Australian Journal of Crop Science

AJCS

AJCS 6(10):1441-1447 (2012) ISSN:1835-2707

Pulsed microwave drying kinetics of fig fruit (*Ficus carica* L.)

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Abstract

The main objective of this study was to investigate the effects of microwave power intensity and pulsing ratio on drying behavior of fig fruit in a laboratory scale microwave dryer. During experiments, weight and temperature of the samples were recorded at regular intervals (10 s). The results showed that drying time of products increased by approximately 200% under pulsing ratio of 1.5 to 4. In contrast drying time decreased by approximately 500% under microwave power intensity of 0.5 to 2.5 W/g. Furthermore, 11 different thin layer drying models were analyzed for investigation of moisture variation of fig fruit. The performance of these mathematical models were compared based on the three statistical criteria, such as coefficient of determination (R^2), standard error of estimate (SEE) and residual sum of square (RSS). According to the results, Quadratic and Logarithmic models described the drying kinetics of fig with the mean coefficient of determination (R^2) of 0.9984. Additionally, microwave power intensity resulted in the raised sample temperature leading to better removal of moisture. The mass transfer was also attenuated with the pulsing ratio.

Keywords: Drying temperature, Drying time, Microwave power intensity, Thin-layer drying models.

Abbreviations: a, b, c and n: constant coefficients in drying models; a_1 and b_2: drying constant (min^{-2}); a_2, b_1, g and k: drying constant (min^{-1}); M: moisture content at any time (kg of water per kg of dry matter); M_e: equilibrium moisture content (kg of water per kg of dry matter); M_o: initial moisture content (kg of water per kg of dry matter); MR: moisture ratio (dimensionless); MW: microwave; PR: pulsing ratio; R^2: coefficient of determination; RSS: residual sum of square; SEE: standard error estimate; t: drying time (min); T: temperature (°C).

Introduction

Fig (*Ficus carica* L.) is a strategic product in Iran with yearly production of 76414 tones ranking forth in the world (FAO, 2010). It can be consumed freshly or in dried, canned, and preserved forms at all seasons (Doymaz, 2005). However, the shelf life of fresh fruit, harvested at ripe stage, is about 2 days under the ambient temperatures of the harvest season at the end of summer (Daisuke et al., 2011). Drying is the most important process to preserve the fruits. Fig fruit can be dried either by traditional methods (sun or solar drying) or in conventional hot-air dryers (Babalis et al., 2006). Sun drying is extremely weather dependent and has the drawbacks of dust contamination, microbial infestation and low quality. The required drying time may be quite long (Ratti and Mujumdar, 1997). On the other hand, using hot-air drying, fig is exposed to elevated drying temperatures, which leads to an increase in shrinkage and toughness. Conventional hot-air drying causes serious damage to flavor, color and nutrient content of fruit (Altan and Maskan, 2005). These drawbacks plus with long drying time and low energy efficiency, have motivated researchers to think about finding alternative drying methods. In recent years, microwave (MW) drying has gained a great deal of popularity as an alternative drying method in the food industry. MW drying is rapid, much uniform and energy efficient compared to conventional hot-air drying (Schiffmann, 2006; Zheng et al., 2004). MW, basically, is a part of the electromagnetic spectrum. The frequencies of MW are between 300 – 300,000 MHz with corresponding wavelengths between 1000 - 1 mm.

The MW energy generates heat in dielectric materials such as foods and fruits through dipole rotation and/or ionic polarization. The MW energy selectively warm up the areas with high liquid content (Metaxas and Meredith, 1993). In other words, MW heating influences on free moisture inside the product, which causes a vapor pressure gradient that removes moisture from the sample (Schiffmann, 2006). On the other side, fig fruit contains free internal moisture that makes MW energy as an appropriate candidate for its drying. Success of MW heating of foods often depends on the expected uniformity of heating. On the other hand, to improve MW drying, product temperature must be controlled and MW power must be adjusted. One of strategies used to control product temperature is applying the MW power in a pulsed form. This strategy can maximize drying efficiency since continuous heating does not accelerate the rate of water removal when critical moisture content is reached, especially for temperature sensitive products such as fruits (Gunasekaran, 1999). Although several researches related to MW drying technique have been published in the literature describing the drying behavior of fruits such as orange slices (Ruíz et al., 2003), apple (Andres et al., 2004), banana (Pereira et al., 2007), and pistachios (Kouchakzadeh and Shafeei, 2010), there is no information concerning MW for the drying of fig. The main objective of this research was to study the effects of the MW power intensity and pulsing ratio on drying kinetics of fig fruit in a laboratory scale MW dryer. In addition, the temperature profile of the samples during the

Table 1. Non-linear regression analysis results for MW drying of fig under various MW power intensities and different levels of pulsing ratios for (a) Quadratic model and (b) Logarithmic model.

(a)	0.5 W/g			1 W/g			1.5 W/g			2 W/g			2.5 W/g		
PR levels	R^2	SEE	RSS	R^2	SEE	RSS	R^2	SEE	RSS	R^2	SEE	RSS	R^2	SEE	RSS
1.5	0.9996	0.0058	0.0859	0.9987	0.0103	0.1236	0.9975	0.0143	0.1397	0.9939	0.0223	0.2447	0.9952	0.0203	0.1547
2	0.9997	0.0049	0.0916	0.9985	0.0109	0.2029	0.9976	0.0144	0.2158	0.9972	0.0153	0.1585	0.9967	0.0163	0.1316
2.5	0.9995	0.0059	0.1730	0.9992	0.0077	0.1334	0.9988	0.0098	0.1299	0.9976	0.0142	0.1762	0.9975	0.0143	0.1432
3	0.9988	0.0098	0.4996	0.9996	0.0052	0.080	0.9989	0.0094	0.1490	0.9984	0.0112	0.1317	0.9979	0.0134	0.1591
3.5	0.9999	0.0031	0.0658	0.9996	0.0057	0.1092	0.9988	0.0095	0.1752	0.9988	0.0097	0.1343	0.9987	0.0101	0.1115
4	0.9998	0.0036	0.1139	0.9998	0.0038	0.0638	0.9994	0.0069	0.1207	0.9989	0.0089	0.1230	0.9988	0.0098	0.1151

PR: Pulsing ratio; R^2 : Coefficient of determination; SEE : Standard error of estimate; RSS : Residual sum of square.

(b)	0.5 W/g			1 W/g			1.5 W/g			2 W/g			2.5 W/g		
PR levels	R^2	SEE	RSS	R^2	SEE	RSS	R^2	SEE	RSS	R^2	SEE	RSS	R^2	SEE	RSS
1.5	0.9995	0.0058	0.0864	0.9987	0.0103	0.1255	0.9969	0.0160	0.1753	0.9939	0.0224	0.2451	0.9952	0.0203	0.1549
2	0.9997	0.0050	0.0951	0.9985	0.0109	0.2032	0.9971	0.0157	0.2570	0.9972	0.0154	0.1600	0.9967	0.0164	0.1322
2.5	0.9994	0.0069	0.2410	0.9992	0.0077	0.1352	0.9988	0.0098	0.1304	0.9976	0.0142	0.1765	0.9974	0.0146	0.1483
3	0.9987	0.0106	0.5812	0.9996	0.0052	0.0809	0.9989	0.0095	0.1501	0.9984	0.0113	0.1351	0.9977	0.0139	0.1707
3.5	0.9998	0.0033	0.0734	0.9996	0.0056	0.1055	0.9988	0.0095	0.1740	0.9988	0.0098	0.1365	0.9986	0.0105	0.1210
4	0.9998	0.0036	0.1099	0.9998	0.0037	0.0623	0.9992	0.0077	0.1522	0.9989	0.0089	0.1231	0.9987	0.0099	0.1186

PR: Pulsing ratio; R^2 : Coefficient of determination; SEE : Standard error of estimate; RSS : Residual sum of square.

radiation is presented and extensive discussion on the effect of pulsing ratio is reported. Moreover, the most suitable mathematical model defining the drying process was obtained.

Results and discussion

In order to determine the effect of MW power intensity and pulsing ratio on the drying of fig, the results were analyzed in terms of the drying kinetics of fig.

Drying characteristics of fig fruit

Moisture content of products as a function of drying time for all levels of MW power intensities is presented in Fig. 1. In all experiments, it is clear that the moisture content decreased slowly at the first stage of drying (warming-up period). In this stage, a major part of MW energy is consumed for warming-up of samples. For the second stage of drying, moisture content rapidly decreased with increase in drying time (constant-rate period) (Kumar and Chakraverty, 2003). In this stage, major part of MW energy is dedicated to moisture removal of samples; hence, a significant section of the drying takes place. These results correspond to the findings of Zhenfeng et al. (2010). According to Doymaz (2005), drying was continued until the samples reached the desired moisture level (25 ± 0.5 %, wet basis). The falling rate in microwave fig drying is negligible. This may be justified by the fact that microwave energy is distributed and rapidly diffused through the sample volume, which facilitates moisture removal. This is integrated with the selective heating attribute proved in microwave tempering (Regier and Schubert, 2001). As a result, a linear curve would be observed in kinetic investigation of the process. Another implication of this phenomenon may be related to the nature of fig fruit, which is mainly composed of free water in the inner flesh. Free water is heated and subsequently removed much easier than bound water (Babalis et al., 2006).

It is well proven that the limiting factor in constant rate period of drying is an external mass transfer. However, internal mass transfer i.e. mostly dominated by diffusion of moisture within the sample, limits the falling rate period (Marinos-Kouris and Maroulis, 2006). A delicate look into this problem can clarify and support the theorem of fig water composition mentioned above. However, the exact explanation can be achieved when the mass transfer of heat in fig is studied that is an extension of this study. Fig. 1 indicates that the drying time increased with pulsing ratio regardless of its MW power intensities. For example, the whole drying time to achieve a desired moisture level of 1.5, 2, 2.5, 3, 3.5 and 4 pulsing ratios were about 430, 640, 835, 865, 1130 and 1436 minutes, respectively, under 0.5 W/g MW power intensity. It can also be seen that the drying time of fig fruit is decreased with MW power intensity in a stable condition of pulsing ratio in agreement with the results of Pereira et al. (2007) on banana. The whole times for reaching desired moisture level at 0.5, 1, 1.5, 2 and 2.5 W/g MW power intensities were observed at 1436, 750, 426, 258 and 201 minutes, respectively. The pulsing ratio for this condition was set to be 4.

Mathematical modeling

In order to describe the moisture ratio as a function of drying time at the various MW power intensities and pulsing ratios, 11 drying models were fitted to experimental data and their coefficient of determination (R^2), standard error of estimate (SEE) and residual sum of square (RSS) were calculated. The quality of fitting was determined by the lowest SEE and RSS values and the highest R^2 values. Drying models together with their compliance to experimental data are detailed in Table 6. Models 1 and 2 (Quadratic and Logarithmic models) performed best with regard to statistical criteria being selected as the best models for predicting and representing pulsed MW thin-layer drying behavior of fig. Table 1 shows R^2, SEE and RSS values of the Quadratic and Logarithmic models for all drying conditions that changed in the range of

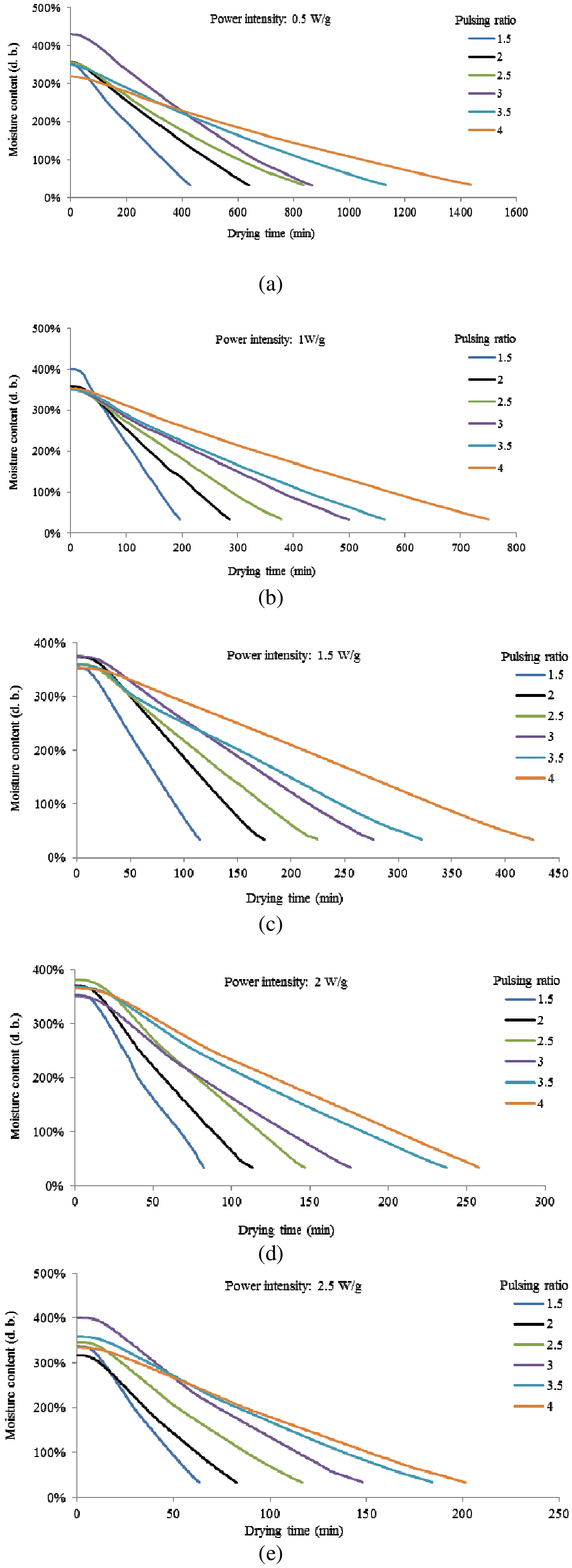

Fig 1. Variation of moisture content as a function of drying time at selected pulsing ratio and (a) 0.5 (b) 1 (c) 1.5 (d) 2 and (e) 2.5 W/g MW power intensities.

0.9939 – 0.9999, 0.0031 – 0.0224 and 0.0658 – 0.2451, respectively. Based on the regression analysis, the constants and coefficients of the Quadratic and Logarithmic models are represented in Tables 2 and 3, respectively. The main principle causing this high fitness of mentioned models can be traced back to the already discussed issue of constant rate period in microwave fig drying. In fact, the approximate linear behavior of the moisture with regards to time makes it distinguished from the conventional kinetic trends reported in the literature. Logarithmic model has been already proposed to describe the hot-air drying behavior of peeled and unpeeled fig by Xanthopoulos et al., (2010). Generally, exponential mathematics best represents the drying process but here, as can be seen in tables, the trend seems to be quadratic resulting from either microwave or the structure of moisture in fig fruit.

Drying temperatures in fig fruit

To overcome the problem of high temperatures which almost occurs in the MW drying process, the temperatures of fig fruit were recorded during the experiments. Fig. 2 shows a typical temperature curve for the drying process. It is obvious that sample temperature increases dramatically at the first stage (warming-up period) of drying (AB in Fig. 2). No remarkable moisture removal occurs at this phase. A steady whilst erratic variation of sample temperature is followed by the first stage noted by BC in Fig. 2. Significant drying takes place at this stage and drying is stopped at the end of second stage. Similarly, Zhang et al. (2006) reported that the temperature profile in microwave drying process has a warming-up period, a nearly uniform temperature period, and a heating-up period. The latter one is commonly observed in low moisture zone of the process. Additionally, Zhenfeng et al. (2010) observed a sudden temperature decrease in the very last stage of apple drying using microwave, which might be caused by the changes of dielectric properties when most of the moisture was removed from the samples. Due to the final moisture content of this research (25% w.b.), the ending heating up and temperature drop periods were not experienced. Temperature and drying time of samples in warming-up and steady stages under various MW power intensities and pulsing ratios can be seen in Table 4. It was found that increasing in MW power intensity led to increases in sample temperature and; hence, reduced the drying time (Table 4). It is also obvious that sample temperature decreases and drying time increases with the pulsing ratio at each drying stage. The higher sample temperatures (> 90 °C) were recorded at 2 and 2.5 W/g MW power intensities, when pulsing ratio was 1.5. These high temperatures are not suitable for drying of fig by the fact that nutrient elements of dried fig might be severely damaged as the result of overheating. It was also found that higher pulsing ratios resulted in larger temperature fluctuations leading to increased thermal stresses (Table 4), and in turn, shrinkage is highly probable at such conditions.

Materials and methods

The microwave (MW) drying system

A home MW oven (Panasonic 686S model, Matsushita Electric Ind. Co. Ltd., Japan) was used in this research. The tray and fan were modified to be controlled separately. The fan of the oven worked continuously at 0.5 m/s air velocity throughout the experiments for moisture removal. To measure the air velocity of fan, an anemometer (model

Table 2. The coefficients of the Quadratic model for MW thin layer drying of fig under various MW power intensities and pulsing ratios.

PR	0.5 W/g			1 W/g			1.5 W/g			2 W/g			2.5 W/g		
	a_1	b_1	c	a_1	b_1	c	a_1	b_1	c	a_1	b_1	c	a_1	b_1	c
1.5	6.51E-7	-2.48E-3	1.034	3.39E-7	-5.09E-3	1.056	-5.89E-6	-7.94E-3	1.064	2.90E-6	-1.22E-2	1.080	6.04E-6	-1.63E-2	1.081
2	2.83E-7	-1.66E-3	1.036	4.64E-7	-3.52E-3	1.055	-2.51E-6	-5.31E-3	1.063	7.69E-6	-9.72E-3	1.071	9.71E-6	-1.27E-2	1.073
2.5	5.10E-7	-1.57E-3	1.042	5.07E-7	-2.74E-3	1.041	8.98E-7	-4.58E-3	1.054	1.83E-6	-7.01E-3	1.066	1.25E-5	-9.94E-3	1.071
3	3.63E-7	-1.46E-3	1.054	6.26E-7	-2.19E-3	1.029	7.98E-7	-3.77E-3	1.053	5.57E-6	-6.48E-3	1.059	1.25E-5	-8.60E-3	1.069
3.5	1.90E-7	-1.04E-3	1.023	7.67E-7	-2.09E-3	1.031	1.29E-6	-3.34E-3	1.027	4.16E-6	-5.03E-3	1.051	6.59E-6	-6.51E-3	1.058
4	1.20E-7	-8.08E-4	1.025	3.03E-7	-1.47E-3	1.025	-1.37E-7	-2.20E-3	1.038	1.89E-6	-4.16E-3	1.045	3.15E-6	-5.43E-3	1.053

PR: Pulsing ratio

Table 3. The coefficients of the Logarithmic model for MW thin layer drying of fig under various MW power intensities and pulsing ratios.

PR	0.5 W/g			1 W/g			1.5 W/g			2 W/g			2.5 W/g		
	A	k	c	a	k	C	a	k	c	a	k	c	a	k	C
1.5	4.220	5.90E-4	-3.186	17.121	3.02E-4	-16.06	27.264	3.22E-4	-26.18	16.41	7.51E-4	-15.33	16.15	1.02E-3	-15.07
2	4.425	3.77E-4	-3.388	12.978	2.71E-4	-11.92	27.515	2.13E-4	-26.44	5.838	1.66E-3	-4.768	8.236	1.54E-3	-7.164
2.5	1.847	8.78E-4	-0.802	7.067	3.87E-4	-6.026	11.491	3.98E-4	-10.44	13.21	5.31E-4	-12.15	3.560	2.80E-3	-2.489
3	2.439	6.08E-4	-1.384	3.333	6.64E-4	-2.304	8.632	4.36E-4	-7.579	3.290	1.98E-3	-2.231	2.440	3.58E-3	-1.370
3.5	2.294	4.61E-4	-1.269	2.293	9.31E-4	-1.260	3.777	8.91E-4	-2.749	2.496	2.05E-3	-1.443	2.728	2.41E-3	-1.670
4	2.197	3.77E-4	-1.170	3.021	4.91E-4	-1.995	21.466	1.07E-4	-20.42	4.072	1.03E-3	-3.026	4.294	1.27E-3	-3.241

PR: Pulsing ratio

Table 4. Temperature and drying time of samples in warming-up and steady stages under various MW power intensities and pulsing ratios.

PR	1.5				2				2.5			
MW power	W. P.		S.S.		W. P.		S.S.		W. P.		S.S.	
intensity (W/g)	t (min)	T (°C)	t (min)	T (°C)	t (min)	T (°C)	t (min)	T (°C)	t (min)	T (°C)	t (min)	T (°C)
0.5	45	20 - 73	384	70 - 73	51	20 - 69	589	64 - 69	60	20 - 66	776	61 - 66
1	32	20 - 84	164	80 - 84	35	20 - 80	250	74 - 80	42	20 - 74	336	67 - 74
1.5	23	20 - 90	92	84 - 90	26	20 - 85	149	77 - 85	28	20 - 81	197	72 - 81
2	15	20 - 95	67	89 - 95	18	20 - 89	95	80 - 89	20	20 - 87	127	78 - 87
2.5	8	20- 100	55	93 - 100	12	20 - 95	70	86 - 95	14	20 - 91	103	81 - 90

PR: Pulsing ratio; W. P. : Warming- up period; S.S. : Steady stage; t: Time; T: Temperature

PR	3				3.5				4			
MW power	W. P.		S.S.		W. P.		S.S.		W. P.		S.S.	
intensity (W/g)	t (min)	T (°C)	t (min)	T (°C)	t (min)	T (°C)	t (min)	T (°C)	t (min)	T (°C)	t (min)	T (°C)
0.5	68	20 - 61	798	54 - 61	75	20 - 56	1055	48 - 56	80	20 - 55	1356	47 - 55
1	45	20 - 70	455	62 - 70	50	20 - 67	514	58 - 67	59	20 - 66	692	57 - 66
1.5	31	20 - 78	247	69 - 78	36	20 - 76	286	67 - 76	41	20 - 75	385	65 - 75
2	22	20 - 85	154	74 - 85	25	20 - 84	212	74 - 84	30	20 - 83	228	72 - 83
2.5	15	20 - 87	133	76 - 87	17	20 - 85	167	74 - 85	23	20 - 84	178	71 -85

PR: Pulsing ratio; W. P. : Warming- up period; S.S. : Steady stage; t: Time; T: Temperature.

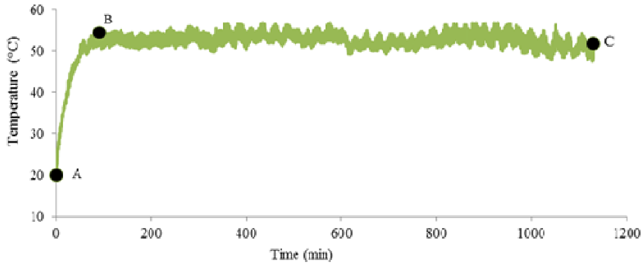

Fig 2. Typical temperature curve for fig fruit during drying process under 0.5 W/g MW power intensity and 3.5 pulsing ratio.

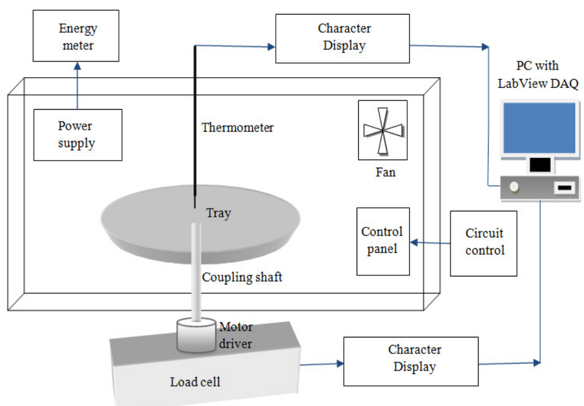

Fig 3. Schematic diagram of the MW drying system used in drying of fig fruits. Samples are placed over the tray and the data logging system was integrated within the character display.

3006HA, Lutron HT, Taiwan) with the sensitivity of 0.05 m/s was used before the experiments were started. Sample tray was installed upon a motor driver located on top of load cell (ZEMIC model, L6D – C3 – 5kg) with accuracy of 0.2 g under the oven housing. Motor driver rotates sample tray to evenly distribute the MW power and simultaneously the sample mass was recorded and displayed via a digital display integrated with the load cell. A thermometer (PT100 sensor with accuracy of 0.1 °C) warped with aluminum foil and insulated with paint was inserted in the geometric center of a singular sample for temperature measurements. This sample was placed at the center of tray (Fig. 3). During MW drying, weight and temperature of the samples were measured at regular intervals (10 s). Subsequently, measured data were transferred to the PC for recording with a "National Instruments LabView" program (Run-Time Engine 6.0 version). Additionally, the control circuits of oven were modified to allow the power-on and -off durations to be controlled with a microcontroller, which could continuously and automatically adjust the on-off MW power.

Samples preparation

Figs (Rashe variety) were obtained locally from Sardasht, Iran and stored in a refrigerator at 4±1 °C before they were used in experiments. Just before drying, samples were taken out from the refrigerator to obtain ambient temperature (20 °C). They were visually inspected and damaged samples were eliminated before tests. Samples were then immediately weighed and placed in a 32 cm diameter tray and submitted to MW oven. To determine the initial moisture content of fresh fruits during the tests, four deferent samples, each having 250 g were kept in the drying oven at 70 °C for 24 h (AOAC, 1980). Consequently, the moisture content of fig was determined to be varying between 3.168 and 4.302 kg of water/kg of dry matter. No pre-treatment was applied to the fresh product.

Drying procedure

The factors studied in present research were: MW power intensity (0.5, 1, 1.5, 2, and 2.5 W/g), and pulsing ratio (1.5, 2, 2.5, 3, 3.5, and 4) which selected according to pretests. These values were selected to best fit the suitable temperature for drying fig. The pulsing ratio, PR was defined as follows and presented in Table 5 (Gunasekaran, 1999):

$$PR = \frac{Cycle\ power\ on\ time + Cycle\ power\ off\ \ time}{Cycle\ power\ on\ time} \qquad (1)$$

In order to achieve a desirable design of dryers together with facilitation of optimization purposes, a precise knowledge on mathematical behavior of the process is required. Therefore, several modeling algorithms have been developed and extended in the literature (Doymaz, 2005; Xanthopoulos et al., 2010). However, microwave has a sophisticated nature which makes it somehow differentiated from the conventional drying processes (Regier and Schubert, 2001). As a consequence, a comprehensive modeling routine is already fulfilled in this research. To find the most suitable and adaptable mathematical model, drying curves were fitted to the experimental data using 11 different thin layer drying models (Table 6), in which quadratic and linear models had not been used in previous studies. The moisture ratio of samples was calculated using the following equation (Xanthopoulos et al., 2010; Karaaslan and Tunçer, 2008):

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

Where, M, M_e and M_o stand for the present moisture content, equilibrium moisture content, and initial moisture content, respectively. The equilibrium moisture content was assumed zero, as the negligible value in this study (Doymaz, 2005; Kouchakzadeh and Shafeei, 2010; Karaaslan and Tunçer, 2008; Sarimeseli, 2011). Non-linear regression analysis was performed using Datafit 8.2 software to estimate the statistical criteria of models. The statistical validity of the models was evaluated and compared by coefficient of determination (R^2), standard error of estimate (SEE) and residual sum of square (RSS).

Conclusions

Drying behavior of fig fruit in a laboratory dryer was investigated at five different levels of MW power intensity and six levels of pulsing ratios. Drying time increased with the pulsing ratio and decreased as MW power intensity increased. Of the 11 thin layer drying models discussed, the Quadratic and Logarithmic models provided the best representation of the pulsed MW drying of fig. Subsequently,

Table 5. Defined pulsing ratios as a variable studied factor in the experiments.

Power on time (s)	30			60		
Power off time (s)	15	45	75	60	120	180
Pulsing ratio	1.5	2.5	3.5	2	3	4

Table 6. Thin layer drying models tested for modeling.

No.	Model name	Model equation	References
1	Quadratic	$MR = a_1t^2 + b_1t + c$	Present research
2	Logarithmic	$MR = a \exp(-kt) + c$	(Yaldiz and Ertekin, 2001)
3	Midilli – Kucuk equation	$MR = a \exp(-k(t^n)) + b_1t$	(Midilli et al., 2002)
4	Modified Page	$MR = \exp(-(kt)^n)$	(White et al., 1981)
5	Page	$MR = \exp(-kt^n)$	(Page, 1949)
6	Linear	$MR = a_2t + b$	Present research
7	Wang and singh	$MR = 1 + a_2t + b_2t^2$	(Wang and Singh, 1978)
8	Verma	$MR = a \exp(-kt) + (1-a) \exp(-gt)$	(Verma et al., 1985)
9	Diffusion approach	$MR = a \exp(-kt) + (1-a) \exp(-kbt)$	(Yaldiz and Ertekin, 2001)
10	Henderson and Pabis	$MR = a \exp(-kt)$	(Henderson and Pabis, 1969)
11	Newton	$MR = \exp(-kt)$	(Ayensu, 1997)

it was possible to conclude that the proposed new model (Quadratic model) can be used to describe the drying kinetics of fig fruit. Sample temperature decreased with the pulsing ratio, while increased with MW power intensity. Warming–up period was short and subsequent drying only took place in the steady temperature period.

Acknowledgements

The authors acknowledge financial support from Urmia University.

References

AOAC (1980) Official method of analysis. 13rd edn. Association of Official Analytical Chemists, Washington, DC.

Altan A, Maskan M (2005) Microwave assisted drying of short-cut (ditalini) macaroni: Drying characteristics and effect of drying processes on starch properties. Food Res Int 38: 787-796.

Andres A, Bilbao C, Fito P (2004) Drying kinetics of apple cylinders under combined hot air-microwave dehydration. J Food Eng 63: 71-78.

Ayensu A (1997) Dehydration of food crops using a solar dryer with convective heat flow. Sol Energy 59(4-6): 121-126.

Babalis SJ, Papanicolaou E, Kyriakis N, Belessiotis VG (2006) Evaluation of thin-layer drying models for describing drying kinetics of figs (*Ficus carica*). J Food Eng 75: 205-214.

Daisuke H, Naoko N, Noriko B, Kozo M, Makoto K, Fumihiko T, Toshitaka U (2011) Surface decontamination of fig fruit by combination of infrared radiation heating with ultraviolet irradiation. Food Control 22: 375-380.

Doymaz I (2005) Sun drying of fig: an experimental study. J Food Eng 71: 403-407.

FAO (2010) Fao Stat: Agriculture Data.< http://faostat.fao.org/site/339/default.aspx>.

Gunasekaran S (1999) Pulsed microwave-vacuum drying of food materials. Dry Technol 17(3): 395-412.

Henderson SM, Pabis S (1969) Grain drying theory I: temperature effect on drying coefficient. J Agri Eng Res 6: 169-174.

Karaaslan SN, Tunçer ÍK (2008) Development of a drying model for combined microwave-fan-assisted convection drying of spinach. Biosyst Eng 100: 44- 52.

Kouchakzadeh A, Shafeei S (2010) Modeling of microwave-convective drying of pistachios. Energy Convers Manage 51: 2012-2015.

Kumar Das S, Chakraverty A (2003) Grain drying systems. In: Chakraverty A, Mujumdar AS, Vijaya Raghavan GS, Ramaswamy HS, (eds) Handbook of postharvest technology, Marcel Dekker, NY USA.

Marinos-Kouris D, Maroulis ZB (2006) Transport properties in the drying of solids. In: Mujumdar AS (ed) Handbook of industrial drying, 3rd edn. CRC Press, USA.

Metaxas AC, Meredith RJ (1993) Industrial microwave heating. London: Peter Peregrinus Ltd.

Midilli A, Kucuk H, Yapar Z (2002) A new model for single layer drying. Dry Technol 20: 1503-1513.

Page G (1949) Factors influencing the maximum rates of air drying shelled corn in thin layers. MSc Thesis, Purdue University, Indiana, USA.

Pereira NR, Marsaioli JA, Ahrné LM (2007) Effect of microwave power, air velocity and temperature on the final drying of osmotically dehydrated bananas. J Food Eng 81: 79-87.

Ratti C, Mujumdar AS (1997) Solar drying of foods: Modeling and numerical simulation. Sol Energy 60(3-4): 151-157.

Regier M, Schubert H (2001) Microwave processing. In: Richardson P (ed) Thermal technologies in food processing, CRC Press, USA.

Ruíz DG, Martínez-Monzó J, Fito P, Chiralt A (2003) Modelling of dehydration-rehydration of orange slices in combined microwave/air drying. Innov Food Sci Emerg 4: 203-209.

Sarimeseli A (2011) Microwave drying characteristics of coriander (*Coriandrum sativum* L.) leaves. Energy Convers Manage 52: 1449-1453.

Schiffmann RF (2006) Microwave and dielectric drying. In: Mujumdar AS (ed) Handbook of industrial drying, 3rd edn. CRC Press, USA.

Verma LR, Bucklin RA, Endan JB, Wratten FT (1985) Effects of drying air parameters on rice drying models. T ASAE 28: 296-301.

Wang CY, Singh RP (1978) A single layer drying equation for rough rice. ASAE Paper No: 78-3001. St. Joseph, MI: ASAE.

White GM, Bridges TC, Loewer OJ, Ross IJ (1981) Thin layer drying model for soybeans. T ASABE 24(6): 1643-1646.

Xanthopoulos G, Yanniotis S, Lambrinos GR (2010) Study of the drying behaviour in peeled and unpeeled whole fig. J Food Eng 97: 419-424.

Yaldiz O, Ertekin C (2001) Thin layer solar drying of some vegetables. Dry Technol 19: 583-597.

Zhenfeng L, Raghavan GSV, Orsat V (2010) Temperature and power control in microwave drying. J Food Eng 97: 478-483.

Zheng WC, Shi YX, Da WS (2004) Microwave-vacuum drying kinetics of carrot slices. J Food Eng 65: 157-164.

Zhang M, Tang J, Mujumdar AS, Wang S (2006) Trends in microwave related drying of fruits and vegetables. Trends Food Sci Tech 17: 524- 534.