green peas," *Journal of Food Engineering*. **115**, 347–356.

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