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Full Length Research Paper

Microwave heat treatment of dent corn *(Zea mays* var. *indentata* sturt.*)*: Drying kinetic and physical properties

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This study is on the determination of drying kinetics of corn and selecting proper model in microwave drying method. For this purpose, semi-mathematical models earlier specified were run with test results; the coefficients in the equations as well as X^2, root mean square error (RMSE) and R^2 values were found and they were compared with the developed model. Also, the corn's physical and mechanical features at initial and final-drying moisture values and post-drying color parameters were specified. It was concluded according to these values that the recommended model is the best model, which can define the drying curves at the practices at 400, 550, 700 and 800 W, but Page 2 is the best model at 300 W in drying corn by microwave. It was determined according to initial and final moisture values that the reduction in moisture value causes decrease in other physical properties measured with the exception of porosity.

Key words: Microwave, dent corn, physical properties, color parameters, drying.

INTRODUCTION

Dent corns (*Zea mays* var. indentata Sturt.) are a cultivated plant grown for fresh and dry consumption and raw material of canned food industry. It contains 9.4 g protein, 4.2 g fat, 72 g total carbohydrates, 9 mg calcium, 2 mg iron, and 363 kcal energy per 100 g (dry) (Anonymous, 2006). Turkey has about 550.000 ha of corn harvesting area, 3.875.000 t of corn production per annual with a yield of 7.045 kg ha^{-1} of corn and is therefore one of the foremost corns producing countries of the world (SIS, 2007).

The most common methods widely used for drying are sun drying and hot-air drying (Soysal, 2004). Compared with sun drying and hot-air drying, microwave drying is an alternative method due to the fact that it has uniform energy and high thermal conductivity to the inner sides of the material, space utilization, sanitation, energy saving, precise process control, fast start-up and shut-down conditions. It also reduces the drying time and prevents food from decomposing (Maskan, 2000; Decareau, 1985).

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The study of the drying kinetic of foods during microwave heat treatment has recently been a subject of interest for various investigators. Some of the previous studies about microwave drying can be listed as; corn (Nair et al., 2011; Gabor et al., 2007; Bake, 1992; Beke and Mujumdar, 1997), basil (Demirhan and Özbek, 2009), apple (Askari et al., 2008), okra (Dadali et al., 2007), spinach (Dadali et al., 2007, 2008), noodles (Xue et al., 2008), garlic (Sharma and Prasad, 2006; Souraki and Mowla, 2008), potato (Gunasekaran and Yang, 2007; Oztop et al., 2007), bacon (James et al., 2006), maize (Velu et al., 2006), mint (Özbek and Dadali, 2007), spaghetti (Cocci et al., 2008), tomato (Al-Harahsheh et al., 2009), red pitaya (Nordin et al., 2008), leek (Dadali and Özbek, 2008), avocado (Guzmán-Gerónimo et al., 2008), Chilean hazelnuts (Uquiche et al., 2008), and parsley (Soysal et al., 2006).

This study is on determination of drying kinetics of corn and selecting proper model in microwave drying method. For this purpose, semi-mathematical models specified before were run with test results; the coefficients in the equations as well as X^2, RMSE and R^2 values were found and they were compared with the developed model. Also the corn's physical and mechanical features at initial and, final drying moisture values and post-drying color parameters were specified.

MATERIALS AND METHODS

Drying equipment and drying procedure

The drying procedure was carried out by a microwave oven (Arcelik MD 500, PRC). The values of the oven are 230 V, 50 Hz and 1200 W, and a frequency of 2450.

The procedure was carried out at 5 microwave powers, which are 300, 400, 550, 700 and 800 W.

The size of the oven is 300 x 460 x 280 mm and its rotating glass plate's diameter is 27 mm. In the tests, 250 g of corn was placed onto the glass plate and the thin layer method was applied. A digital balance (Baster, Istanbul, Turkey) was placed under the microwave oven. Weight losses were measured at every 10 s through the digital balance with the sensitivity of 1 g uninterruptedly and recorded. Energy consumption of microwave oven was determined using a digital electric counter (Alfatech, Type A016M1W0, Turkey) with 0.01 kWh precision. The tests were repeated three times and then, the means were calculated.

Mathematical modeling of drying data

In order to determine the moisture ratio as a function of drying time, 10 different thin-layer drying models were used. The moisture ratio was calculated using the following equation:

$$MR = \frac{Mt - Me}{Mo - Me} \quad (1)$$

Where, MR is the moisture ratio; M_t is the moisture content at a specific time (g water per g dry solids); M_0 is the initial moisture content (g water per g dry solids); M_e is the equilibrium moisture content (g water per g dry solids). The equilibrium moisture content (M_e) was assumed to be zero for microwave drying as stated by Dadali and Özbek (2007).

Statistical analysis

Excel program was employed in obtaining data, their graphical assessment and obtaining regression equations. MATLAB R2008a program was employed in the determination of the coefficients, X^2, R^2 and RMSE values for the said 10 models. Herein, the best model is defined as the one having low X^2 and RMSE values and high R^2 values.

The model, which has these values, is the model, which can estimate the study best (Mengeş et al., 2005). These statistical values are defined as follows:

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

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (MR_{pre,i} - MR_{\exp,i})}{N}} \quad (3)$$

Where, $MR_{exp,i}$, is the experimental moisture ratio in the test with number I; $MR_{pre,,i,}$ is the estimated moisture ratio in the test with number I; N is the observation number and n is the number of constants in the drying model.

Methods of determination of physical properties

The dent corn seeds used in the study were obtained from the fields of Agricultural Faculty, Uludag University. The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken seeds.

All the physical properties of the seeds were determined at two moisture contents [initial moisture content 31% and final moisture content 13% d.b. (all moisture content dry basis)] with 10 replications at each moisture content. To determine the average size of the seed, 100 seeds were randomly picked and their three linear dimensions namely, length (L), width (W) and thickness (T) were measured using a digital compass (Minolta, England) with a accuracy of 0.01 mm.

The average diameter of seed was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter D_a and geometric mean diameter D_g of the seed were calculated by using the following relationships (Mohsenin, 1970):

$$D_a = (L + W + T)/3 \quad (4)$$

$$D_g = (LWT)^{1/3} \quad (5)$$

The sphericity of seeds ϕ was calculated by using the following relationship (Mohsenin, 1970):

$$\phi = \frac{(LWT)^{1/3}}{L} \quad (6)$$

The one thousand seed mass was determined by means of an electronic balance reading to 0.01 g (Radwag PS 4500/C/2, Poland).

The surface area A_s in mm^2 of dent corn seeds was found by analogy with a sphere of same geometric mean diameter, using the following relationship (Dursun and Dursun, 2005):

$$A_s = \pi D_g^2 \quad (7)$$

The projected area was determined from the pictures of dent corn seeds which were taken by a digital camera (Creative DV CAM 316; 6.6 Mpixels), in comparison with the reference area to the sample area by using the Global Lab Image 2-Streamline (trial version) computer program (Işik and Güler, 2003).

The average bulk density of the dent corn seeds was determined using the standard test weight procedure reported by Singh and Goswami (1996) and Gupta and Das (1997) by filling a container of 500 ml with the seed from a height of 150 mm at a constant rate and then weighing the content.

The average true density was determined using the toluene displacement method. The volume of toluene (C_7H_8) displaced was found by immersing a weighed quantity of dent corn seeds in the toluene (Yalçin and Özarslan, 2004). The porosity was calculated from the following relationship (Mohsenin, 1970):

$$\varepsilon = (1 - \frac{\rho_b}{\rho_t})100 \quad (8)$$

The terminal velocities of seed at different moisture contents were measured using a cylindrical air column in which the material was suspended in the air stream (Nimkar and Chattopadhyay, 2001). Relative opening of a regulating valve provided at blower output end was used to control the airflow rate. In the beginning, the blower output was set at minimum. For each experiment, a sample was dropped into the air stream from the top of the air column. Then airflow rate was gradually increased till the seed mass gets suspended in the air stream. The air velocity which kept the seed suspension was recorded by a digital anemometer (Thies clima, Germany) having a least count of 0.1 m s^{-1} (Özdemir and Akinci, 2004).

The static coefficient of friction of dent corn seeds against six different structural materials, namely rubber, galvanized iron, aluminum, stainless steel, glass and medium density fiberboard (MDF) was determined. A polyvinylchloride cylindrical pipe of 50 mm diameter and 100 mm height was placed on an adjustable tilting plate, faced with the test surface and filled with the seed sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was raised gradually with a screw device until the cylinder just started to slide down and the angle of tilt was read from a graduated scale (Unal et al., 2006).

The coefficient of friction was calculated from the following relationship:

$$\mu = \tan\alpha \qquad (9)$$

Where, μ is the coefficient of friction and α is the angle of tilt in degrees.

Shelling resistance was determined by forces applied to one axial dimension (length). The shelling resistance of seed was determined under the point load by using a penetrometer.

Color analysis

Color (*L, a, b*) of dent corns was measured by two readings on the two different symmetrical faces of the fruit in each replicate (three replicate), using a Minolta Chromameter CR-300 (Konica-Minolta, Osaka, Japan; light source: pulsed xenon lamp, port size: 229 x 91 x 60 mm, standard observer: closely matches CIE 1931 standard observer curves, measuring area: 50 mm, receptors: six silicon photocells [three to measure source illumination, three to measure reflected light] filtered to detect primary stimulus values for red, green, and yellow light) colorimeter calibrated with a white standard tile. Color analyses were made in 3 replicates. Data were analyzed by analysis of variance (MINITAB), with means significance test by LSD at $p \leq 0.05$.

RESULTS AND DISCUSSION

Drying kinetic of dried corn

The initial moisture content of the corn samples was determined as 31% (w.b.) using a standard method by drying oven at 105°C for 24 h. The experiment was continued until the moisture ratio reached 13% (w.b.). During the tests, the moisture ratio of 31% reduced to 13% in 18.2, 12.5, 7.3, 6 and 5.2 min at 300, 400, 550, 700 and 800 W respectively. Alteration of the removable moisture ratio in drying corn versus time is seen in Figure 1.

The coefficients obtained in the 10 models by employing the experimental data, X^2, R^2 and RMSE values are seen in Table 1. According to Table 1, the best R^2 values at 300, 400, 550, 700 and 800 W are obtained as 0.99327, 0.99148, 0.98914, 0.98925 and 0.98709 respectively on Page 2 and 0.98908, 0.99279, 0.99339, 0.98885 and 0.98867 in Wang and Sing when the model recommendded in this paper was kept out of the operation. These two modeled X^2 and RMSE values are more suitable compared with the other models. However, X^2 values for the corn experiment in the recommended model are 0.00098, 0.00065, 0.00067, 0.00119 and 0.00133 at 300, 400, 550, 700 and 800 W respectively. The values for R^2, which is another important parameter in acceptance of the model, are 0.99135, 0.99388, 0.99363, 0.98983 and 0.98849 respectively. The root mean square errors of the estimation (RMSE) are 0.03065, 0.02566, 0.02578, 0.03535 and 0.03606 respectively for each test. It may be said according to these values that the model, used in the 9 numbered equation and recommended in this paper, is the best model, which can define the drying curves at the practices at 300, 400, 550, 700 and 800 W in drying corn by microwave:

$$MR = a + bt^2 + ct$$

Energy consumption

Figure 2 shows energy consumption values versus time in corn drying in microwave oven. According to the figure, 0.68, 0.60, 0.44, 0.44 and 0.40 W was consumed per gram (Whg^{-1}) at 300, 400, 550, 700 and 800 W respectively for reducing the moisture in corn from 31 to 13%. According to these values, the lowest energy was consumed in reducing the moisture in corn from 31 to 13% at 800 W and the highest energy was consumed for the same purpose at 300 W.

Physical and mechanical properties of corn

Width, length and thickness, which define corn size, are given in Figure 3 for two different moisture contents. According to the figure, width, length and thickness of the grain decrease as moisture content decreases. This decrease occurred depending on the variation in moisture is seen in arithmetical and geometrical diameter as well as spherical form also (Figure 3). The same affinity is seen between the moisture ratios of 11.4 and 24.07% (Işik and Izli, 2007).

Variations on arithmetic mean diameters, geometric mean diameters, sphericity, projected area, surface area and weight of corn versus moisture ratio are seen in Figures 4 and 5. Thousand-grain weight (369.31 to 464.95), bulk density (463.24 to 547.443) and true density (1065.51 to 1213.175), which are especially

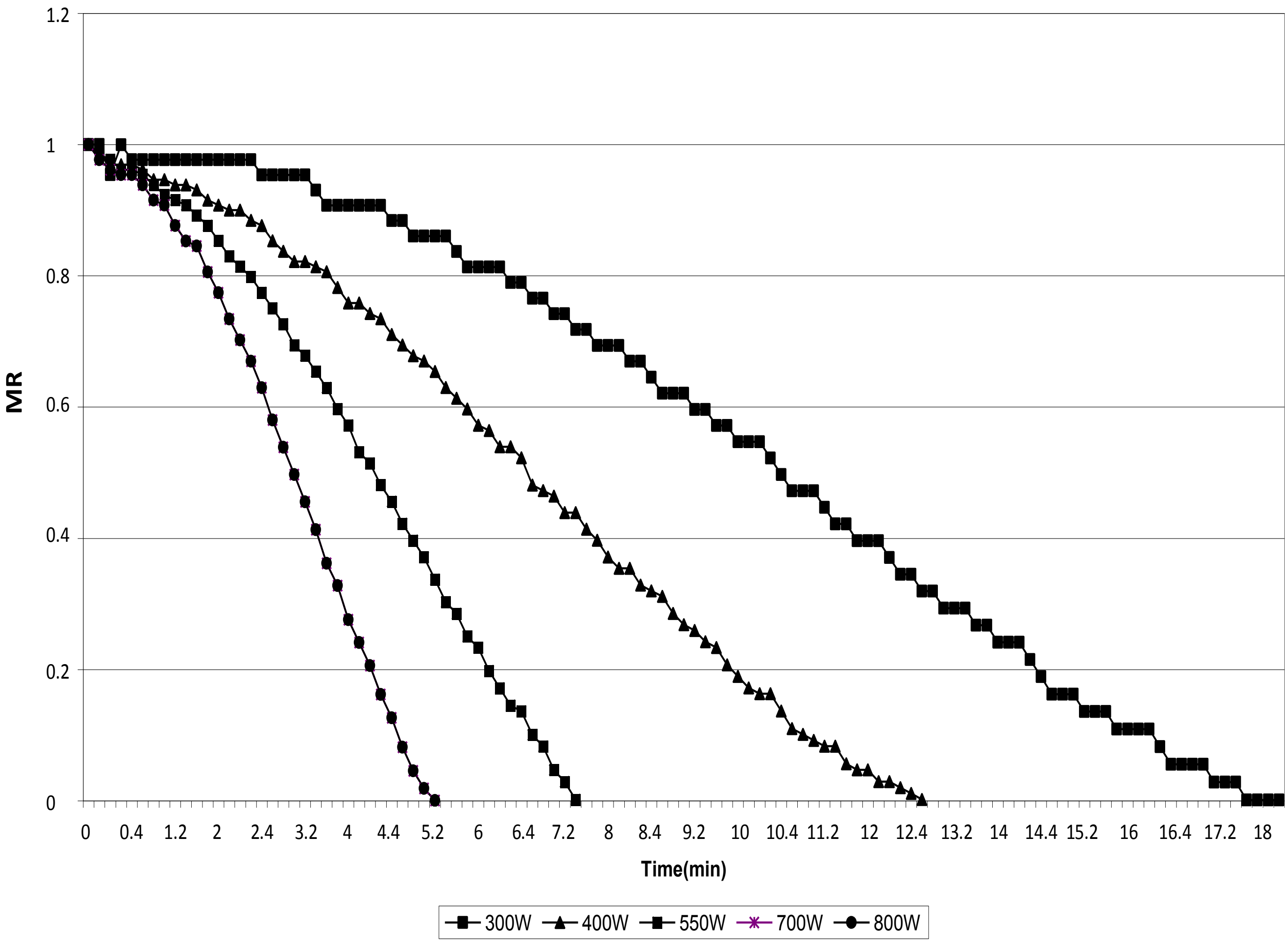


Figure 1. Moisture ratio of corn on 300, 400, 550, 700 and 800 W microwave treatment.

important in storage of corn and machinery design, increase depending on the reduction in moisture content (31 and 13%). The critical rate value, which affects pneumatic transfer, classification by air-flow and cleaning operations, reached 5.26 at moisture content of 13% while it was 6.49 at the moisture content of 31% db. This value reduced from 24.07 to 11.4% logarithmically (Işik and Izli, 2007) (Figure 6).

However, porosity, which is an important parameter in warehouse design, increased depending on the decrease in moisture content while rolling resistance of the corn grain on steel, rubber, aluminum, steel plate, glass and MDF reduced depending on the decrease in moisture content (Figure 7).

Color results of the corns treated with different microwave

The effect of the microwave drying on the color of the corns was assessed by the color values on a Hunter Lab color meter by measuring the L, a, and b. L values represent the brightness of the corns. The more the value of L, the brighter is the sample. The highest b value is an indication of the yellow color content. It was seen in the color assessments on the corns dried in microwave oven at different concentrations that although very significant discolorations in corns' color compounds did not occur, this variation is statistically significant at a level of 5% (Figure 8). The practice in which more maturity was obtained in corns according to L values was determined as control practice. The practice in which the lowest variation in color occurred according to L values among other practices is the practice at 550 W. Discoloration at 550, 700 and 800 W was slower from the point of view of red-color formation compared with other practices. According to b values, the practice at 550 W yielded the better result and discoloration was slower in this practice. Krokida et al. (2001) investigated the effects of different drying methods on the color of the obtained products. They found that color characteristics are significantly affected by the drying methods. Askari et al. (2008)

Table 1. Mathematical models and constants during microwave treatment and X^2, R^2 ve RMSE values.

Model	Equation	Reference	Constant	300 W	400 W	550 W	700 W	800 W
Henderson and Pabis	MR = a exp(-kt) (10)	Togrul and Pehlivan (2002)	a	1.2022	1.5721	1.14581	1.15411	1.14175
			k	0.09498	0.14672	0.22323	0.29534	0.31732
			X^2	0.01439	0.0101	0.01169	0.01351	0.01464
			R^2	0.87223	0.90563	0.8886	0.884	0.87217
			RMSE	0.1193	0.1005	0.1081	0.1162	0.121
Newton	MR = exp(-kt) (11)	Ayensu (1997) and Sarsavadia et al. (1999)	k	0.07598	0.12403	0.18851	0.24903	0.26986
			X^2	0.02086	0.01375	0.01518	0.01744	0.01801
			R^2	0.81197	0.86986	0.85205	0.846	0.83775
			RMSE	0.1437	0.1173	0.1232	0.132	0.1342
Page2	MR = exp(-(kt)^n) (12)	Yaldız and Ertekin (2001)	k	0.08425	0.13002	0.20661	0.26814	0.29476
			n	2.48151	2.04991	2.1869	2.28183	2.33723
			X^2	0.00075	0.00091	0.00114	0.00125	0.00148
			R^2	0.99327	0.99148	0.98914	0.98925	0.98709
			RMSE	0.02696	0.03021	0.03376	0.03538	0.03845
Logarithmic	MR = a exp(-kt)+c (13)	Saçılık (2005)	a	102.92371	102.90198	103.32384	100.37581	257.29541
			k	0.0006	0.00084	0.00138	0.00186	0.0008
			c	-101.79704	-101.84241	-102.24188	-99.29106	-256.21213
			X^2	0.00239	0.0009	0.00185	0.00222	0.00296
			R^2	0.97887	0.99166	0.98277	0.98144	0.97504
			RMSE	0.06303	0.03352	0.04622	0.0484	0.0552
Two term	MR=a exp(-k_ot)+b exp(-k_1t) (14)	Madamba et al. (1996)	a	40.51293	15.65949	70.22723	70.82423	71.0464
			k_o	0.2187	0.30927	0.51032	0.67494	0.74458
			b	-39.6373	-14.74384	-69.30558	-69.89918	-70.13643
			k_1	0.22763	0.33853	0.52069	0.68894	0.76029
			X^2	0.00373	0.00257	0.00331	0.00408	0.00451
			R^2	0.96726	0.97661	0.96988	0.96695	0.9632
			RMSE	0.07854	0.05072	0.07098	0.06828	0.06936

Two term exponential	MR=a exp(-kt)+(1-a) exp(-kat) (15)	Sharaf-Elden et al. (1980) and Yağcıoğlu et al. (1999)	a	2.27543	2.16844	2.19047	2.22159	2.21862
			k	0.14848	0.22336	0.35338	0.46656	0.50926
			X^2	0.00532	0.00354	0.00428	0.00509	0.00574
			R^2	0.9525	0.96695	0.95927	0.9563	0.94992
			RMSE	0.07237	0.05949	0.06538	0.07134	0.07575
Wang and Singh	$MR=1+at+bt^2$ (16)	Özdemir and Devres (1999)	a	-0.02531	-0.06142	-0.07832	-0.10316	-0.10509
			b	-0.00192	-0.00182	-0.0086	-0.01372	-0.01907
			X^2	0.00122	0.00077	0.00069	0.0013	0.0013
			R^2	0.98908	0.99279	0.99339	0.98885	0.98867
			RMSE	0.03458	0.02779	0.02635	0.03604	0.03603
Diffusion approach	MR=a exp(-kt)+(1-a) exp(-kbt) (17)	Kassem(1998) and Ertekin and Yaldız (2004)	a	-2.391E+09	-2.293E+09	-2.518E+09	-2.483E+09	-2673506117.53
			k	0.21129	0.31004	0.49457	0.65651	0.71809
			b	1	1	1	1	1
			X^2	0.00445	0.00298	0.00372	0.00443	0.00508
			R^2	0.96063	0.97253	0.96537	0.96302	0.95713
			RMSE	0.06616	0.05931	0.061	0.07936	0.07126
Modified Henderson	MR=a exp(-kt)+b exp(-gt)+c exp(-ht) (18)	Menkov et al. (2005)	a	0.40266	0.38533	0.37991	0.38131	0.37558
			k	0.0962	0.14675	0.22324	0.29535	0.31736
			b	0.4072	0.38495	0.38114	0.38183	0.37654
			g	0.09621	0.1467	0.22325	0.29535	0.31728
			c	0.40566	0.38694	0.3848	0.39097	0.38966
			h	0.0962	0.14673	0.22323	0.29537	0.31733
			X^2	0.01467	0.01066	0.01286	0.01525	0.01681
			R^2	0.87384	0.90563	0.8886	0.884	0.87217
			RMSE	0.1216	0.09052	0.1291	0.1279	0.1267
Recommendation	$MR=a+bt^2+ct$ (19)	This study	a	1.04649	1.03393	1.02064	1.03673	1.01949
			b	-0.00146	-0.00112	-0.00735	-0.01024	-0.01676
			c	-0.03549	-0.07209	-0.08942	-0.12794	-0.11981
			X^2	0.00098	0.00065	0.00067	0.00119	0.00133
			R^2	0.99135	0.99388	0.99363	0.98983	0.98849
			RMSE	0.03065	0.02566	0.02578	0.03535	0.03606

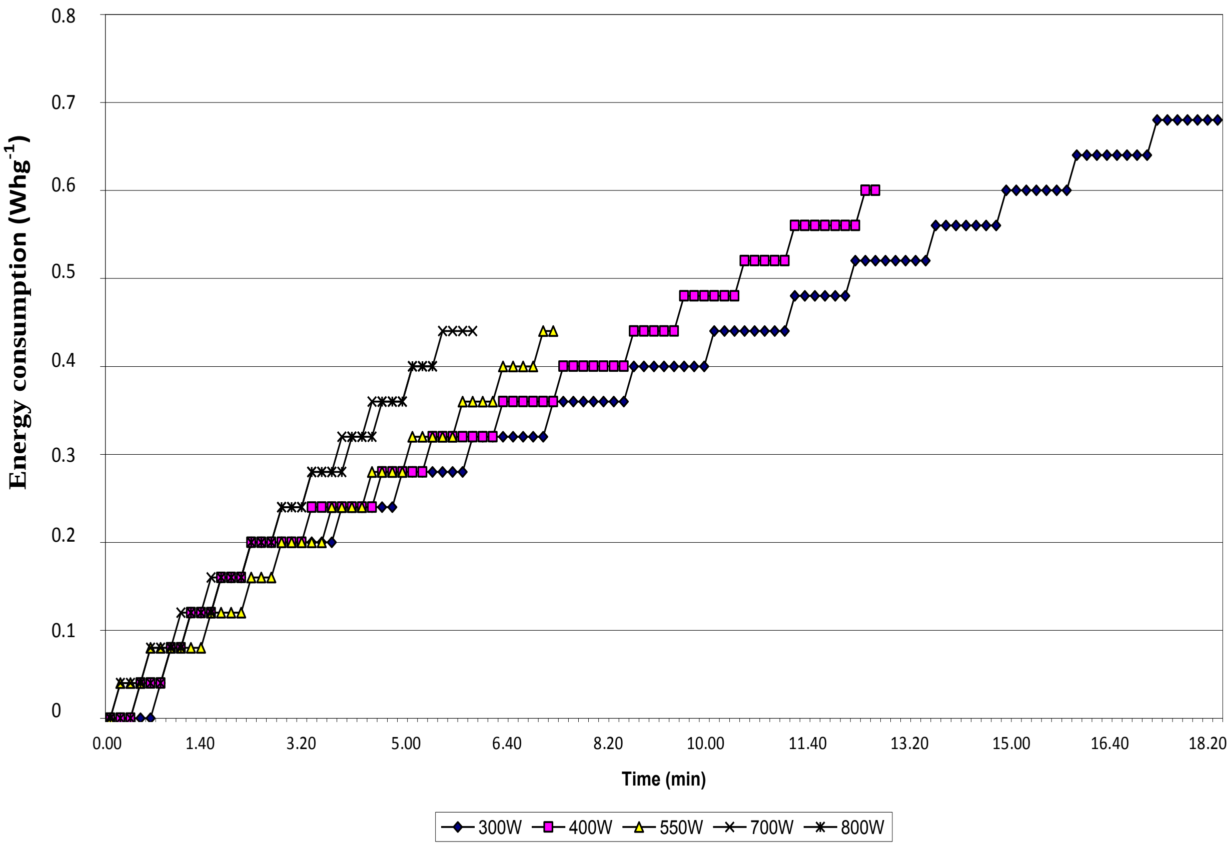


Figure 2. Energy consumption of corn on 300, 400, 550, 700 and 800 W microwave treatment.

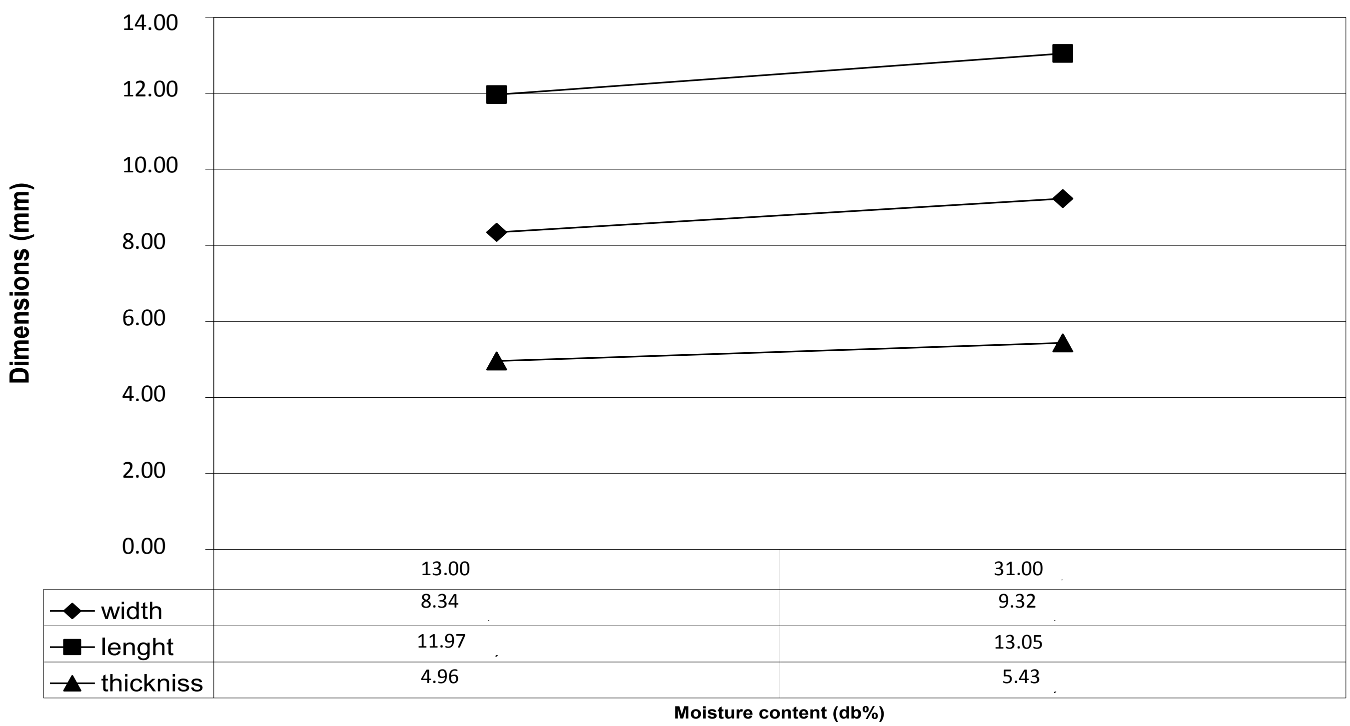
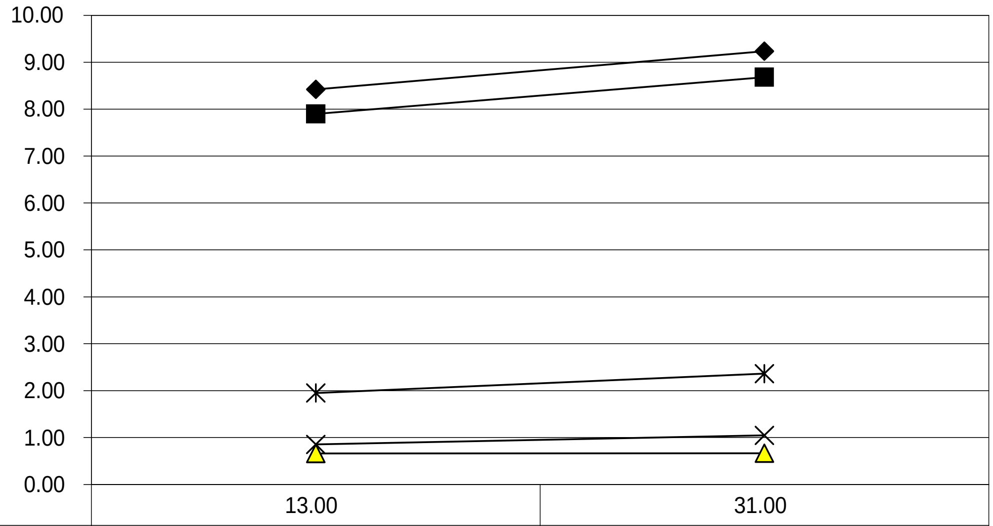


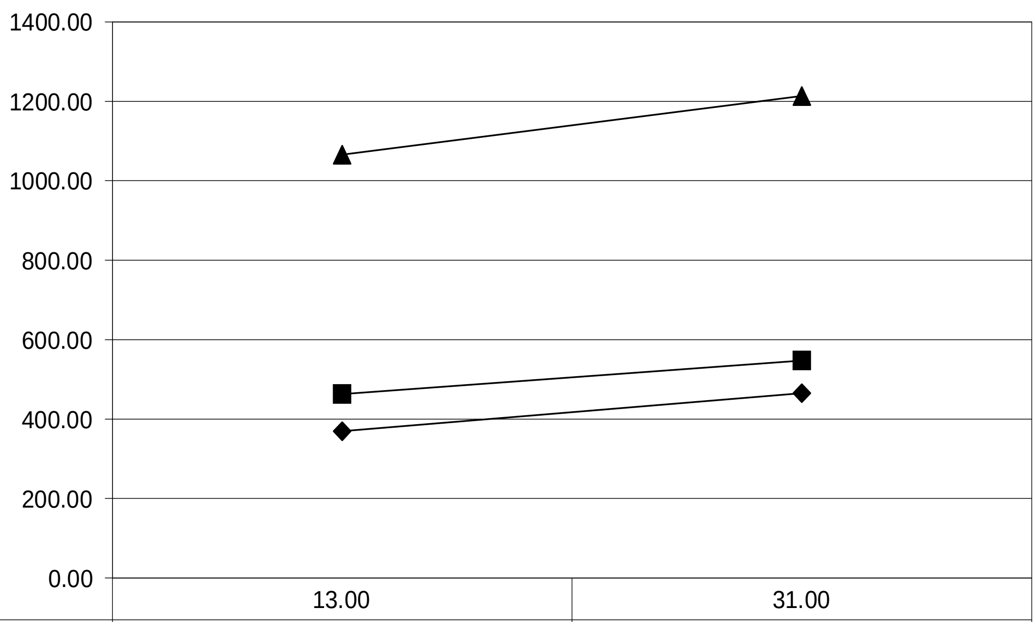
Figure 3. Three dimensions of dent corns, length (L), width (W) and thickness (T).



	13.00	31.00
Arithmetic diameters (mm)	8.42	9.24
Geometric diameters (mm)	7.90	8.68
Sphericity (%)	0.66	0.67
Projected area (cm^2)	0.85	1.05
Surface area (cm^2)	1.95	2.36

Moisture content (db%)

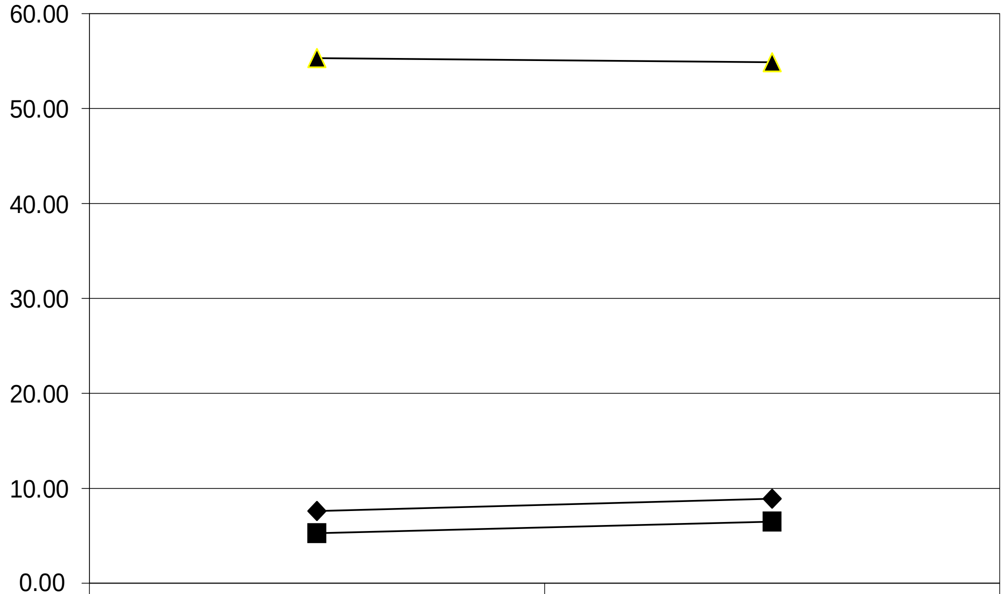
Figure 4. Effect of moisture content on arithmetic mean diameters, geometric mean diameters, sphericity, projected area, surface area of dent corn seeds.



	13.00	31.00
Thousand mass (g)	369.32	464.96
Bulk density (kgm^{-3})	463.24	547.44
True density (kgm^{-3})	1065.51	1213.18

Moisture content (db%)

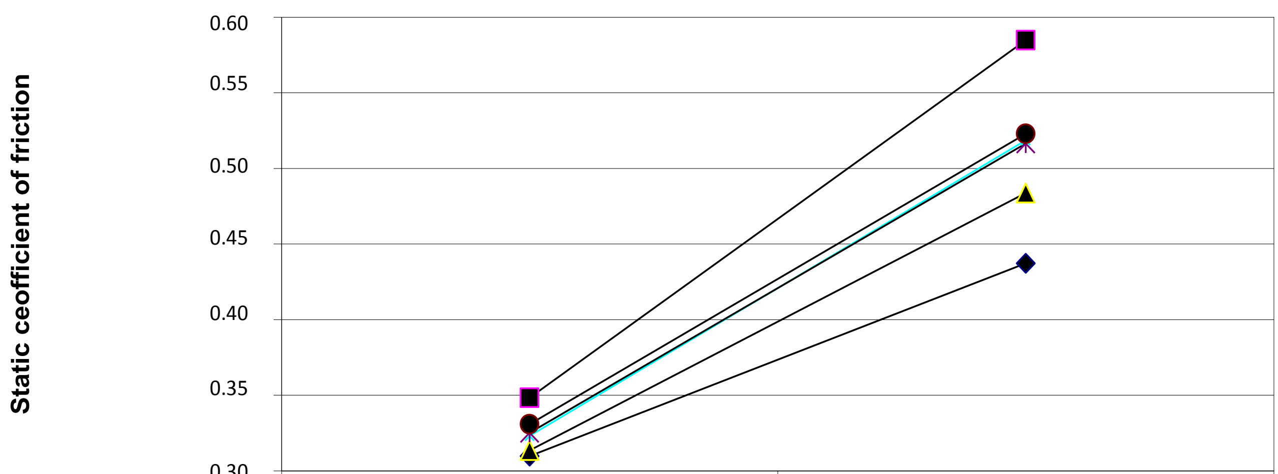
Figure 5. Effect of moisture content on thousand mass, bulk density, and true density of dent corn seeds.



	13.00	31.00
Shelling resistance (kg)	7.60	8.90
Terminal velocity (ms^{-1})	5.26	6.49
Porosity (%)	55.31	54.87

Moisture content (db%)

Figure 6. Effect of moisture content on shelling resistance, terminal velocity, and porosity of dent corn seeds.



	13.00	0.31
Stanless steel	0.31	0.44
Rubber	0.35	0.58
Aluminium	0.31	0.48
Galvanised iron	0.32	0.52
Glass	0.33	0.52
MDF	0.33	0.52

Moisture content (db%)

Figure 7. Effect of moisture content on static coefficient of friction of dent corn seeds against various surfaces.

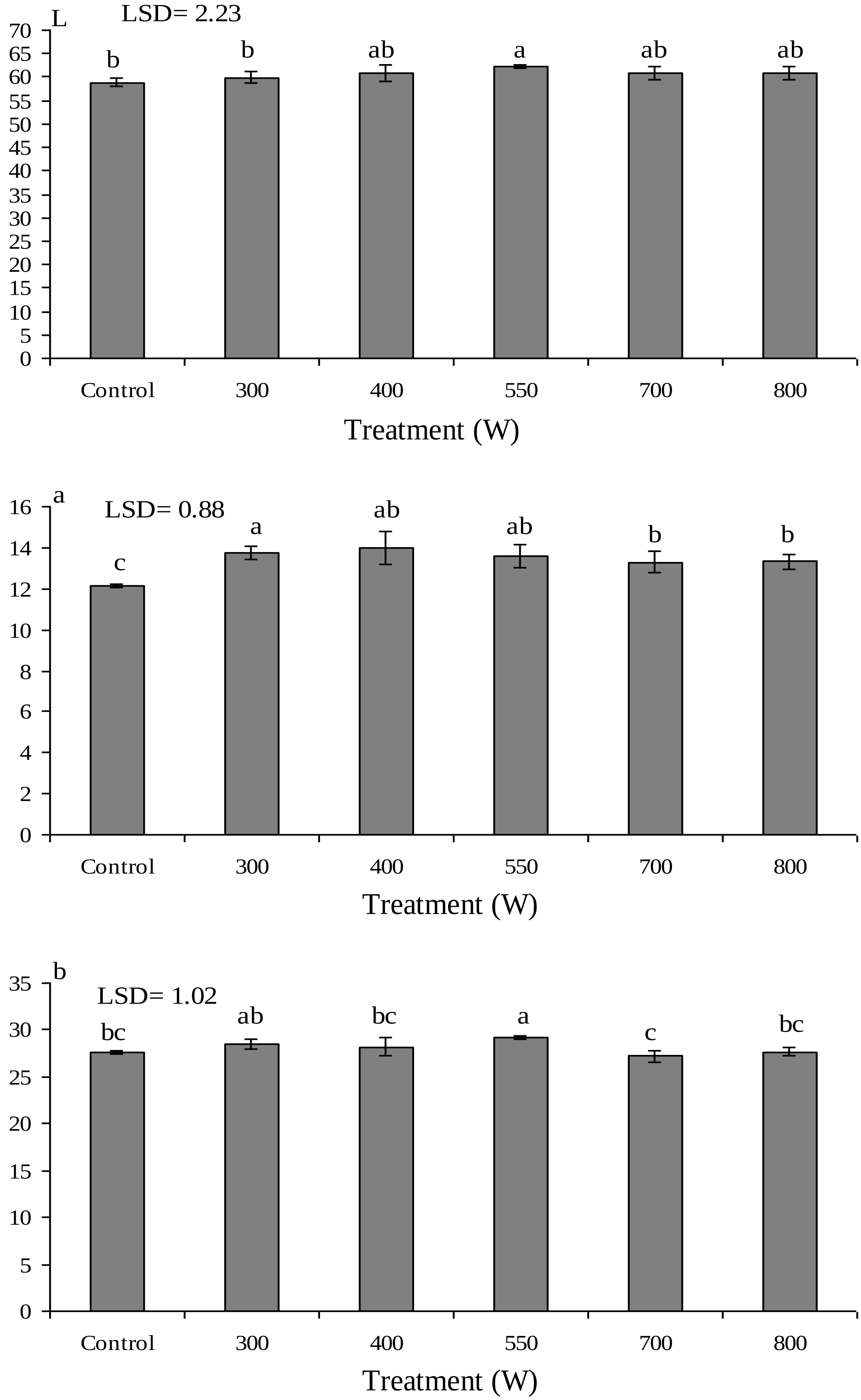


Figure 8. Changes in the color (L, a, b) during drying of the corns treated with 300, 400, 550, 700 and 800 W.

determined that microwave treatment could affect the color parameters of apple slice samples. During microwave treatment, color parameters have different behavior, which cannot be explained apart from structural change caused during treatment. Measurements were in agreement with our hypothesis; thus, because of induced excess volume, pigment concentration of samples surface was reduced. Results show that the trend in color change for all parameters was converted after microwave treatment. Karaaslan and Tunçer (2008) investigated with a microwave, a microwave–fan combination and fan drying in spinach leaves.

They were found that *L** and *a** values were not significantly different from the values of the fresh leaves (P>0.05). On the other hand, *b** values, chroma, *C** and hue angle *α* of dried spinach leaves differed significantly (P<0.01) from fresh spinach leaves.

Conclusions

1. X^2 values for the corn experiment in the recommended model are 0.00098, 0.00065, 0.00067, 0.00119 and 0.00133 at 300, 400, 550, 700 and 800 W respectively. The values for R^2, which is another important parameter in acceptance of the model, are respectively 0.99135, 0.99388, 0.99363, 0.98983 and 0.98849. The root mean square errors of the estimation (RMSE) are 0.03065, 0.02566, 0.02578, 0.03535 and 0.03606 respectively for each test. It may be said according to these values that the model, used in the 9 numbered equation and recommended in this paper is the best model, which can define the drying curves at the practices at 400, 550, 700 and 800 W, but Page 2 is the best model at 300 W in drying corn by microwave.
2. The lowest energy was consumed in reducing the moisture in corn from 31 to 13% at 800 W and the highest energy was consumed for the same purpose at 300 W.
3. Thousand-grain weight (369.31 to 464.95), bulk density (463.24 to 547.443) and true density (1065.51 to 1213.175), which are especially important in storage of corn and machinery design, increase depending on the reduction in moisture content (31 and 13%). Porosity increased depending on the decrease in moisture content while rolling resistance of the corn grain on steel, rubber, aluminum, steel plate, glass and MDF reduced depending on the decrease in moisture content.
4. The practice in which the lowest variation in color occurred according to L values among other practices is the practice at 550 W. Discoloration at 550, 700 and 800 W was slower from the point of view of red-color formation compared with other practices. According to b values, the practice at 550 W yielded the better result and discolorration was slower in this practice.

NOMENCLATURE: A_s**,** Surface area, mm^2; D_a**,** arithmetic mean diameter of seed, mm; D_g**,** geometric mean diameter of seed, mm; L**,** length of seed, mm; MR**,** moisture ratio, decimal; M_t**,** moisture content at a specific time, g water per dry solids; M_o**,** initial moisture content, g water per g dry solids; M_e**,** equilibrium moisture content, g water per g dry solids; $MR_{exp,i}$**,** experimental moisture content, %d.b; $MR_{pre,I}$**,** prediction moisture content, %d.b; N**,** observation number; ***RMSE*****,** root mean square error; R^2**,** coefficient of determination; X^2**,** chi-square; Q**,** mass of water to added, kg; T**,** thickness of seed, mm; V_t**,** terminal velocity, m s^{-1}; W**,** width of seed, mm; W_i**,** initial mass of sample, kg; ε**,** porosity, %; α**,** angle of tilt, degree; μ**,** static coefficient of friction; ρ_b**,** bulk density, kg m^{-3}; ρ_t**,** true density, kg m^{-3}; ϕ**,** sphericity of seed (decimal); **a, k, n, c, k_o, b, k_1, g, h,** experimental constants

REFERENCES

Al-Harahsheh M, Al-Muhtaseb HA, Magee TRA (2009). Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. Chemical Eng. Proc. 48: 524-531.
Askari GR, Emam-Djomeh Z, Mousavi SM (2008). Investigation of the effects of microwave treatment on the optical properties of apple slices during drying. Drying Tech. 26(11): 1362-1368.
Anonymous (2006) http://www.yaylabakliyat.com.tr.
Ayensu A (1997). Dehydration of food crops using solar dryer with convective heat flow. Solar Energy, 59 : 4-6.
Cocci E, Sacchetti G, Vallicelli M, Angioloni A, Rosa DM (2008). Spaghetti cooking by microwave oven: Cooking kinetics and product quality. J. Food Eng. 85: 537-546.
Dadali G, Demirhan E, Özbek B (2007). Microwave heat treatment of spinach: Drying kinetic and effective moisture diffusivity. Drying Tech. 25(10): 1713-1723.
Dadali G, Özbek B (2008). Microwave heat treatment of leek: drying kinetic and effective moisture diffusivity. Int. J. Food Sci. Tech. 43: 1443-1451.
Dadali G, Demirhan E, Özbek B (2008). Effect of drying conditions on rehydration kinetics of microwave dried spinach. Food Biol. Proc. 86: 235-241.
Decareau RV (1985). Microwaves in the food processing industry, 1st edn. Orlando, FL: Academic Press Inc.
Demirhan E, Özbek B (2009). Color Change Kinetics of Microwave-Dried Basil. Drying Tech. 27(1): 156-166.
Dursun E, Dursun I (2005). Some physical properties of caper seed. Biosyst. Eng. 92(2): 237-245.
Ertekin C, Yaldiz O (2004). Drying of eggplant and selection of a suitable thin layer drying model, J. Food Eng. 63: 349-359.
Gunasekaran S, Yang HW (2007). Optimization of pulsed microwave heating. J. Food Eng. 78: 1457-1462.
Gupta RK, Das SK (1997). Physical properties of sunflower seeds. J Agri. Eng. Res. 66: 1-8.
Guzmán-Gerónimo IR, López GM, Dorantes-Alvarez L (2008). Microwave processing of avocado: Volatile flavor profiling and olfactometry. Inn. Food Sci. Emer. Tech. 9: 501-506.
Işık E, Güler T (2003). Determination of surface area for apples with image analysis technique. J. Uludag Univ. Agric. Fac. 17(1): 59-64.
Işık E, Izli N (2007). Physical properties of sunflower seeds (Helianthus annuus L.), Int. J. Agric. Res. 2(8): 677-686.
James C, Barlow EK, James JS, Swain JM (2006). The influence of processing and product factors on the quality of microwave pre-cooked Bacon. J. Food Eng. 77: 835-843.
Karaaslan SN, Tunçer IK (2008). Development of a drying model for combined microwave–fan-assisted convection drying of spinach. Bio. Eng. 100(1): 44-52.
Kassem AS (1998). Comparative studies on thin layer drying models for wheat. 13th Int. February, Morocco. Congress on Agric. Eng. 6: 2-6
Krokida MK, Maroulis ZB, Saravacos GD (2001). The effect of the method of drying on the color of dehydrated products. Int. J. Food

Sci. Tech. 36(1): 53-59.
Madamba PS, Driscoll RH, Buckle KA (1996). The thin-layer drying characteristics of garlic slices, J. Food Eng. 29(1): 75-97.
Maskan M (2000). Microwave/air and microwave finish drying of banana. J. Food Eng. 44(2): 71-78.
Menge HO, Ertekin C, Aydin C (2005). Determination of appropriate model to drying with convection of apple slices. J. Agric. Mach. Sci. 1(3): 229-235.
Merkov ND, Durakova AG, Krasteva A (2005). Moisture sorption isotherms of common bean flour at several temperatures. Electron. J. Environ. Agric. Food Chem. 4(2): 892-898.
Mohsenin NN (1970). Physical Properties of Plant and Animal Materials. Newyork: Gordon and Breach Science Publishers.
Nimkar PM, Chattopadhyay PK (2001). Some physical properties of green gram. J. Agric. Eng. Res. 80(2): 183-189.
Nordin MFM, Daud WRW, Talib MZM, Osman HO (2008). Effect of process parameters on quality properties of microwave dried red pitaya (Hylocereus costaricensis). Int. J. Food Eng. 4(6): 1-17.
Ozdemir M, Devres OY (1999). The thin layer drying characteristics of hazelnuts during roasting. J. Food Eng. 42: 225-233.
Oztop HM, Sahin S, Sumnu G (2007). Optimization of microwave frying of potato slices by using Taguchi technique. J. Food Eng. 79: 83-91.
Özbek B, Dadali G (2007). Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. J. Food Eng. 83: 541-549.
Özdemir F, Akinci I (2004). Physical and nutritional properties of four major commercial Turkish hazelnut varieties. J. Food Eng. 63(3): 341-347.
Saçılık K, Eliçin AK (2005). The thin layer of characteristics of organic apple slices, J. Food Eng. 73(3): 281-289.
Sarsavadia, PN, Sawhney RL, Pangavhane DR, Singh SP (1999). Drying behaviour of brined onion slices. J. Food Eng. 40: 219-226.
Sharaf-Elden YI, Blaisdell JL, Hamdy MY (1980). A model for ear corn drying.Transac. ASAE. 23: 1261-1265.
Sharma PG, Prasad S (2006). Optimization of process parameters for microwave drying of garlic cloves. J. Food Eng. 75: 441-446.
SIS (2007) Agricultural Statistic, Ankara, Turkey.
Singh KK, Goswami TK (1996). Physical properties of cumin seed. J. Agric. Eng. Res. 64(2): 93-98.
Souraki AB, Mowla D (2008). Experimental and theoretical investigation of drying behaviour of garlic in an inert medium fluidized bed assisted by microwave. J. Food Eng. 88: 438-449.
Soysal Y (2004). Microwave drying characteristics of parsley. Biol. Eng. 89: 167-173.
Soysal Y, Öztekin S, Eren Ö (2006). Microwave Drying of Parsley: Modelling, Kinetics, and Energy Aspects. Biol. Eng. 93(4): 403-413.
Togrul IT, Pehlivan D (2002). Mathematical modelling of solar drying of apricots in thin layers, J. Food Eng. 55: 209-216.
Unal H, Işik E, Alpsoy HC (2006). Physical Properties of Black-eyed Pea. Pakistan J. Biol. Sci. 9(9): 1799-1806.
Uquiche E, Jeréz M, Ortíz J (2008). Effect of pretreatment with microwaves on mechanical extraction yield and quality of vegetable oil from Chilean hazelnuts (*Gevuina avellana* Mol). Inn. Food Sci. Emerging Tech. 9: 495-500.
Velu V, Nagender A, Rao PGP, Rao DG (2006). Dry milling characteristics of microwave dried maize grains (*Zea mays* L.). J. Food Eng. 74: 30-36.
Xue C, Sakai N, Fukuoka M (2008). Use of microwave heating to control the degree of starch gelatinization in noodles. J. Food Eng. 87: 357-362.
Yagcioglu A, Degirmencioglu A, Cagatay F (1999). Drying characteristics of bay leaves under different drying conditions. Proceedings of the Seventh International Congress on Mechanization and Energy in Agriculture. Adana, Turkey, 26-27 May. pp. 565-569.
Yaldız O, Ertekin C, (2001). Thin layer solar drying of some vegetables. Drying Tech. 19: 583-596.
Yalçin I, Özarslan C (2004). Physical properties of vetch seed. Biol. Eng. 88(4): 507–512.