Tarım Makinaları Bilimi Dergisi (Journal of Agricultural Machinery Science)
2012, 8 (2), 161-170

Microwave Drying of Strawberry Slices and the Determination of the Some Quality Parameters

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Received (Geliş Tarihi): 09.05.2012 Accepted (Kabul Tarihi): 29.06.2012

Abstract: Strawberry slices (*Fragaria* x *ananassa* cv. Camarosa) weighing 100 g (±0.04) with a moisture of 11.74 $kg_{(moisture)}$ $kg^{-1}_{(dry\ matter)}$ (92.15% wb) were dried using four different microwave output powers: 1000 W, 750 W, 500 W and 350 W. Drying continued until the slices moisture decreased to 0.16 (±0.02) $kg_{(moisture)}$ $kg^{-1}_{(dry\ matter)}$ (13.87% (±0.01) wb). Drying periods lasted 4-13.5 min for microwave drying, depending on the microwave output powers. In this study, measured values of moisture were compared with values of predicted obtained from 21l thin-layer equations; the Alibas Model was found to have the best fit. The optimum drying period, color, ascorbic acid and rehydration ratio content were obtained by 500 W.
Key words: Ascorbic acid, color, microwave drying, strawberry, thin layer drying.

Çilek Dilimlerinin Mikrodalga ile Kurutulması ve Bazı Kalite Parametrelerinin Belirlenmesi

Özet: İlk ağırlıkları 100 g (±0.04) ve nemi 11.74 $kg_{(su)}$ $kg^{-1}_{(kuru\ madde)}$ (92.15% yb) olan çilek dilimleri (*Fragaria* x *ananassa* cv. Camarosa) 1000 W, 750 W, 500 W and 350 W güç seviyelerinde dört farklı mikrodalga çıkış gücü kurutulmuşlardır. Kurutma işlemleri materyallerin nemi 0.16 (±0.02) $kg_{(su)}$ $kg^{-1}_{(kuru\ madde)}$ (13.87% (±0.01) yb) oluncaya dek sürdürülmüştür. Kurutma işlemleri mikrodalga güç seviyesiyesine bağlı olarak 4-13.5 d sürmüştür. Çalışmada, ölçülen nem değerleri 21 farklı ince tabaka kurutma eşitliğinin tahmin ettiği verilerle karşılaştırılmış ve Alibas Modeli'nin en yüksek sonuçları verdiği saptanmıştır. Renk, askorbik asit ve yeniden su alma oranları açısından en uygun modelin 500 W olduğu belirlenmiştir.
Anahtar kelimeler: Askorbik asit, renk, mikrodalga kurutma, çilek, ince tabaka kurutma.

INTRODUCTION

Strawberry (*Fragaria* x *ananassa* cv. Camarosa) is a member of the genus Fragaria (Rosaceae) (Kafkas *et al*., 2005). It is the most important berry fruit with the higher production in all over the world (Özuygur *et al*., 2006; Doymaz, 2008) because of its rich in vitamins, flavour, great taste, potassium, fiber and other secondary metabolies, also simple sugar source of energy and importance of human diet (Özuygur *et al*., 2006). Strawberry is one of the most delicate and highly perishable fruits, due to respiration, weight loss and susceptibility to fungal contamination (Zhang, 2006; Doymaz, 2008). Therefore, strawberry can be preserved by freezing and drying processes such as freeze, osmotic, microwave, and air drying (Evans *et al*., 2002; Shishehgarha *et al*., 2002; Taiwo *et al*., 2003; Askari *et al*., 2006; Doymaz, 2008). Besides, it can consume fresh or in many other forms such as juice, concentrate jam, and jelly and dried rehydrated with yoghurt and bakery products (El-Beltagy *et al*., 2006).

Drying is the most important process to preserve crops, grains and foods of all kinds (Doymaz, 2008). It suppresses the activities of the micro-organisms, enzymes or ferments in the material, allowing the product to be stored for a long period of time (Alibas, 2010). Microwave drying of products has become common because microwave drying prevents a decline in the quality of the product and ensures the rapid and efficient distribution of heat within the material (Díaz *et al*., 2003). Moreover, microwave drying reduces the drying time and saves energy during drying in producing high quality dry products

(Feng, 2002). Microwave drying can be successfully applied in the food processing industry due to the volumetric heating of materials (Torringa *et al.*, 2001).

Thin layer drying is the process of drying one layer of sample particles or slice; many mathematical models are used to describe this drying process, since mathematical modeling is important for performance improvements of these drying systems (Cihan *et al.*, 2007). Thin layer drying models fall into three categories: theoretical, semi-empirical and empirical (Ozdemir and Devres, 1999; Midilli and Kucuk, 2003).

The aims of this study were i) to evaluate the efficacy of microwave drying technique for strawberry slices; ii) to compare the measured findings obtained during the drying of strawberry slices with the predicted values obtained through several thin layer drying equations ; iii) to determine the best fit using statistical analysis; iv) to examine the changes in color, ascorbic acid content and rehydration ratio of the product after drying; and v) to determine the optimum output power for microwave drying strawberry slices considering the color, drying period and rehydration ratio.

MATERIAL and METHODS

Fresh strawberry slices

Fresh strawberry slices (*Fragaria* x *ananassa* cv. Camarosa) used for the drying experiments were harvested from plants in the Orhaneli county of Bursa. The strawberries were selected from healthy, uniform plants and were stored at a temperature of 4 °C ± 0.5 until used (Soysal, 2004). The fruits were removed from the refrigerator about 2h before experimentation and were allowed to attain room temperature (Doymaz, 2008). Three different samples, each weighing 50 g, were kept in the drying oven at 105 °C for 24 h after which the moisture content of the strawberry slices decreased to 4.08 ± 0.05 on a dry basis.

Drying equipment and drying method

Fresh strawberry slices were pretreated in the chamber of a steam cooker (Raks Buharlim, Manisa, Turkey) before drying to reduce enzymatic changes. The cooker was pre-set to produce 100 °C steam for 30 seconds.

The technical specifications of the programmable, multifunctional, domestic microwave oven used in the study (Arcelik MD592, Gebze, Turkey) were as follows: 230 V~, 50 Hz and 2900 W. When operating in the microwave function, the power produced by the oven was continuous. The oven can be operated at microwave output powers of 90, 160, 350, 500, 650, 750, 850 and 1000 W. The area on which microwave drying was conducted was 327 x 370 x 207 mm in size and consisted of a rotating glass plate with a 280 mm diameter at the base of the oven.

Tests were conducted in triplicate for each microwave power level, and mean moisture content as a function of drying time was calculated. Weight was measured by an electronic balance (Sartorious EX 2000A, Germany) with an accuracy of 0.01 g.

Drying tests were repeated three times at each microwave power level, and the average weight loss was reported. Moisture content [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$] was determined using the following equation:

$$M_0 = \frac{(W_o - W_k)}{W_k} = \frac{[W_o - (W_t - W_s)]}{W_t - W_s} \qquad (1)$$

where M_0 is the initial moisture content at any time[$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$], W_0 is weight of sample at any time, W_t is the initial weight of the sample, W_k is the total dry matter content of the sample and W_s is the total water amount content of the sample. The moisture ratio *(MR)* in these model equations was defined as follows:

$$MR = \frac{M_t - M_e}{M_o - M_e} \qquad (2)$$

where M is the moisture content at any time [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$], M_0 is the initial moisture content (kg moisture kg^{-1}dry matter) and M_e is the equilibrium moisture content [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$]. The equilibrium moisture content (M_e) was assumed to be zero for microwave drying (Diamente and Munro, 1993; Maskan 2000; Ertekin and Yaldız, 2004). Drying rate *(DR)* during drying experiments was calculated using the following equation:

$$DR = \frac{M_{t+dt} - M_t}{d_t} \qquad (3)$$

where M_t is the moisture content at t time and M_{t+dt} is the moisture content at t+dt [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$] (Doymaz *et al.*, 2006; Karaaslan and Tunçer, 2008).

Table 1.Mathematical thin-layer drying models used for the approximation

	Model name	*Model equation*	*Eq no*	*References*
1	Lewis	$M_R = \exp(-kt)$	(4)	(Lewis, 1921)
2	Page	$M_R = \exp(-kt^n)$	(5)	(Page, 1949)
3	Modified Page	$M_R = \exp[-(kt)^n]$	(6)	(Overhults *et al.*, 1973)
4	Henderson and Pabis	$M_R = a\exp(-kt)$	(7)	(Henderson and Pabis, 1961)
5	Yagcioglu et al. (Logarithmic)	$M_R = a\exp(-kt) + c$	(8)	(Yagcioglu *et al.*, 1999)
6	Two-term	$M_R = a\exp(-k_0 t) + b\exp(-k_1 t)$	(9)	(Henderson, 1974)
7	Two-term exponential (Approximation of diffusion)	$M_R = a\exp(-kt) + (1-a)\exp(-kat)$	(10)	(Sharaf-Elden *et al.*, 1980)
8	Wang and Singh	$M_R = 1 + at + bt^2$	(11)	(Wang and Singh, 1978)
9	Thomson	$t = a.\ln(M_R) + b[\ln(M_R)]^2$	(12)	(Thomson *et al.*, 1968)
10	Diffusion approach	$M_R = a\exp(-kt) + (1-a)\exp(-kbt)$	(13)	(Kassem, 1998)
11	Verma et al.	$M_R = a\exp(-kt) + (1-a)\exp(-gt)$	(14)	(Verma *et al.*, 1985)
12	Modified Henderson and Pabis	$M_R = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	(15)	(Karathanos, 1999)
13	Simlified Fick's diffusion (SFFD) equation	$M_R = a\exp[-c(t/L^2)]$	(16)	(Diamente and Munro, 1991)
14	Modified Page equation-II	$M_R = \exp[-k(t/L^2)^n]$	(17)	(Diamente and Munro, 1993)
15	Midilli et al.	$M_R = a\exp(-kt^n) + bt$	(18)	(Midilli *et al.*, 2002)
16	Weibull distribution	$M_R = a - b\exp[-(kt^n)]$	(19)	(Babalis *et al.*, 2006)
17	Aghbashlo et al.	$M_R = \exp(-k_1 t / 1 + k_2 t)$	(20)	(Aghbashlo *et al.*, 2009)
18	Logistic	$M_R = a_0 / (1 + a\exp(kt))$	(21)	(Chandra and Singh, 1995)
19	Jena and Das	$M_R = a\exp(-kt + b\sqrt{t}) + c$	(22)	(Jena and Das, 2007)
20	Demir et al.	$M_R = a\exp(-kt)^n + c$	(23)	(Demir *et al.*, 2007)
21	Alibas	$M_R = a\exp((-kt^n) + (bt)) + g$	(24)	(Alibaş, 2012)

M_R, moisture ratio; *a*, a_0, *b, c, g, h,* coefficients and *n,* microwave drying exponent specific to each equation; *k*, k_0, k_1, k_2, drying coefficient specific to each equation; *t*, time; *L*, thickness.

Data analysis

This research was conducted using a randomized plots factorial experimental design, and all measures were tested in triplicate. Mean differences were tested for significance using a LSD (MSTATC) test at 0.01 level of significance.

Twenty one empirical and semi-empirical thin-layer drying equations [Eq. (4)-Eq. (24)] were used in this study and are listed in Table 1. Non-linear regression analyses of these equations were made using SPSS 17.0 and were performed to estimate the parameters *k*, k_0, k_1, k_2, *a*, a_0, *b, c, g,* and *n* of empirical and semi-empirical equations (Table 1).

Compared Mathematical Formulations

The regression coefficient *(R^2)* was the primary criterion for selecting the most suitable equation to describe the microwave drying curves of strawberry slices. The correlation was used to test the linear relationship between the measured and estimated values, which were calculated from the following equation:

$$R^2 = \frac{\sum_{i=1}^{N}(M_{R_{\exp,i}} - M_{R_{\exp mean,i}})^2 - (M_{R_{pre,i}} - M_{R_{\exp,i}})^2}{\sum_{i=1}^{N}(M_{R_{\exp,i}} - M_{R_{\exp mean,i}})^2} \quad (25)$$

where R^2 is the coefficient of correlation, $M_{Rexp,i}$ is the experimental moisture ratio found in any measurement, $M_{Rpre,i}$ is the predicted moisture ratio for this measurement and *N* is the total number of observations.

The standard error of estimate (*SEE*) provides information on the long-term performance of the correlations by allowing for a comparison between the actual deviations of predicted and measured values term by term. The ideal value of *SEE* is zero, and *SEE* was calculated as follows:

$$SEE = \sqrt{\frac{\sum_{i=1}^{N}(M_{R_{\exp,i}} - M_{R_{pre,i}})^2}{N - n_i}} \quad (26)$$

where n_i is the number of constants.

The root mean square error (*RMSE*) was computed from the following equation and provided information on the short-term performance of the correlations.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(M_{R_{pre,i}} - M_{R\exp,i})^2}{N}} \quad (27)$$

Chi square (χ^2) was the mean square of the deviations between the experimental and predicted moisture levels. Lower values of χ^2 indicated a better goodness of fit.

$$\chi^2 = \frac{\sum_{i=1}^{N}(M_{R_{\exp,i}} - M_{R_{pre,i}})^2}{N-n} \quad (28)$$

Color parameters

Strawberry slice color was determined by two readings on each of the different symmetrical faces of the slice using a Minolta CR 400 colorimeter (Konica-Minolta, Osaka, Japan), calibrated with a white standard tile. The color brightness coordinate *L* measures the whiteness value of *a* color 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. In addition, the chroma (*C*) [Eq. (29)] and hue angle (*α°*) [Eq. (30)] were calculated from the values for *a* (redness/greenness) and *b* (yellowness/blueness) and used to describe the color change during drying (Soysal, 2004):

$$C = \sqrt{a^2 + b^2} \quad (29)$$

$$\alpha = \tan^{-1}(b/a) \quad (30)$$

Ascorbic acid

Ascorbic acid was determined by extracting the samples with oxalic acid (0.4%) and then reading and calculating the absorbency values at 520 nm with a spectrophotometer (Shimadzu UV-120-01, Shimadzu Co., Duisburg, Germany) (Alibas-Ozkan *et al*., 2007, Holden, 1976).

Rehydration capacity

Five grams of the dried products were added to 200 ml distilled water, in a 400 ml flask beaker at 25 ◦C for 24 h. After rehydration, samples were taken out, residual water was removed and adhering water was absorbed carefully with tissue paper and then weighed (Al-Khuseibi *et al*., 2005; Doymaz, 2008). The rehydration capacity was calculated as following:

$$rehydration\_capacity = \frac{W_r}{W_d} \quad (31)$$

Where; *Wr* is the weight after rehydration (kg) and *Wd* is the weight of dried material (kg).

RESULTS and DISCUSSION

Drying curves

Microwave drying trials were conducted at the microwave output power values of 1000, 750, 500 and 350 W. Moisture-time diagrams of strawberry slices along the drying period on a dry basis are presented in Figure 1, which shows a reduction in drying time occurred with the increase in microwave power level (Soysal, 2004). The drying periods of strawberry slices from initial moisture content of 11.74 on a dry basis (92.15% w.b.) to a moisture content of to 0.16 (±0.02) $kg_{(moisture)}$ $kg^{-1}_{(dry\ matter)}$ (13.87% (±0.01) wb) were 4, 6.5, 9.5 and 13.5 min in microwave output powers of 1000, 750, 500 and 350 W, respectively. A marked decline in the drying period of the strawberry slices was noted with increasing microwave power levels (Prabhanjan *et al*., 1995; Drouzas and Schubert, 1996; Funebo and Ohlsson, 1998; Soysal, 2004, Alibas-Ozkan *et al*. 2007). The drying time at the 350 W microwave power level was 3.4 times longer than that of 1000 W. The drying time was reduced by 1.6 and 2.4 times when the slices were dried at 750 and 500 W microwave output powers compared with the drying treatment at 1000 W of microwave output power.

The drying rates [$kg_{(moisture)}$ $kg^{-1}_{(dry\ matter)}$ min^{-1}] obtained in unit time under different microwave power levels are shown in Figure 2. The average drying rates of the strawberry slices at the microwave output powers of 350, 500, 750 and 1000 W were 0.20, 0.30, 0.45 and 0.67 $kg_{(moisture)}$ $kg^{-1}_{(dry\ matter)}$ min^{-1}, respectively. The moisture content of the material was very high during the initial phase of the drying, which resulted in a higher absorption of microwave power and higher drying rates because of the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave power and resulted in a fall of the drying rate (Feng, 2002; Maskan, 2000; Soysal, 2004; Alibas, 2010).The drying rates increased with the increasing microwave power levels; therefore, microwave power level had a considerable effect on the drying rates, as found in previous studies (Funebo and Ohlsson, 1998; Maskan, 2000; Sharma and Prasad, 2001; Soysal, 2004, Alibas-Ozkan *et al.*, 2007).

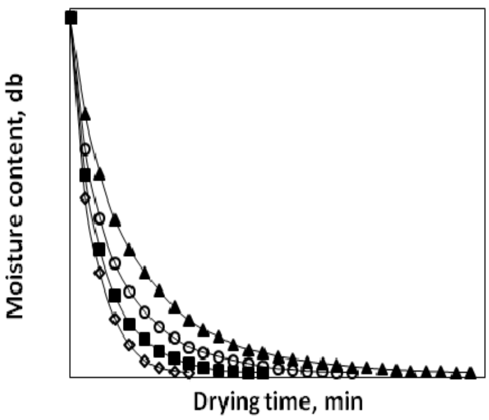

Figure 1.The microwave drying curve of strawberry slices on dry basis; ◇, 1000 W; ■, 750 W; ○, 500 W; ▲, 350 W.

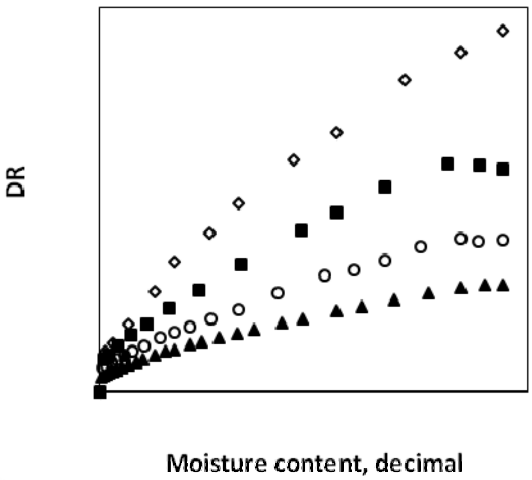

Figure 2. Microwave drying rates of the strawberry slices at different microwave power levels; ◇, 1000 W; ■, 750 W; ○, 500 W; ▲, 350 W.

Modeling drying data

In this study, 21 thin-layer drying models were used as defined by various researchers and are shown in Table 1. The coefficient of correlation (R^2), standard error of estimate (*SEE*), root mean square error (*RMSE*) and chi-square (χ^2) are shown for the microwave drying of thin layer drying models in Table 2. The coefficient of correlation (R^2) was one of the primary criteria for selecting the best model to define the drying curves of the strawberry slices. (Ertekin and Yaldız, 2004; Doymaz *et al.*, 2006; Movagharnejat and Nikzad, 2007). In this study, the thin-layer drying model in which (R^2) value was closest to 1.0000, and the smallest *SEE* values were chosen to be the most optimum model (Jena and Das, 2007; Movagharnejat and Nikzad, 2007; Demir *et al.*, 2007; Saeed *et al.*, 2008). Within all drying trials, the coefficient of correlation (R^2) of the Alibas model was closest to 1.0000 compared with the other 21 thin-layer drying models defined in the literature. The microwave drying constants and the coefficients of the thin-layer drying models are shown in Table 3. The drying curves calculated according to the best fit model are shown for microwave drying in Figure 3.

Color parameters

The results of the color parameters obtained from the drying processes of microwave drying are presented in Table 4 for *L* (brightness), *a* (redness/greenness), *b* (yellowness/blueness), *C* (chroma) and *α°* (hue angle) values. The color parameters obtained through microwave drying trials were compared with fresh strawberry slices and are shown in Table 4.

An important loss in *L* , *a* and *b* values occurred in strawberry slices dried by microwave energy compared with fresh slices. The highest loss in brightness (*L*) occurred with the 1000 W, the highest loss in redness (*a*) occurred with the 350 W and the highest loss in yellowness (*b*) occurred with the 750 W microwave output level. The *L* and *a* level of the strawberry slices after the drying process carried out at 500 W of microwave power level was closest to that of fresh strawberry slices compared with the other microwave output power levels. Color values closest to those of fresh strawberry slices were achieved in the drying process carried out at 500 W and 750 W microwave output powers in this study, confirming the results obtained in several other studies (Schiffmann, 1995; Feng, 2002; Piotrowski *et al.*, 2004; Soysal, 2004).

Table 2. Statistical results obtained from different thin-layer drying models for the different microwave power density; R^2, coefficient of regression; *SEE*, standard error of estimate; χ^2, chi-square; *RMSE*, root mean square error.

Model No	***SEE***	R^2	***RMSE***	χ^2	***SEE***	R^2	***RMSE***	χ^2
			1000 W				***750 W***	
1	0.0145	0.9980	8.3439 10^{-03}	7.8324 10^{-05}	0.0205	0.9947	3.0097 10^{-02}	9.7552 10^{-04}
2	0.0064	0.9997	2.8252 10^{-03}	1.0262 10^{-05}	0.0036	0.9999	4.5701 10^{-03}	2.4367 10^{-05}
3	0.0155	0.9980	8.3439 10^{-03}	8.9513 10^{-05}	0.0213	0.9947	3.0097 10^{-02}	1.0568 10^{-03}
4	0.0106	0.9982	1.1105 10^{-02}	1.5857 10^{-04}	0.0201	0.9953	3.3669 10^{-02}	1.3225 10^{-03}
5	0.0137	0.9987	4.6837 10^{-09}	3.2905 10^{-17}	0.0136	0.9980	6.7109 10^{-10}	5.7319 10^{-19}
6	0.0043	0.9999	3.0347 10^{-03}	1.6577 10^{-05}	0.0038	0.9999	2.1970 10^{-03}	6.7577 10^{-06}
7	0.0155	0.9980	8.3439 10^{-03}	8.9513 10^{-05}	0.0048	0.9997	7.7787 10^{-03}	7.0594 10^{-05}
8	0.0953	0.9258	5.8624 10^{-02}	4.4188 10^{-03}	0.1251	0.8183	1.1231 10^{-01}	1.4715 10^{-02}
9	0.0830	0.9968	1.0638 10^{-02}	1.4551 10^{-04}	0.1964	0.9919	2.7774 10^{-02}	8.9994 10^{-04}
10	0.0078	0.9995	1.8513 10^{-03}	5.1410 10^{-04}	0.0223	0.9947	2.5238 10^{-03}	8.1065 10^{-06}
11	0.0043	0.9999	1.0908 10^{-03}	1.7849 10^{-06}	0.0036	0.9999	2.0172 10^{-03}	5.1791 10^{-06}
12	0.0042	0.9999	1.8176 10^{-03}	9.9113 10^{-06}	0.0023	1.0000	1.3263 10^{-03}	3.0786 10^{-06}
13	0.0149	0.9982	1.1105 10^{-02}	1.8499 10^{-04}	0.0202	0.9953	3.3669 10^{-02}	1.4427 10^{-03}
14	0.0064	0.9997	2.8252 10^{-03}	1.1972 10^{-05}	0.0026	0.9999	4.5701 10^{-03}	2.6582 10^{-05}
15	0.0070	0.9997	4.1687 10^{-04}	3.1281 10^{-07}	0.0019	1.0000	6.5678 10^{-05}	6.0391 10^{-09}
16	0.0067	0.9997	5.7805 10^{-12}	6.0145 10^{-23}	0.0019	1.0000	1.9287 10^{-16}	5.2077 10^{-32}
17	0.0096	0.9992	3.9265 10^{-03}	1.9822 10^{-05}	0.0048	0.9997	3.0986 10^{-03}	1.1202 10^{-05}
18	0.0161	0.9982	1.1105 10^{-02}	1.8499 10^{-04}	0.0210	0.9953	3.3669 10^{-02}	1.4427 10^{-03}
19	0.0056	0.9998	1.1180 10^{-12}	2.2498 10^{-24}	0.0026	0.9999	2.5297 10^{-10}	8.9594 10^{-20}
20	0.0150	0.9987	2.8635 10^{-10}	1.4759 10^{-19}	0.0142	0.9980	4.3309 10^{-09}	2.6259 10^{-17}
21	**0.0023**	**1.0000**	**1.8516 10^{-12}**	**7.7137 10^{-24}**	**0.0020**	**1.0000**	**7.8416 10^{-12}**	**9.5653 10^{-23}**
No			***500 W***				***350 W***	
1	0.0279	0.9879	4.8038 10^{-02}	2.4291 10^{-03}	0.0245	0.9899	4.8778 10^{-02}	2.4674 10^{-03}
2	0.0043	0.9997	6.0926 10^{-03}	4.1245 10^{-05}	0.0049	0.9996	9.5276 10^{-03}	9.7759 10^{-05}
3	0.0287	0.9879	4.8038 10^{-02}	2.5641 10^{-03}	0.0249	0.9899	4.8778 10^{-02}	2.5623 10^{-03}
4	0.0260	0.9901	5.1573 10^{-02}	2.9554 10^{-03}	0.0214	0.9926	5.1117 10^{-02}	2.8139 10^{-03}
5	0.0180	0.9955	1.3182 10^{-11}	2.0444 10^{-22}	0.0140	0.9969	9.7299 10^{-11}	1.0603 10^{-20}
6	0.0024	0.9998	2.7111 10^{-03}	9.1873 10^{-06}	0.0044	0.9997	4.1603 10^{-03}	2.0193 10^{-05}
7	0.0105	0.9984	2.0765 10^{-02}	4.7908 10^{-04}	0.0073	0.9991	1.7978 10^{-02}	3.4807 10^{-04}
8	0.1327	0.7417	1.5431 10^{-01}	2.6456 10^{-02}	0.1238	0.7507	1.7516 10^{-01}	3.3041 10^{-02}
9	0.1729	0.9968	1.0507 10^{-02}	1.2267 10^{-04}	0.1435	0.9988	5.9357 10^{-02}	3.7943 10^{-03}
10	0.0032	0.9998	2.4884 10^{-03}	7.2847 10^{-06}	0.0051	0.9996	8.2080 10^{-03}	7.5455 10^{-05}
11	0.0033	0.9998	2.4599 10^{-03}	7.1187 10^{-06}	0.0044	0.9997	3.7558 10^{-03}	1.5799 10^{-05}
12	0.0020	1.0000	5.9861 10^{-04}	5.1191 10^{-07}	0.0028	0.9999	2.7271 10^{-03}	9.4652 10^{-06}
13	0.0267	0.9901	5.1574 10^{-02}	3.1292 10^{-03}	0.0218	0.9926	5.1117 10^{-02}	2.9265 10^{-03}
14	0.0044	0.9997	6.0926 10^{-03}	4.3671 10^{-05}	0.0050	0.9996	9.5276 10^{-03}	1.0167 10^{-04}
15	0.0030	0.9999	3.8822 10^{-04}	1.8839 10^{-07}	0.0028	0.9999	3.9140 10^{-04}	1.7872 10^{-07}
16	0.0028	0.9999	1.1381 10^{-15}	1.6191 10^{-30}	0.0026	0.9998	2.4137 10^{-11}	6.7969 10^{-22}
17	0.0070	0.9993	6.6358 10^{-03}	4.8926 10^{-05}	0.0061	0.9994	6.5919 10^{-03}	4.6795 10^{-05}
18	0.0267	0.9901	5.1573 10^{-02}	3.1292 10^{-03}	0.0218	0.9926	5.1117 10^{-02}	2.9265 10^{-03}
19	0.0049	0.9997	1.1055 10^{-11}	1.5276 10^{-22}	0.0044	0.9997	4.2601 10^{-14}	2.1173 10^{-27}
20	0.0186	0.9955	5.2112 10^{-09}	3.3946 10^{-17}	0.0143	0.9969	7.6742 10^{-07}	6.8710 10^{-13}
21	**0.0020**	**1.0000**	**3.0314 10^{-06}**	**1.2252 10^{-11}**	**0.0023**	**0.9999**	**2.7815 10^{-12}**	**9.4190 10^{-24}**

Ascorbic acid content

The ascorbic acid levels in strawberry slices dried by microwave were compared with the levels in a fresh sample; the results, which are presented in Table 5. Ascorbic acid values were the lowest (37.66 mg 100^{-1} g^{-1}) at 1000 W microwave output power with the shortest drying period. Of all the drying methods, the highest ascorbic acid content of the strawberry slices was achieved at 500 W microwave levels (57.69 mg 100^{-1} g^{-1}). A study of microwave drying treatment of spinach leaves by Alibas-Ozkan *et al.* (2007) showed that the best ascorbic acid values were obtained at 750 W power with 43.09 mg 100^{-1} g^{-1} and at 650 W power with 43.57 mg 100^{-1} g^{-1}.

Table 3. Coefficients obtained from different thin-layer drying models for the different microwave powers.

Model No	***Coefficients 1000 W***	***Coefficients 750 W***
1	k=1.2621	k=0.9989
2	k=1.2693 n=0.8977	k=1.0425 n=0.8363
3	k=1.1356 n=1.1114	k=1.0134 n=0.9857
4	k=1.2493 a=0.9890	k=0.9756 a=0.9769
5	k=1.3016 a=0.9801 c=0.0124	k=1.0581 a=0.9644 c=0.0220
6	k=1.1015 m=44.0854 a=0.8653 b=0.1347	k=1.9003 m=0.6618 a=0.4599 b=0.5394
7	k=1.2621 a=1.0001	k=2.4112 a=0.3125
8	a=-0.7252 b=0.1252	a=-0.4874 b=0.0550
9	a=-0.3120 b=0.0184	a=-0.3210 b=0.0671
10	k=2.3540 a=0.3043 b=0.4345	k=2.0349 a=0.4236 b=0.3345
11	k=5.8994 a=0.1398 g=1.1065	k=0.6626 a=0.5410 g=1.9079
12	k=1.1199 a=0.8870 b=-0.7083 10^{04} c=0.7084 10^{04} g=27.3533 h=64.9200	k=0.5625 a=0.3347 b=0.0730 c=0.5923 g=38.2557 h=1.3025
13	a=0.9890 c=3.5754 L=1.6918	a=0.9769 c=1.1417 L=1.0818
14	k=0.9064 n=0.8977 L=0.8290	k=2.1618 n=0.8363 L=1.5465
15	k=1.2590 n=0.8831 a=0.9994 b=-0.0015	k=1.0470 n=0.8530 a=1.0001 b=0.0011
16	k=1.2428 n=0.8752 a=-0.0079 b=1.0074	k=1.0578 n=0.8589 a=0.0070 b=-0.9930
17	k_1=1.3835 k_2=0.0785	k_1=1.1823 k_2=0.1191
18	k=1.2493 a_0=0.1697 10^{07} a=0.1716 10^{07}	k=0.9756 a_0=0.4656 10^{06} a=0.4766 10^{06}
19	k=0.9505 a=1.0039 b=-0.2955 c=-0.0042	k=0.7593 a=0.9899 b=-0.2975 c=0.0104
20	k=1.3591 a=0.9801 n=0.9577 c=0.0124	k=1.0710 a=0.9644 n=0.9880 c=0.0220
21	**k=0.0219 n=-2.0669 a=0.9963 b=-1.2163 g=0.0037**	**k=1.4343 n=0.8961 a=0.9935 b=0.3766 g=0.0065**
M.no	***500 W***	***350 W***
1	k=0.7239	k=0.4878
2	k=0.8170 n=0.7882	k=0.5788 n=0.8207
3	k=1.3873 n=0.5218	k=0.5901 n=0.8265
4	k=0.6877 a=0.9538	k=0.4600 a=0.9473
5	k=0.7709 a=0.9435 c=0.0279	k=0.5103 a=0.9409 c=0.0250
6	k=1.5426 m=0.4376 a=0.4818 b=0.5169	k=0.9885 m=0.3118 a=0.4594 b=0.5371
7	k=2.0297 a=0.2737	k=1.3280 a=0.1913
8	a=-0.3387 b=0.0265	a=-0.2377 b=0.0131
9	a=-0.4417 b=0.1096	a=-0.6365 b=0.1584
10	k=1.5627 a=0.4783 b=0.2812	k=1.2889 a=0.3516 b=0.2654
11	k=0.4383 a=0.5187 g=1.5516	k=0.3144 a=0.5471 g=1.0139
12	k=0.3513 a=0.2899 b=0.5258 c=0.1842 g=0.8571 h=2.7115	k=0.2659 a=0.3468 b=0.1056 c=0.5477 g=2.4145 h=0.6435
13	a=0.9538 c=2.3402 L=1.8447	a=0.9473 c=2.8482 L=2.4883
14	k=2.6637 n=0.7882 L=2.1163	k=2.5459 n=0.8207 L=2.4657
15	k=0.8179 n=0.8036 a=1.0012 b=0.0008	k=0.5766 n=0.8386 a=1.0019 b=0.0007
16	k=0.8261 n=0.8107 a=0.0079 b=-0.9930	k=0.5816 n=0.8464 a=0.0095 b=-0.9918
17	k_1=0.9083 k_2=0.1190	k_1=0.5947 k_2=0.0695
18	k=0.6877 a_0=0.4198 10^{06} a=0.4401 10^{06}	k=0.4600 a_0=0.4091 10^{06} a=0.4318 10^{06}
19	k=0.4928 a=0.9883 b=-0.3336 c=0.0132	k=0.3732 a=0.9882 b=-0.2112 c=0.0144
20	k=0.6853 a=0.9435 n=1.1249 c=0.0279	k=0.7150 a=0.9409 n=0.7137 c=0.0250
21	**k=0.2887 10^{03} n=0.9995 a=0.9983 b=0.2879 10^{03} g=0.0022**	**k=88.0134 n=0.9991 a=0.9941 b=87.4354 g=0.0063**

Rehydration capacity

The results for rehydration capacity are shown in Figure 4. The rehydration tests show that the rehydration at 1000 W microwave output power is slower than 750 W (2.86%), 500 W (2.88%) and 350 W (2.80%) microwave powers.

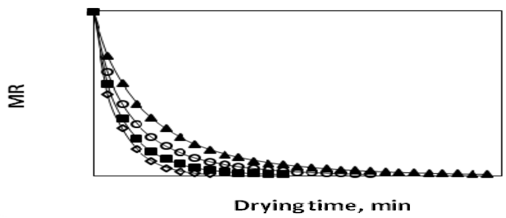

Figure3. Moisture ratio versus time, comparing experimental curve with the predicted one (-) through Alibas Model for strawberry slices under various microwave powers; ◇, 1000 W; ■, 750 W; ○, 500 W; ▲, 350 W.

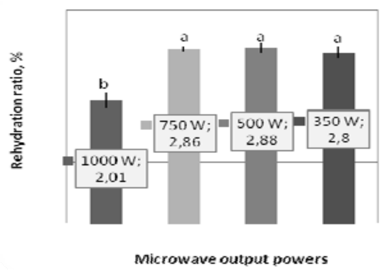

Figure4. Rehydration ration of microwave dried samples,% (P < 0.01)

CONCLUSION

Strawberry slices were dried using microwave drying. Drying periods lasted 4-13.5 min for microwave drying, depending on the microwave output powers. The measured values of moisture were compared with values of predicted obtained from several thin-layer equations; the Alibas Model was found to have the best fit. The best color parameters, ascorbic acid contents and rehydration ratio were obtained at 500 W microwave power for microwave drying. The optimum microwave level was 500 and 750 W microwave power levels with a drying period of 9.5 and 6.5 min, respectively.

Table 4. Colour parameters of dried and fresh strawberries.

Microwave Powers	***Colour Parameters***				
	L**	***a*****	***b*****	***C*****	***α°*****
Fresh strawberries	39.64^{a} ± (0.52)	35.23^{a} ± (0.34)	14.45^{a} ± (0.20)	38.08^{a} ± (0.39)	22.39^{b} ± (0.17)
1000 W	27.78^{d} ± (0.89)	29.08^{b} ± (0.52)	14.16^{a} ± (0.15)	32.35^{c} ± (0.53)	26.05^{a} ± (0.22)
750 W	36.91^{b} ± (0.68)	33.56^{a} ± (0.57)	13.45^{b} ± (0.24)	36.16^{b} ± (0.62)	21.84^{b} ± (0.02)
500 W	37.10^{b} ± (1.23)	33.75^{a} ± (0.74)	13.51^{b} ± (0.34)	36.35^{ab} ± (0.81)	21.81^{b} ± (0.06)
350 W	31.24^{c} ± (0.97)	28.65^{b} ± (1.09)	14.07^{ab} ± (0.18)	31.92^{c} ± (1.00)	26.17^{a} ± (0.53)

** Means with same letter do not show significance at P < 0.01.

L, brightness (+100)/ darkness (+0); a, redness (+50)/greenness (-50) coordinate; b, yellowness (+50)/blueness (-50) coordinate; C, chroma; α°, hue angle

Table 5. Ascorbic acid content of dried and fresh strawberries

Microwave Powers	***Ascorbic Acid (mg)*****
Fresh strawberries	60.85^{a} ± (0.60)
1000 W	37.66^{c} ± (1.80)
750 W	56.15^{b} ± (2.41)
500 W	57.69^{ab} ± (1.05)
350 W	40.24^{c} ± (1.97)

** Means with same letter do not show significance at P < 0.01.

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