Microwave Drying Behaviour of Tomato Slices

Soner ÇELEN[1] and Kamil KAHVECI[2]

[1]Mechanical Engineering Department, Namık Kemal University, Çorlu/Tekirdağ, Turkey;
[2]Mechanical Engineering Department, Trakya University, Edirne, Turkey

Abstract

Çelen S., Kahveci K. (2013): **Microwave drying behaviour of tomato slices**. Czech J. Food Sci., **31**: 132–138.

The microwave drying behaviour of tomato slices was investigated experimentally to determine the effects of microwave power on the drying rate, energy consumption, and dried product quality in terms of colour, and a theoretical model was proposed to define the drying curves of tomato slices. The experiments performed with the microwave power of 90, 180, 360, and 600 W indicate that the drying time and the energy consumption decreased considerably with an increase in microwave power. The experiments also revealed that the drying rate shows first an increase and then a decrease during drying, and that the colour quality of the product deteriorates significantly with the increase of the microwave power. A theoretical model was developed using the solution of energy equation considering the microwave power as an internal heat source. The electric field strength inside the material was assumed to be dependent on the moisture content and the constants emerging from this assumption were obtained by minimising the sum of squared differences between the theoretical results and experimental data obtained for various drying conditions. The results show that the values proposed for the constants provide a good agreement between the theoretical and experimental drying behaviour.

Keywords: drying rate; diffusion; moisture content; colour analysis

Tomato is a popular food for its culinary properties and their health benefits. It is a natural source of lycopene, a carotenoid that reduces the risk of cancer and coronary heart disease (Brooks *et al*. 2008). It is also the most commercially produced vegetable in the world. Major producers are China, the United States of America, India, Egypt, Turkey, and Italy and the yearly production was estimated as 145 751 507 Mt in 2010 (FAO 2012). Much of the total tomato production is consumed fresh or used to produce tomato paste. A certain percentage is dried to reduce the moisture content to a level that allows the product to be stored safely for an extended period of time. Drying also reduces the weight and volume of the product, thereby reducing packing, storage, and transportation costs. Dried tomato is generally used for making pizza and various culinary dishes (Brooks *et al*. 2008).

Until recently, one of the most commonly used drying techniques was the convective hot air drying. However, in this drying technique, food materials are exposed to elevated temperatures, which leads to an increase in shrinkage and toughness, reduction of both the bulk density and rehydration capacity of the dried product, and it also causes serious damage to flavour, colour, and nutrient content (Maskan 2000). The other major disadvantages of convective hot air drying method are the increased drying time and higher energy consumption due to the higher drying temperature. The desire to reduce the above problems led to the use of microwave and dielectric heating methods for food drying (Bondaruk *et al.* 2007). Microwave energy is rapidly absorbed by water molecules which, consequently, results in rapid evaporation of water and thus higher drying rates, therefore microwave drying offers significant energy savings, with a potential reduction in drying times in

Support by the Trakya University Research Fund, Grant No. 901/2011.

addition to the inhibition of the surface temperature of the treated material (McLoughlin *et al.* 2003).

Many studies have been done on microwave drying or microwave assisted drying for a great variety of food products. The references and the subjects for some of these studies are: Al-Duri and McIntyre (1992) – skimmed milk, whole milk, casein powders, butter and fresh pasta drying, Soysal (2004) – parsley drying, Soysal (2005) and Ozbek and Dadali (2007) – mint drying, Erdem (2006) – red pepper drying, Sarimeseli (2011) – coriander leaves drying, Tulasidas (1997) and Kassem *et al.* (2011) – grape drying, Liamkaew *et al.* (2008) and Alibas (2007a) – pumpkin drying, Workneh *et al.* (2011) – tomato drying, Miller and Braddock (1982) – citrus peel drying, Evin (2011) – roseships drying, Dadali and Ozbek (2008) – leek drying, Ozkan *et al.* (2007) – spinach drying, Dadali *et al.* (2007) – okra drying, Işık *et al.* (2011) – lentil drying, Albanese *et al.* (2006) – potatoes drying, Inchuen *et al.* (2008) – thai red curry paste drying, and ElHana (2008) and Wang *et al.* (2007) – apple drying.

In most of the aforementioned studies, empirical or semi-empirical models were used to simulate drying. However, more realistic models are needed for a better understanding of the physical phenomena behind the microwave drying and for an appropriate simulation of drying. In this study, microwave drying behaviour of tomato slices was investigated experimentally for various values of the microwave power and a theoretical drying model was proposed for the simulation of drying. Furthermore, colour analysis was conducted to investigate the effects of microwave drying on the product quality in terms of colour.

MATERIAL AND METHODS

The tomato cultivar Rio de Grande, which is used in the production of tomato paste, was used to specify the microwave drying behaviour. Tomatoes obtained from a local supplier (Tekirdağ/Turkey) were at harvest maturity. The experiments were carried out in a microwave oven (Arçelik MD 554; Arçelik A.Ş, İstanbul, Turkey) of 2450 MHz frequency, 800 W capacity, and 19 l inner volume. The weight of the tomato slices during the drying process was specified with a digital scale (Presica XB 620 M; Precisa Instruments AG, Dietikon, Switzerland) of ± 0.001 g precision and a capacity of 620 g. The energy consumption during drying was measured by an energy meter (Enda, Turkey). The colour analysis of the product was conducted by a Hunter Lab D25LT (Hunter Associates Laboratory, Inc., Virginia, USA) colorimeter.

The mean diameter and weight of the tomatoes used in the experiments were 6 ± 0.3 cm and 50 ± 1 g, respectively. The moisture content of the tomatoes with respect to the wet basis was 96%. In order to specify the moisture content, the tomatoes were initially dried in an oven at 105°C for 24 h and the dry mass was measured. Prior to the drying experiment, the tomatoes were cut into the slices of 5 mm. After that, the tomato slices were placed on a glass plate. The glass plate was connected to the scale on the microwave oven. Then, the drying experiments were conducted at various values of the microwave power. During the drying, the weight values of the tomato slices were transferred to a computer at regular intervals of time by Balint software. The drying was continued until the moisture content reached around 12% with respect to the wet basis. This moisture content was selected as the final moisture content because a lot of dark spots develop due to burning on the surfaces of the tomato slices at the moisture levels below this value. After each test, the energy consumption during drying and the colour parameters of the dried product were measured and recorded. Also, the first and the final volumes of the tomato slices were determined by measuring the volume

Table 1. Density of the tomato slices at the beginning and at the end of the drying

Power (W)	V_o (cm^3)	V (cm^3)	M_o (g)	M (g)	ρ_o (g/cm^3)	ρ (g/cm^3)
90	80	16	5.1	0.5	6.3×10^{-02}	$3.13.10^{-02}$
180	80	11	5.1	0.3	6.3×10^{-02}	$2.73.10^{-02}$
360	80	6	5.1	0.3	6.3×10^{-02}	$5.00.10^{-02}$
600	80	5	5.1	0.4	6.3×10^{-02}	$8.00.10^{-02}$

V – volume of the tomato slices; M – weight of tomato slices; ρ – density of tomato slices changes after the samples were added to a scaled glass tube filled with water (Table 1).

The microwave power absorbed in the unit volume of the material can be taken as internal heat source in the energy equation. Therefore, energy equation subjected to the microwave heating can be written as follows (Markov & Yulenets 2002): equation

$$\frac{\partial T}{\partial t} = \alpha \nabla 2T + \frac{h_{fg}}{c}\frac{\partial m}{\partial t} + \frac{q_v}{c\rho} \quad (1)$$

where:
t – time (s)
T – temperature (°C)
h_{fg} – specific heat of the phase transition (J/kg)
c – specific heat (J/kg·°C)
ρ – density (kg/m^3)
m – moisture content (kg water/kg wet matter)
α – thermal diffusivity (m^2/s)
q_v – internal heat source (W/m^3)

Usually, the preheating of the body to the point of phase transition ($T = T_p$) is carried out at the highest possible rate. There is almost no evaporation under such conditions until the system reaches the transition point T_p (°C) (Zhmakin 1960; Yulenets *et al.* 1992). Therefore, it can be assumed that the evaporation and drying begin after the system has reached the transition point. The temperature remains constant during drying at $T = T_p$. The experiments also prove negligible magnitude of the moisture-content gradients as well as the temperature in high-frequency heating and drying (Lyons *et al.* 1972). In this case, mathematical description of drying can be written as follows (Markov & Yulenets 2002):

$$\frac{d\bar{m}}{dt} = \frac{q_v}{h_{fg}\rho} \quad (2)$$

where:
$\bar{m}$ – average moisture content (kg water/kg wet matter)
q_v – can be defined as follows (Houšová & Hoke 2002; Markov & Yulenets 2002) (W/m^3) :

$$q_v = 2\pi f \varepsilon_o \varepsilon'' E^2 \quad (3)$$

where:
f – electromagnetic field frequency of the microwave oven (Hz)
ε_o – absolute dielectric constant (F/m)
ε'' – dielectric loss factor of the material
E – electric field strength inside the material (V/m)

The prediction of the electric field strength inside the material is extremely difficult because of the complexity of the interaction between the material parameters and the oven characteristics (Houšová & Hoke 2002). Therefore, it was assumed in this study that it is uniform inside the material and can be defined by the following relation:

$$E = k_1\bar{m}^2 + k_2\bar{m} + k_3 \quad (4)$$

where:
k_1, k_2, k_3 – constant

The colour analysis was also conducted in this study to obtain some knowledge about the quality of the dried product. Three parameters, L^* (lightness), a^* (redness), and b^* (yellowness), were used to study the colour changes. The L^* refers to the lightness of the samples and ranges from black = 0 to white = 100. The negative value of a^* indicates green, while the positive a^* indicates red colours. The positive b^* indicates yellow and the negative b^* indicates blue colours (Babalik 1996; Alibas 2007b). The total colour difference (Δe^*) was also calculated. In addition to the parameters a^*, b^*, and L^*, the colour density C^* and the hue angle H^* were also determined. These parameters depend on the colour space coordinates and are defined as follows (Abonyi *et al.* 2002; Karabulut *et al.* 2007):

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (5)$$

$$H^* = \arctan\frac{b^*}{a^*} \quad (6)$$

The following equations were used in the specification of the change in the colour parameters with respect to the fresh product:

$$\Delta a^* = a^*_{fresh} - a^* \quad (7)$$

$$\Delta b^* = b^*_{fresh} - b^* \quad (8)$$

$$\Delta L^* = L^*_{fresh} - L^* \quad (9)$$

$$\Delta e^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (10)$$

RESULTS AND DISCUSSIONS

Equation (2) governs the moisture removal from the material and depends on the specific heat of the phase transition (h_{fg} = 2258.10^3 J/kg), the density of the material, and the heat source. The density of food materials varies during the drying depending on the moisture content and this variation can be

Table 2. Constants for electrical field strength

Power (W)	k_1	k_2	k_3	r	Err
90	–128	209	30	0.999	3.037×10^{-3}
180	–402	664	–40	0.997	7.791×10^{-3}
360	–1141	1300	60	0.999	4.449×10^{-3}
600	–1968	2192	13	0.998	4.633×10^{-3}

k_1, k_2, k_3 – constant; r – correlation coefficient; err – sum of the squared differences

assumed to be linear (Kahveci & Cihan 2008). Therefore, the linear variation for the density of the tomato slices was assumed in this study. The heat source depends on the electromagnetic field frequency of the microwave oven, the absolute dielectric constant ε, the dielectric loss factor of the material ε", and the electric field strength inside the material E. The electromagnetic field frequency of the microwave oven used in the experimental study is f = 2450 MHz and the absolute dielectric constant is $\varepsilon_o = 8.854 \times 10^{-12}$ F/m. Using the data available in the literature, Sipahioglu and Barringer (2003) proposed the following equation for the dielectric loss factor of vegetables and fruits as a function of temperature, ash content and moisture content:

$$\varepsilon'' = 33.41 - 0.4415T + 0.001400T^2 - 0.1746m + 1.438A + 0.001578mT + 0.2289AT \quad (11)$$

where:
T – temperature (°C)
m – wet basis moisture content (%)
A – wet basis ash content (%)

This equation was adapted to this study. Using the method defined in the literature (Ahaye 2010; Buntaran *et al.* 2010; Purkayastha & Mahanta 2011), the wet basis ash content for the tomatoes used in this study was obtained as 0.40% after 41 ± 0.5 g samples were burned in a muffle furnace (Nüve MF120; Nüve, Ankara, Turkey) at 550°C during 4 h until it became charcoal. Therefore, the constants (k_1, k_2, and k_3) of the electrical field strength are the only unknowns in the governing equation. These constants were obtained by minimising the sum of squared differences between the experimental and theoretical moisture contents. Theoretical moisture contents were determined by solving the first order first degree linear ordinary differential equation given in Eq. (2). The solution of this equation was obtained numerically using the forth order Runge Kutta method by a code

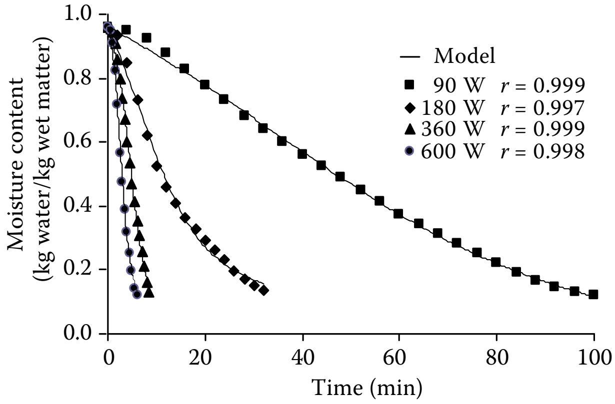

Figure 1. Drying curves at different microwave power levels

developed by the Fortran programming language. The values of the constants obtained for various values of microwave power are given in Table 2. The acceptability of the drying model has been based on the value of the correlation coefficient, which has values close to one for a good fit with the experimental data. According to this evaluation, the proposed model simulates the drying behaviour of the tomato slices in a microwave drier very well with a minimum r of 0.997.

The predicted drying curves for the tomato slices are shown along with the experimental data in Figure 1. It can be concluded from this figure that the microwave power is an effective factor in reducing the drying time. The drying time decreases from 100 min to 6 min with the increase of the microwave power from 90 W to 360 W.

The drying rates during drying are seen in Figure 2 for different microwave power levels. The

Table 3. Energy consumptions

Power (W)	Energy consumption (Wh)
90	350
180	79.5
360	12.04
600	8.4

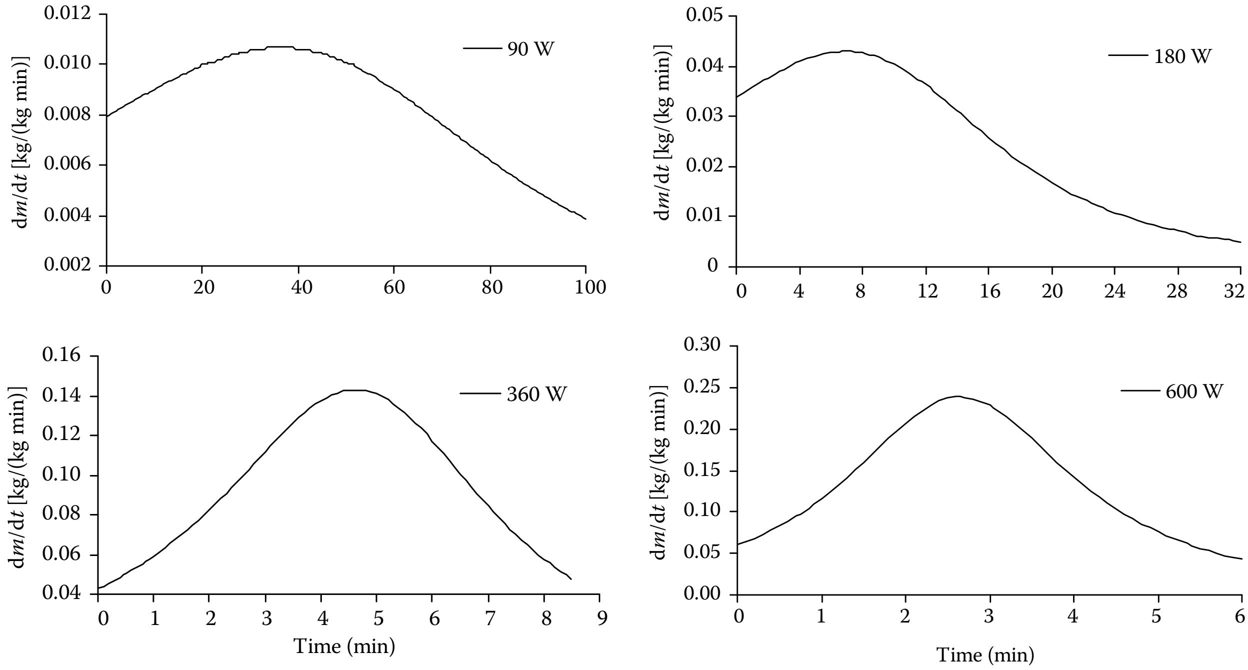

Figure 2. Variations of drying rate at different microwave power levels

drying rate increases in the early stage of drying and then begins to decrease. The decrease in the moisture content has a negative effect on the electric field strength and therefore the drying rate. This is the most important reason for the falling-rate drying period in the later stage of drying.

The energy consumptions during drying are shown in Table 3 for various microwave power levels. The energy consumption decreases considerably with an increase in the microwave power level depending on the decrease in the drying time. Increasing microwave power from 90 W to 360 W decreases energy consumption from 350 Wh to 8.4 Wh.

The colour analysis results for the dried tomato slices are shown in Table 4 for various values of the microwave power. The colour characteristics were considered as the most important quality parameters in this study. In terms of the desired tomato colour properties, higher L^* (lightness) and higher a^* (redness) and lower H^* (hue angle) are preferred (Sacilik 2007). It can be seen from Table 4 that the lightness decreases and the hue angle and the changes in the colour including redness increase significantly as the microwave power increases. The assessment of the colour quality can be made according to the closeness of the values of the colour parameters of the dried product to those of the fresh one. The colour characteristics of the dried tomato with 90 W microwave power are relatively much closer to those of the fresh one. Therefore, it can be concluded that the most preferable microwave power level is 90 W. Moreover, dark spots develop in the product due to burning at the microwave powers of 360 W and 600 W. Therefore, the microwave power below 360W has to be preferred to prevent the product from burning.

Table 4. Color parameters for tomato slices

	a^*	b^*	L^*	C^*	H^*	Δa^*	Δb^*	ΔL^*	Δe^*
Fresh	23.50 ± 0.4	23.90 ± 0.4	42.80 ± 0.4	33.60	0.72	–	–	–	–
90 W	18.90 ± 0.7	17.50 ± 0.3	33.30 ± 0.1	25.80	0.74	4.50	6.40	9.50	12.30
180 W	12.50 ± 0.7	17.10 ± 0.4	29.60 ± 0.1	21.20	0.93	11.00	6.80	13.20	18.50
360 W	11.80 ± 0.7	13.70 ± 0.4	26.70 ± 0.3	18.10	0.86	11.70	10.20	16.10	22.30
600 W	10.40 ± 1.0	13.40 ± 0.2	25.90 ± 0.2	16.90	0.90	13.10	10.50	16.90	23.80

± represents the standard deviation

In the design of a drier, it is aimed at the product drying as quickly as possible, energy consumption during the drying being low, and the product quality after the drying being high. Drying temperature should be kept high for a quick drying process. But, as a general rule, high drying temperatures tend to spoil the quality of food products (Bonazzi & Dumoulin 2011). On the other hand, both drying time and energy consumption acquire higher values at low drying temperatures. Considering all these facts and the results of this study, we propose that the microwave drying of tomato slices conducted at microwave power levels higher than 90 W and lower than 360 W.

CONCLUSIONS

In this study, microwave drying behaviour of tomato slices was investigated experimentally and a theoretical model was proposed to simulate the drying. The experiments were performed at the microwave power of 90 W, 180 W, 360 W, 600 W. The theoretical model was developed using the solution of energy equation considering the microwave power as an internal heat source. The electric field strength inside the material was assumed to be dependent on the moisture content and the constants emerging from this assumption were obtained by minimising the sum of squared differences between the theoretical results and experimental data. The concluding remarks are as follows: (1) The drying time and energy consumption decrease considerably with an increase in the microwave power. (2) The drying rate shows first an increase and then a decrease during drying. (3) The colour quality of the product decreases significantly with the increase of the microwave power. (4) The values proposed for the constants of the electric field strength provide a good agreement between the theoretical and experimental drying behaviour.

References

Abonyi B.I., Feng H., Tang J., Edwards C.G., Chew B.P., Mattinson D.S., Fellman J.K. (2002): Quality retention in strawberry and carrot purees dried with Refractance Window system. Journal of Food Science, **67**: 1051–1056.

Albanese D., Cinquanta L., Russo L., Crescitelli S., Farina M., Brasiello A., Di Matteo M. (2006): Modelling convective and microwave drying of potatoes slices. In: 13th World Congress of Food Science and Technology, Nantes, France.

Al-Duri B., McIntyre S. (1992): Comparison of drying kinetics of foods using a fan-assisted convection oven, a microwave oven and a combined microwave/convection oven. Journal of Food Engineering, **15**: 139–155.

Alibas I. (2007a): Microwave air and combined microwave-air drying parameters of pumpkin slices. Lebensmittel Wissenschaft und Technologie, **40**: 1445–1451.

Alibas İ. (2007b): Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying. Biosystems Engineering, **96**: 495–502.

Ashaye O.A. (2010): Effect of processing methods on chemical and consumer acceptability of kenaf and corchorus vegetables. Journal of American Science, **6**: 165–170.

Babalik Ö. (1996): Application of sulphure dioxide in drying of tomatoes. [M.Sc. in Food Engineering.] Ege University, İzmir. (in Turkish)

Bonazzi C., Dumoulin E. (2011): Quality changes in food materials as influenced by drying processes. In: Modern Drying Technology, 3: Product Quality and Formulation, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim.

Bondaruk J., Markowski M., Blaszczak W. (2007): Effect of drying conditions on the quality of vacuum-microwave dried potato cubes. Journal of Food Engineering, **81**: 306–312.

Brooks M.S., Abou El-Hana N.H., Ghaly A.E. (2008): Effects of tomato geometries and air temperature on the drying behavior of plum tomato. American Journal of Applied Sciences, **5**: 1369–1375.

Buntaran W., Astirin O. P., Mahajoeno E. (2010): Effect of various sugar solution concentrations on characteristics of dried candy tomato (*Lycopersicum esculentum*). Nusantara Bioscience, **2**: 55–61.

Dadali G., Ozbek B. (2008): Microwave heat treatment of leek: drying kinetic and effective moisture diffusivity. International Journal Food Science Technology, **43**: 1443–1451.

Dadali G., Apar D.K., Ozbek B. (2007): Microwave drying kinetics of ocra. Drying Technology, **25**: 917–924.

ElHana A.N.H. (2008): Microwave drying of apple. Misr Journal of Agricultural Engineering, **25**: 980–1003.

Erdem T. (2006). Drying by microwave energy of washed red pepper by ozonated water. [MSc. Thesis.] University of Çukurova, Turkey. (in Turkish)

Evin D. (2011): Investigation on the drying kinetics of sliced and whole rosehips at different moisture contents under microwave treatment. Scientific Research and Essays, **6**: 2337–2347.

FAO (2012): Agriculture data. Food and Agriculture Organization of the United Nations. Available at http://faostat.fao.org

Houšová J., Hoke K. (2002): Microwave heating – the influence of oven and load parameters on the power absorbed in the heated load. Czech Journal of Food Sciences, **20**: 117–124.

Inchuen S., Narkrugsa W., Pornchaloempong P., Chanasinchana P., Swing T. (2008): Microwave and hot-air drying of Thai red curry paste. Maejo International Journal of Science and Technology, **1**: 38–49.

Işık E., Izli N., Bayram G., Turgut I. (2011): Drying kinetic and physical properties of green laird lentil (*Lens culinaris*) in microwave drying. African Journal of Biotechnology, **10**: 3841–3848.

Kahveci K., Cihan A. (2008): Drying of Food Materials: Transport Phenomena. Nova Science, Hauppauge.

Karabulut I., Topcu A., Duran A., Turan S., Ozturk B. (2007): Effect of hot air drying and sun drying on color values and β-carotene content of apricot (*Prunus armenica* L.). Lebensmittelwissenschaft und Lebensmitteltechnologie, **40**: 753–758.

Kassem A.S., Shokr A.Z., El-Mahdy A.R., Aboukarima A.M., Hamed E.Y. (2011): Comparison of drying characteristics of Thompson seedless grapes using combined microwave oven and hot air drying. Journal of the Saudi Society of Agricultural Sciences, **10**: 33–40.

Liamkaew R., Thipayarat A., Koetsinchai W. (2008): Kinetics model of vacuum microwave drying of dried pumpkin slices. In: 2nd Technology and Innovation for Sustainable Development Conference, 28–29 January 2008, Khon Kaen, Thailand: 11–16.

Lyons D.W., Hatcher J.D., Sunderland J.E. (1972): Drying of porous medium with internal heat generation. International Journal of Heat and Mass Transfer, **15**, 897–905.

Markov A.V., Yulenets Y.P. (2002): Mass-transfer mechanism in high-intensity drying in the presence of internal heat sources. Theoretical Foundations of Chemical Engineering, **36**: 241–246.

Maskan M. (2000): Microwave/air and microwave finish drying of banana. Journal of Food Engineering, **44**: 71–78.

McLoughlin C.M., McMinn W.A.M., Magee T.R.A. (2003): Microwave drying of multicomponent powder systems. Drying Technology, **21**: 293–309.

Miller W.M., Braddock R.J. (1982): Microwave drying of citrus peel. Proceedings of the Florida State Horticultural Society, **95**: 204–207.

Ozbek B., Dadali G. (2007): Thin layer drying characteristics and modeling of mint leaves undergoing microwave treatment. Journal Food Engineering, **83**: 541–549.

Ozkan I.A., Akbudak B., Akbudak N. (2007):Microwave drying characteristics of spinach. Journal Food Engineering, **78**: 577–583.

Purkayastha M.D., Mahanta C. (2011): Physicochemical properties of five different tomato cultivars of Meghalaya and their suitability in food processing. African Journal of Food Science, **5**: 657–667.

Sacılık K. (2007): The thin-layer modeling of tomato drying process. Agriculturae Conspectus Scientificus, **72**: 343–349.

Sarimeseli A. (2011): Microwave drying characteristics of coriander (*Coriandrum satiyum* L.) leaves. Energy Conversion & Management, **52**: 1449–1453.

Sipahioglu O., Barringer S.A. (2003): Dielectric properties of vegetables and fruits as a function of temperature, ash, and moisture content. Journal of Food Science, **68**: 234–239.

Soysal Y. (2004): Microwave drying characteristics of parsley. Biosystems Engineering, **89**: 167–173.

Soysal Y. (2005): Mathematical modeling and evaluation of microwave drying kinetics of mint (*Mentha spicata* L.). Journal of Applied Sciences, **5**: 1266–1274.

Tulasidas T.N., Ratt C., Raghavan G.S.V. (1997): Modeling of microwave drying of grapes. Canadian Agricultural Engineering, **39**: 57–67.

Wang Z., Sun J., Chen F., Liao X., Hu X. (2007): Mathematical modeling on thin layer microwave drying of apple pomace with and without hot air pre-drying. Journal Food Engineering, **80**: 536–544.

Worknech T.S., Raghavan V., Gariepy Y. (2011): Microwave assisted hot air ventilation drying of tomato slices. In: International Conference on Food Engineering and Biotechnology (ICFEB 2011): 150–161.

Yulenets Yu.P., Markov A.V., Kosintseva Yu.F. (1992): High-frequency heating of the Blue Phosphor Stock. In: International Conference on Phosphor Physics, Chemistry, and Technology, Stavropol' NPO "Lyuminofor", 50.

Zhmakin N.P. (1960): Heating wet capillary porous materials in a high-frequency electric field. [Cand. Sci. (Eng.) Dissertation.] Minsk.

Received for publication January 26, 2012
Accepted after corrections August 3, 2012

Corresponding author

Dr Soner Çelen, Namık Kemal University, Mechanical Engineering Department, 59860 Çorlu/Tekirdağ, Turkey; E-mail: scelen@nku.edu.tr