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Evaluating of Microwave Drying for Hawthorn Slice as Alternative to Convective Drying

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HIGHLIGHTS

- Microwave drying lead to improve the drying characteristics of Hawthorn slices.
- Page model was found as the best described the microwave drying data.
- Microwave drying at 360 W can be applied as an effective technology for drying of hawthorn slices.

Abstract: This study aimed to investigate the influence of microwave drying with different power levels as alternative to convective drying method on drying kinetics and main quality attributes of hawthorn slice. At increasing microwave power values, higher drying rate and shorter drying time was observed. The page model was found to give best fit ($R^2 > 0.9961$, $RMSE < 0.028$ and $\chi^2 < 0.675 \times 10^{-3}$) for all drying treatments. Although the minimum change of color and texture value were obtained at microwave power of 600 W, the convective drying caused less total color and texture change depending fresh sample. Drying process at microwave powers of 600 W and 360 W showed the best quality in terms of rehydration and bioactive properties, respectively. The findings in current work demonstrated that microwave drying at 360 W microwave power might be suitable for drying of hawthorn slices with high quality and bioactive properties as well as low operating costs.

Keywords: hawthorn fruits; microwave drying; convective drying; drying kinetics; rehydration keyword.

INTRODUCTION

Hawthorn, belonging to the subfamily Maloideae in the Rosaceae family, is one of most important fruits in Turkey flora [1, 2]. Hawthorn fruits include high amounts of bioactive components such as phenolics, flavonoids and triterpenoid acids that is offer as anti-oxidative, free radical scavenging, anti-inflammatory, vasorelaxing, and hypolipidemic effects [3, 4]. So that, it has been widely use as medicinal remedies with a variety of biological activities like antitumor, hypotensive, anti-inflammation etc. [2]. Although leaves, flowers and pollen of hawthorn are rich in phenolic compounds [5], they are commonly cultivated for their fruits which are consumed fresh or used to produce jams, jellies, juices or alcoholic beverages [6]. The hawthorn is a seasonal fruit and has a limited harvest period, and also fresh hawthorns are extremely perishable within a week in ambient conditions due to their high moisture content [6, 7]. So that, it needs to be dried to extend the storage-life by preventing physiological and morphological changes that occur after harvest and also availability throughout the year.

Drying is one of the primary used methods of vegetables and fruits preservation as it reduces water activity leading to reduction of microbial growth, obtain a good quality dried product, and reduce shipping weight and packaging cost [4]. Also, various products such as dried fruits, snacks and soups obtained after the drying process can be consumed directly or after rehydration [8]. Recently, there is an increasing interest in fruit chips by modern consumers due to their nutritional values with an attractive crispy taste [9]. Although convectional drying has been used for a long time due to its simplicity and affordability, it presents a high-energy consumption due to long process, and also leads to loss of quality because of high temperature [8]. Therefore, microwave-drying method is recently being studied as alternative to convective drying method due to high drying velocity and better food quality [10-14]. Microwave drying is based on electromagnetic waves to heat the material volumetrically, which leads to remove moisture from the food due to rising of temperature during microwave drying by application of an electromagnetic field [15]. Several advantages including less processing time, a homogeneous energy distribution, low energy usage and formation of suitable dry product characteristics are provided during drying by microwave energy application due to the increment of temperature in the material's center [16]. However, microwave drying has disadvantages such as inherent non-uniformity of the electromagnetic field within microwave cavity, requires constant movement in space to avoid hot spots, penetration depth and too rapid mass transport [17]. In the literature, there are several studies used microwave drying technique for drying spinach, [18] mushroom, [19] mango, [20] Trabzon Persimmon [13]. However, microwave drying of hawthorn slice is limited. Liu, Liu [4] and Coklar, Akbulut [5] investigated the changing of the bioactive compounds and antioxidant activities in hawthorn drying with different processes.

Drying is a complicated process involving four prevailing transfer phenomena (internal and external heat transfer, internal and external mass transfer) and mathematical models are used to study and gain insights of these transport phenomena in the drying system [21, 22]. Theoretical, semi-theoretical and empirical models have recommended to describe the drying behavior of agricultural materials [23]. Semi-theoretical models have been widely used because they offer a compromise between theory and ease of application, which are mainly derived from direct solution of Fick's second law by assuming some simplifications [24].

The information on the impact of microwave drying compared to convective drying on the drying kinetics and quality of dried hawthorn fruit are scarce and still required further enrichment. Therefore, the aim of current study was to: (1) explore the influences of microwave drying with different power levels on drying characteristics and to determine the changes in quality parameters such as color, texture, rehydration and bioactive properties of the dried fruit: (2) to find the most appropriate thin-layer drying model for describing the microwave drying behavior of hawthorn. In addition, convectional drying at 60°C was evaluated and used as reference method due to industrially most important drying method.

MATERIAL AND METHODS

Material

Fresh hawthorn fruits were procured from a local market in Karaman, Turkey during the harvest season in October of 2020, washed and checked carefully to discard spoiled fruits, and then sliced approximately to 10 mm thickness using a kitchen slider. After the cutting step, sliced hawthorn samples were kept in a lid plate in order to prevent color change. The fresh sliced fruit samples had an average initial moisture content $72.33 \pm 0.31\%$, which was determined at 105°C until the weight remained unchanged.

Drying Process

Microwave drying experiments were performed with a microwave oven (NN-SD691S Panasonic inverter, Panasonic, Brisbane, Australia), which has a maximum power of 1100 W. The microwave power used was 180, 360 and 600 W for each run. About 25 g of sliced fruit samples were placed in a single layer on the rotating glass plate fitted inside of the oven. During the microwave drying process, samples were removed at intervals from the driers and weighed ahead being returned to the dryer. The drying experiments were performed until final moisture content of samples was below 10%. The microwave drying were completed between 36 and 84 min depending on the microwave power level. In the conventional drying process, the drying experiment was performed with an oven at 60 °C under speed of 1 m/s. In the experiments, 25 g of sliced fruit samples were placed on an aluminum plate and dried until the moisture content of samples was below 10%. The hot air drying treatment was completed about 480 min. Each drying processes was run in triplicate.

Drying kinetics

Drying kinetics was determined based on the weight losses of slice hawthorn samples. The moisture ratio (MR) and drying rate (DR) of the hawthorn samples during drying were calculated according to Eq. (1) and (2), respectively [3, 25]:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

$$DR = \frac{M_t - M_{t+dt}}{dt} \quad (2)$$

where, M_t refers the moisture content at time t , M_e refers the equilibrium moisture content, M_0 refers the initial moisture content, M_{t+dt} refers the moisture content at time $t+dt$ and dt refers the drying time.

To describe the drying kinetics of hawthorn slice samples, the drying curves were fitted into eight thin-layer drying kinetic models; Newton (Eq. 3), Page (Eq. 4), Modified Page (Eq. 5), Logarithmic (Eq. 6), Henderson and Pabis (Eq. 7), Wang and Singh (Eq. 8), Two Term (Eq. 9) and Diffusion Approach (Eq. 10), which are widely used in modeling drying curves of products.

$$MR = \exp(-kt) \quad (3)$$

$$MR = \exp(-kt^n) \quad (4)$$

$$MR = \exp(-(kt)^n) \quad (5)$$

$$MR = a \exp(-kt) + b \quad (6)$$

$$MR = a \exp(-kt) \quad (7)$$

$$MR = 1 + at + bt^2 \quad (8)$$

$$MR = a_1 \exp(-k_1 t) + a_2 \exp(-k_2 t) \quad (9)$$

$$MR = a \exp(-kt) + (1 - a) \exp(-kbt) \quad (10)$$

A non-linear regression procedure was used for the estimation of these model parameters. The goodness of fitting models used in the drying curves of hawthorn samples were evaluated using the determination coefficient (R^2), the reduced chi-square (χ^2) and the root mean square error ($RMSE$). These parameters can be determined with the following Eqs:

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2}{N - z} \quad (11)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \quad (12)$$

Where, $MR_{exp,i}$ refers the experimentally dimensionless moisture ratio for test, $MR_{pre,i}$ refers the estimated dimensionless moisture ratio for test i , N refers the number of observation and z refers the number of constants in a model. The best model describing the thin layer drying characteristic was selected based on the lowest χ^2 and $RMSE$ values and also the highest R^2 value.

Color analysis

The color values of fresh and dried hawthorn samples were determined by using colorimeter (Konica Minolta CM-5, Osaka, Japan), which was calibrated with a black and white ceramic plate. The CIELAB scale was used to evaluate the L^* , a^* , b^* color values. To describe color changes during drying, the total color difference (ΔE) was calculated using Eq. (13):

$$\Delta E = \sqrt{(L_0 - L^*)^2 + (a_0 - a^*)^2 + (b_0 - b^*)^2} \quad (13)$$

Texture properties

The textural properties of fresh and dried hawthorn samples were evaluated in a texture profile analysis with a texture analyzer (TA.XT plus, Stable Microsystems, Godalming, UK) with a 5 kg load cell. The measurements were conducted by using a cylindrical probe of 3 mm diameter. The TPA was conducted at 50% strain at a constant rate of 2 mm/s until the distance of 3 mm. The hardness was measured and recorded. The hardness value was calculated from the force (N) versus penetration (mm) curve. The analysis was conducted with four hawthorn samples for each treatment [8].

Rehydration kinetics

The rehydration analysis was conducted by using the method described by Santos, Guedes [8]. The rehydration kinetics of dried hawthorn samples was determined by soaking a weighed amount of dried samples into distilled water at 25°C. Each dried sample (5 g), which were wiped with filter paper to eliminate the superficial water, were weighed and soaked in 1 L of distilled water. At given intervals of times, the samples were removed from the water, drained with paper towels superficially, weighed and then immediately returned to the same water. Rehydration procedure was repeated until reaching constant mass. The rehydration ratio (RR) was calculated Eq. (14) [26]:

$$RR = \frac{W_t}{W_0} \quad (14)$$

where, W_t (g) refers the weight of rehydrated samples at t time and W_0 (g) refers the weight of dried samples.

For fitting rehydration kinetics of dried samples, the Peleg Model (Eq. (15)) [27] was applied:

$$M(t) = M_0 + \frac{t}{k_1 + k_2 * t} \quad (15)$$

where, $M(t)$ refers the moisture content in dry basis at a specific time during rehydration, M_0 refers the initial moisture content, k_1 and k_2 refer the parameters related with the water absorption rate and quantity.

Total phenolic contents

To determination of total phenolic contents of hawthorn samples, the extraction method described by Tekin and Baslar [28] was employed. The fresh and rehydrated dried samples (5 g) weighed and then mixed with 20 mL of aqueous methanol (80%) followed by homogenization with ultra-Turrax (IKA, T18 Basic, Germany) at 1500 rpm for 5 min. The samples were then incubated using a shaker overnight at room temperature, after which the mixture was centrifuged at 4000 rpm for 10 min. The centrifugation process was repeated twice, and the supernatants were collected and filtered. The extract was used both the determination of total phenolic content and antioxidant capacity of hawthorn samples.

Total phenolic content of the extracts was assayed by Folin-Ciocalteu method. For this, 0.5 mL of extracted samples was mixed with 2.5 mL of 0.2 N Folin Ciocalteu's phenol reagent and 2 mL of aqueous Na_2CO_3 . After incubation of the mixture for 30 min at room temperature, the absorbance was read at 760 nm using a spectrophotometer (Shimadzu UV-1800, Japan). Total phenolic content was expressed in terms of gallic acid equivalents per 100 g (mg GAE/g) on dry weight (d.w.) using the calibration curve ($R^2=0.9998$).

Antioxidant capacity

The antioxidant activity of the hawthorn samples was based on the 2,2-diphenyl-1-picrylhydrazyl radical-scavenging activity (DPPH) and radical cation decolorization (ABTS) assays. For the determination of DPPH radical scavenging activity, 0.1 mL of extracted samples (extraction performed as described in Section 2.7) was mixed with 4.9 mL DPPH solution (0.1 mM in methanol) [29]. The mixture was incubated at room temperature for 30 min and its absorbance was read at 517 nm. The results were presented as mmol Trolox equivalent of dry weight (mmol TE/100 g d.w.).

The ABTS radical cation decolorization assay was determined using the procedure described by Šamec and Piljac-Žegarac [30]. For this analysis, 7.4 mM ABTS radical solution and 2.45 mM potassium per sulfate was mixed with a volume ratio of 1:1 and allowed to stand in a dark condition for 12 h at room temperature. The mixture was then diluted with methanol to obtain an absorbance of 0.6 at 734 nm using the spectrometer. After that, 20 μ L of extracted sample (extraction performed as described in section Total phenolic contents) was combined with 2 mL of fresh ABTS solution, and absorbance was measured at 734 nm after waiting for 4 min. The results were expressed as mmol Trolox equivalents of dry weight (mmol TE/100 g d.w.).

Statistical analysis

The drying experiments and analyses were done with three replicates and all data were expressed as mean \pm standard deviation. Results were evaluated by ANOVA and differences were determined using the Duncan test at a 5% significance level, which were performed by using SPSS statistical package program (version 21.0, SPSS Inc., Chicago). A correlation analysis between total phenolic content and antioxidant activity was performed with the Pearson's test. The Sigma Plot software (version 10.0) was used to fit the mathematical models to experimental data by nonlinear regression analysis procedure.

RESULTS

Drying characteristics

The drying curves of sliced hawthorn samples during drying using convective and microwave drying at 180, 360 and 600 W were shown in Figure 1. The moisture content of fresh sample was 72.32%, and was reduced to below 10% after drying process. As expected, the loss of moisture was affected by drying techniques and also microwave powers. The moisture content of sliced hawthorn samples decreased gradually using convective drying, while a sharp linear decrease occurred by microwave drying depending on the increase in the microwave power. Microwave drying significantly shortened the drying time to reached <10% moisture content when compared to convective drying, and increasing the microwave power significantly lead to a decrease of the drying time ($p < 0.05$). The total drying time for convective drying to achieve the target moisture content was 480 min, whereas it was reduced by 82.5%, 90% and 92.5% at microwave power of 180, 360 and 600 W, respectively. In the case of microwave drying, increasing microwave power from 180 to 600 W resulted in a more than two-fold decrease in the drying duration. Similar results have been observed in the microwave drying of sliced Trabzon persimmon [13], green peas [15] and mango ginger [20]. The electromagnetic intensity increased by the increase of microwave power and therefore more microwave energy was absorbed by samples, which resulted shorter drying time due to accelerated the moisture migration and evaporation rate [10].

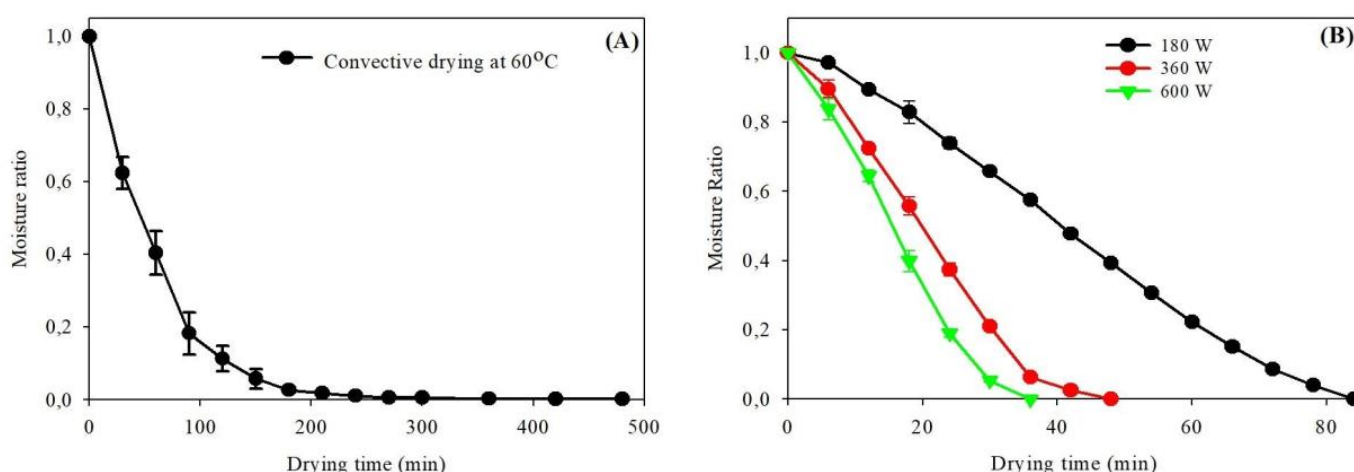


Figure 1. Changes in the moisture content based on time of the hawthorn slices dried with convective drying (A) and microwave drying at different powers (B).

Figure 2 presents the changes of drying rate versus drying time. The highest drying rate of convective drying reached to $0.032 \text{ g water g dry matter}^{-1} \text{ min}^{-1}$, while was reached to 0.041 , 0.077 and $0.102 \text{ g water g dry matter}^{-1} \text{ min}^{-1}$ in microwave drying with the power of 180, 360 and 600 W, respectively. The drying rate of hawthorn samples increased with higher microwave power, in which attributed the high internal heat

generation due to higher absorption of microwave energy with high microwave intensity, resulted great driving force for heat and mass transfer inside of product [31]. These findings have also been found by Demiray, Seker [16] for onion, Horuz, Bozkurt [32] for sour cherries and Chahbani, Fakhfakh [15] for green peas that microwave drying shortened the drying time required until the equilibrium moisture content reached. In microwave drying, a linear trend varied from 0.65 to 1.96 g water g dry matter⁻¹ min⁻¹ was shown in the drying period when the microwave power was set 180 W. In contrast, two drying period were observed for the power of 360 and 600 W. In the first stage of drying treatments, the drying rate increased rapidly and then decreased to reach equilibrium. Similar phenomena on the drying rate was observed at high microwave power for microwave drying of apple [33], pomelo [34] and green coffee beans [35]. According to Soysal [36], higher absorption microwave power occurs due to high amount of free water inside of the material during the initial phase, caused to great driving force of moisture transfer. As the drying progressed, the removal moisture in the product leads to a reduction in the absorption capability of microwave energy due to dielectric loss factor, hereby resulting in the reducing drying rate [31, 36].

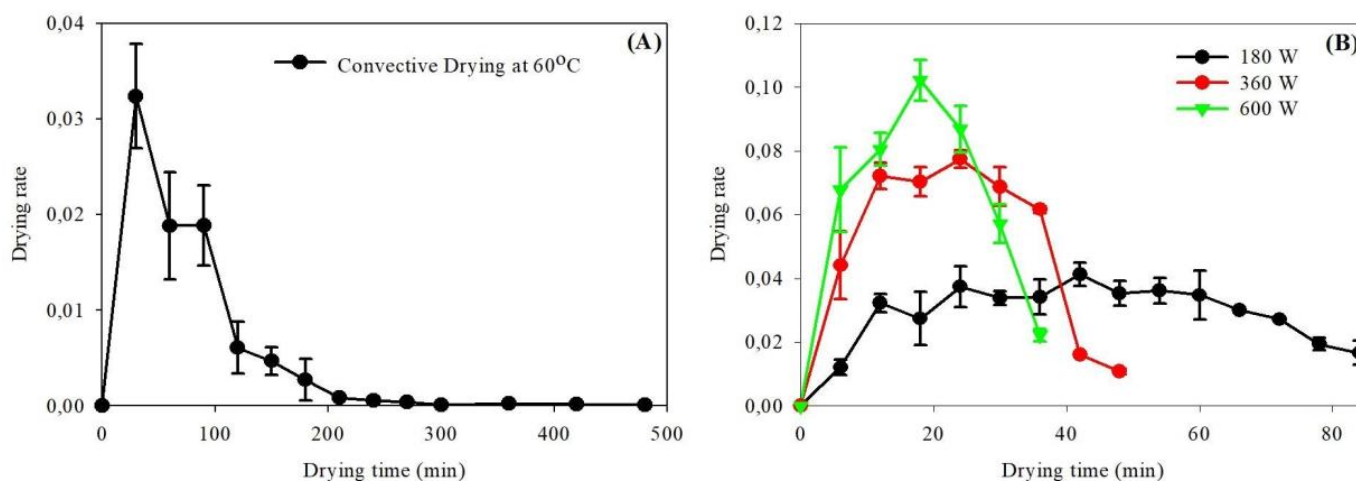


Figure 2. Variations drying rate of hawthorn slices dried with convective drying (A) and microwave drying at different powers (B)

Mathematical model

In order to accuracy the convective and microwave drying processes of hawthorn slice samples, eight thin-layer drying kinetic models were adopted to fit the experimental data and the results are presented in Table 1. Determination coefficient (R^2), reduced chi-square (χ^2) and root mean square error ($RMSE$) were calculated and used to evaluate the model performance. The models were found appropriate to predict the drying behavior of hawthorn samples based on the statistical criteria of the high determination coefficient (from 0.9061 to 0.9986) and low reduced chi-square (from 0.13×10^{-3} to 11.784×10^{-3}) and root mean square deviation (from 0.011 to 0.097) values. However, Newton, Logarithmic, Henderson and Pabis, Two term and Diffusion approach models were the least compatible with the experimental data for microwave drying at all microwave power depending on the relatively low R^2 (0.9061-0.9412). Page was found as the more suitable model described the drying curves for all drying treatments. These results are compatible with previous results reported by Horuz and Maskan [37], Zhu and Shen [38] and İler, Akyıl [14] who reported that the page model gives better representation for pomegranate arils, peach slice and garlic puree, respectively.

The kinetics parameter (k) in Page model, which is related to the velocity of mass transfer, found between 0.001 to 0.009 and comparing to convective drying, it decreased when applied microwave drying. On the other hand, k values increased with an increase in microwave power. İler, Akyıl [14] also obtained similar findings for drying garlic puree with convective and microwave drying processes. The n parameter, which can be related to mass transport during drying process [39], was found as 1.147 for convective drying and between 1.874 to 1.914 for microwave drying at different powers. The n values for microwave drying were higher than convective drying. This is in line with the findings of Carvalho, Monteiro [40] who obtained parameters from about 1.06 and 1.079 when used two convective drying and about 1.426 and 1.322 when used microwave drying processes. Simpson, Ramírez [39] stated that n parameters indicate a super-diffusive phenomenon when $n > 1$. Therefore, it can be stated that the n values can be related with both water transport through capillarity and microwave energy in the present case. The direct conversion of microwave energy into heat energy in water molecules can cause an increase in mass transfer through capillaries either in liquid or vapor state [40].

Table 1. The selected drying models, model constants and statistical results (R^2 , $RMSE$ and χ^2) for hawthorn samples

Drying conditions	Model	R^2	$RMSE$	$\chi^2(10^{-3})$	Model constants
Convective drying at 60°C	Newton	0.9959	0.018	0.341	$k=0.017$
	Page	0.9984	0.011	0.138	$k=0.009; n=1.147$
	Modified Page	0.9981	0.012	0.13	$k=0.016; n=1.105$
	Logarithmic	0.9961	0.018	0.318	$k=0.017; a=1.015; b=0.008$
	Henderson and Pabis	0.9909	0.019	0.306	$k=0.011; a=1.052$
	Wang and Singh	0.9678	0.086	9.008	$k=-0.007; b=0.012$
	Two term	0.9967	0.018	0.301	$k_1=0.097; k_2=0.09; a_1=1.016; a_2=0.013$
Diffusion Approach	0.9977	0.013	0.194	$k=0.018; a=1.125; b=0.078$	
Microwave drying at 180 W	Newton	0.9061	0.071	1.172	$k=0.021$
	Page	0.9961	0.022	0.675	$k=0.001; n=1.914$
	Modified Page	0.9949	0.019	0.642	$k=0.021; n=1.904$
	Logarithmic	0.9253	0.083	8.408	$k=0.024; a=1.145; b=0.007$
	Henderson and Pabis	0.9273	0.08	8.006	$k=0.021; a=1.041$
	Wang and Singh	0.992	0.047	2.276	$k=-0.012; b=0.078$
	Two term	0.9253	0.081	8.403	$k_1=0.024; k_2=0.021; a_1=1.078; a_2=0.066$
Diffusion Approach	0.9131	0.048	11.784	$k=0.034; a=0.447; b=0.615$	
Microwave drying at 360 W	Newton	0.9146	0.077	1.032	$k=0.045$
	Page	0.9986	0.028	0.563	$k=0.003; n=1.892$
	Modified Page	0.9967	0.021	0.561	$k=0.043; n=1.862$
	Logarithmic	0.9309	0.097	9.008	$k=0.049; a=1.112; b=0.004$
	Henderson and Pabis	0.9412	0.093	8.964	$k=0.058; a=1.106$
	Wang and Singh	0.9828	0.053	0.227	$k=-0.029; b=0.002$
	Two term	0.9309	0.097	9.271	$k_1=0.049; k_2=0.019; a_1=1.112; a_2=0.039$
Diffusion Approach	0.9146	0.086	9.172	$k=0.045; a=0.404; b=0.099$	
Microwave drying at 600 W	Newton	0.9194	0.068	1.061	$k=0.057$
	Page	0.9985	0.024	0.518	$k=0.004; n=1.874$
	Modified Page	0.9974	0.012	0.581	$k=0.055; n=1.807$
	Logarithmic	0.931	0.095	9.106	$k=0.062; a=1.089; b=0.006$
	Henderson and Pabis	0.9401	0.091	9.371	$k=0.057; a=1.001$
	Wang and Singh	0.9874	0.041	0.165	$k=-0.037; b=0.002$
	Two term	0.9317	0.095	9.064	$k_1=0.062; k_2=0.012; a_1=1.088; a_2=0.044$
Diffusion Approach	0.9194	0.093	10.095	$k=0.271; a=1.04; b=0.211$	

Rehydration kinetics

Rehydration indicates the physical and chemical changes occurred during drying and treatments before dehydration [9] and therefore, it is a crucial characteristic for dried products, which can be addressed as a measure of the physicochemical characteristics changes [41]. The rehydration ratios of hawthorn slices dried with convective and microwave drying method were shown in Figure 3. Overall, the rehydration ratios increased steeply at the beginning of rehydration for all samples, the tendency gradually slowed down over time and almost completed within 6.5 h of the test. The rehydration ratio of sample possessed by convective method was increase slower than those of sample dried with microwave and the minimum rehydration ratio was observed for sample dried with convective method at the end of dehydration treatment. Similarly, Miraei Ashtiani, Sturm [42] stated that the rehydration ratio of nectarine slices dried with hot air was about 11.81% lower than the lowest rehydration ratio of samples dried using microwave method. Commonly, microwave drying treatment led to higher rehydration capacity compared with convective drying, which may be due to the intercellular gaps caused by microwave energy resulted an increment in rehydration capacity of dried fruits [43]. In the microwave method, the rehydration ratio increased by increasing of microwave power, and at the end of rehydration test, the highest value (2.99) was found for sample dried at 600W. This is in line with the findings of Tagawaa [44] and Aghilinategh, Rafiee [45], who observed that increasing the microwave led to increase in rehydration ratio. It can be explained that the less dense structure obtained during drying at microwave powers due to the high internal pressure causing to expansion and puffing of the product, which has a higher capacity to absorb water. [46] Contrary to our findings, Horuz, Bozkurt [23] and Miraei Ashtiani, Sturm [42] found that the rehydration capacities of samples dried with microwave decreased with the increase of microwave powers, which can be explained by the formation of irreversible cellular displacement and rupture during microwave drying. However, ANOVA results showed that the rehydration capacity of dried hawthorn slices at 180 and 360 W did not influenced significantly by microwave power ($p>0.05$).

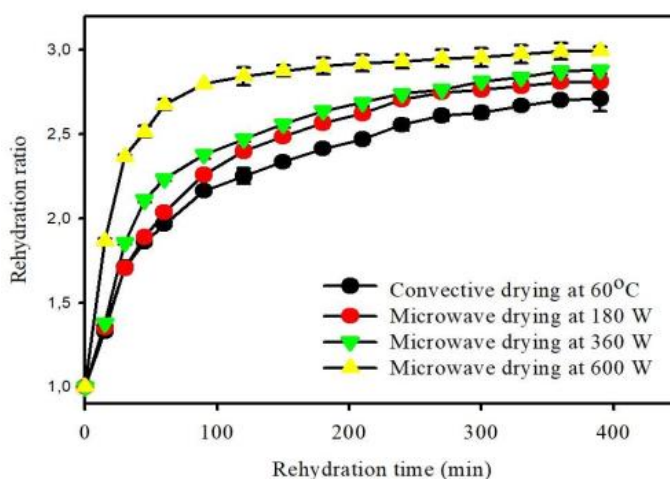


Figure 3. Rehydration ratio curves of dried hawthorn slices using convective drying and microwave drying at different powers.

To describe rehydration kinetics of hawthorn slices dried with convective and microwave methods was employed and the estimated data of determinations of Peleg's model, k_1 and k_2 , were given in Table 2. Overall, Peleg's model could well describe rehydration kinetics of hawthorn slices over the range of experiments with higher values of the coefficient of determination ($R^2 > 0.99$). Peleg rate constant of k_1 is related with the mass transfer rate and the lower k_1 value, the higher the initial rate of rehydration, detected for sample dried at 600 W, indicating higher water absorbing capacity compared to other treatments. Increasing of microwave power led to decrease in value of k_1 , which a similar trend was reported by Dadali, Demirhan [47]. For estimated value of k_2 that is inversely related to the absorption ability of foods, no significant differences ($p > 0.05$) were determined between microwave drying at different power, however k_2 value for product dried by convective drying was higher than that of microwave drying. These results evidence the better rehydration capacity product dried with microwave drying method.

Table 2. The estimated parameters and statistical analysis of Peleg's model at rehydration

Drying conditions	R^2	RMSE	$\chi^2(10^{-3})$	k_1	k_2	Y_0
Convective drying at 60°C	0.9952	0.035	1.193	32.064	0.512	1.005
Microwave drying at 180 W	0.9989	0.017	0.317	29.014	0.466	0.983
Microwave drying at 360 W	0.9966	0.044	1.107	20.859	0.474	0.9661
Microwave drying at 600 W	0.9957	0.033	1.144	8.166	0.474	0.982

Color properties

The color of dehydrated foods is one of the most important attribute for quality assessment, in which recorded by human receptors, so that it plays an important role in consumer evaluation of food quality. The color attributes (L^* , a^* and b^*) and derived color parameter of ΔE values for fresh and dried hawthorn are present in Table 3. The L^* , a^* and b^* values for sliced fresh sample were recorded as 71.14, 5.08 and 34.35, respectively and they were significantly affected by drying process ($p < 0.05$). Overall, a considerably decrease in the L^* value and a considerably increase in the b^* and a^* values were observed for all drying methods in comparison with the fresh hawthorn sample, indicating that the color was significantly darker, redder and yellower than that of non-dried sample ($p < 0.05$). These changes of L^* , a^* and b^* values may be due to the degradation of pigments and the formation of brown pigments by non-enzymatic Maillard reactions and enzymatic reactions [3, 48, 49]. It was observed that the convective drying led to less total color change ($\Delta E = 7.16$) compared to microwave treatment ($\Delta E = 14.86$ to 24.61). Similar results obtained by İzli [50] and İzli, İzli [51], who stated that the ΔE was the greatest in case of convective drying, whereas samples obtained after microwave drying were the darkest. In general, color changes of samples during drying could be ascribed the formation of brown compounds as a results of various reactions, including Maillard condensation of carbohydrates, polyphenols polymerization and pigment destruction, principally degradation of carotenoids [52] and the molecular changes towards the formation of this brown compounds are accelerate at the temperature above 120 °C [53]. In microwave drying, the minimum value of ΔE obtained for the sample at microwave power of 600 W and followed by those of power at 360 W, the highest ΔE observed dried samples at power of 180 W. These results indicate that lower microwave power increases degradations due to longer time exposed to heat. Similarly, Tagawaa [44] reported that the okra sample dried at the power of 800 W

shows the least color change (10.3) and the highest ΔE value (16.5) obtains at the lower microwave power level of 500 W. This can be explained by the fact that high microwave intensity led to faster transfer from the interior of the sample to its surface and this liquid quickly converted into vapor, and thus resulted less color change in the surface color due to no surface overheating [44, 54]. Ozkan, Akbudak [18], Horuz and Maskan [37] and Celen [13] reported similar observations for drying spinach, pomegranate arils and persimmon in microwave dryer, respectively, in which drying processes made using the high energy levels is the best option to preserve majority of color values considering the color values of non-dried samples. On the contrary, Ghanem, Mihoubi [55] and Dong, Cheng [35] stated that the ΔE value is obtained at the lower microwave power level and it is increased rapidly at higher microwave power settings.

Table 3. Color and hardness values of fresh and dried hawthorn slices

Drying conditions	L^*	a^*	b^*	ΔE	Hardness (N)
Fresh	71.14±0.89 ^a	5.08±0.29 ^d	34.35±1.41 ^b	-	5.85±0.68 ^e
Convective drying at 60°C	65.54±2.59 ^b	9.42±1.09 ^c	35.46±0.64 ^b	7.18±1.78 ^d	7.36±0.91 ^d
Microwave drying at 180 W	49.18±0.22 ^e	14.94±0.38 ^a	39.46±0.52 ^a	24.61±0.15 ^a	10.13±1.53 ^a
Microwave drying at 360 W	54.40±0.56 ^d	12.10±1.25 ^b	41.16±0.09 ^a	19.41±0.03 ^b	8.29±0.16 ^b
Microwave drying at 600 W	60.03±2.01 ^c	12.15±0.51 ^b	41.23±0.53 ^a	14.86±0.99 ^c	7.69±0.06 ^c

^{a-e} Values in the same column with different letters are significantly different ($p < 0.05$), according to Duncan's test.

Textural properties

The textural property of fresh and dried hawthorn samples that belonging to convective and microwave drying methods was described using the hardness value that shown in Table 3. The hardness value of fresh sample was 5.85 N and a significant increase was determined after drying process ($p < 0.05$). Our results were in accordance with the finds of Miraei Ashtiani, Sturm [42] and Aamir and Boonsupthip [56] who stated more hardness is samples dried as compared to fresh. The hardness value of dried hawthorn slices with convective drying was determined as 7.36 N that was lower than that of dried samples by microwave drying. In contrary to the study results, Miraei Ashtiani, Sturm [42] noted that the dried nectarine slices after microwave drying had lower hardness than that of the samples dried with hot air. Regarding microwave drying, the hawthorn slices dried at 180 W exhibited more hardness (10.13 N) among all samples. When the microwave power increased to 600 W, the hardness value of dried hawthorn slices had reached a minimum value (7.69 N). It is probably the microwave treated hawthorn slice at 600 W lost its surface moisture faster than those of the other powers (Figure 1b), and therefore a harder external layer on the surface formed during drying, which caused harsher textures of dried fruits [57]. These results are consistent with findings of past studies for blueberries [58] and nectarine slices [42], which increased microwave power yielded products with softer texture.

Total phenolic content

The results of the total phenolic contents of the fresh and hawthorn slices dried by convective and microwave drying methods are shown in Table 4. The drying treatment with different drying methods led to a significant change in total phenolic content ($p < 0.05$). Taking the fresh hawthorn slice as reference (215.29 mg GAE/100 g d.w.), a significant decrease in the total phenolic content was observed in the samples dried with convective (126.34 mg GAE/100 g d.w.). Several research studies found that a significant loss of total phenolic content of convectional dried has been detected [5, 32, 34]. The loss of phenolic contents during the thermal processing may be explained by oxidative and thermal degradation of phenolic compounds due to the heat treatment [59]. Nevertheless, higher levels of phenolic contents have been found after drying processes depending on the type of phenolic compound [11, 60]. The increase in the phenolic content in dried products could be ascribed to the destroy the integrity of the cell structure of products during heating processes thereby promoting the extractability of the phenolic compounds because the disruption of the cell structure was concomitant with the breakdown of insoluble bound phenolics [4, 61].

Table 4. Total phenolic content and antioxidant properties of fresh and dried hawthorn slices

Drying conditions	Total phenolic content (mg GAE/100 g d.w.)	DPPH* (mmol TE/100 g d.w.)	ABTS* (mmol TE/100 g d.w.)
Fresh	215.29±2.41 ^c	5.11±0.16 ^c	3.15±0.29 ^b
Convective drying at 60°C	126.34±7.11 ^d	4.26±0.28 ^d	1.61±0.07 ^c
Microwave drying at 180 W	220.37±9.81 ^c	5.69±0.31 ^b	3.17±0.44 ^b
Microwave drying at 360 W	270.95±3.41 ^a	6.79±0.29 ^a	4.27±0.21 ^a
Microwave drying at 600 W	238.60±8.59 ^b	6.47±0.36 ^a	3.33±0.07 ^b

^{a-d} Values in the same column with different letters are significantly different ($p < 0.05$), according to Duncan's test.

As shown in Table 4, the hawthorn slices dried with microwave had higher total phenolic contents than the fresh hawthorn fruits, which in accordance with the result of Ozcan, Al Juhaimi [11] and Chahbani, Fakhfakh [15], who reported that the degradation of fresh cells during microwave drying leads to an increment in the phenolic contents. The phenolic content increased by increasing microwave power from 180 to 360 W, but the microwave power used 600 W instead of 360 W resulted in lower total phenolic contents of the sample. These results were compatible with the study of Wojdyło, Figiel [59], revealed that the drying at 120 W yields higher polyphenols content in the dried product despite the power ranging from 240 W to 480 W due to the lower temperatures of the material.

Antioxidant activity

Valadez-Carmona, Cortez-Garcia [62] stated that the antioxidant activity should be evaluated using more than one method due to the complexity of the composition of the phytochemical and oxidative processes, thereby two methods, DPPH and ABTS, were used in this study and results were given in Table 3. The antioxidant activity of fresh hawthorn sample was determined as 5.11 and 3.15 mmol TE/100 g d.w. in DPPH and ABTS assay, respectively. It was observed that the antioxidant activity of the samples was changing under different drying conditions. While the antioxidant activity of samples dried with convective drying was found lower than those of fresh sample, but was significantly increased after microwave drying processes ($p < 0.05$). However, a greater decrease in the antioxidant activity was observed when the microwave over increased from 360 to 600 W. Similar trends was observed for both of DPPH and ABTS of hawthorn samples during drying. In this study, we determined a quite strong correlation between total phenolic content and antioxidant activity in DPPH and ABTS ($r = 0.938$ and $r = 0.951$, respectively), which indicate that higher phenolic compounds would increase the antioxidant activity. According to Mraihi, Journi [63], the antioxidant activity of phenolics is mainly due to their redox potentials hence allow them to act as reducing agents, hydrogen donors, and singlet oxygen quenchers. Our results are comparable with most published studies [3, 4, 32, 62], which indicate that the convective drying method decrease the antioxidant activity that may be attributed to decrease in total phenolic content. In general, high temperatures (i.e. 60 °C and 70 °C) and long exposure to drying process might destroy some of the phenolic compounds during drying processes, which may cause loss of bioactive compounds [64]. Previous studies have noted that increases antioxidant activity of products after microwave drying due to shorter drying time [11, 15, 35, 65]. However, antioxidant activity tends to decrease when the drying is conducted at higher microwave power [35], which can be explained by higher temperature. Samoticha, Wojdyło [66] stated that better preservation of bioactive compounds is obtained at low temperature, resulting higher antioxidant activity. On the other hand, higher temperature during drying processes may be led to formation of Maillard reaction products that also exhibit antioxidant activity [66].

CONCLUSION

In this study, the effect of microwave drying at different microwave power levels on the drying characteristics and quality parameters (color, texture, rehydration and bioactive properties) of hawthorn slices were investigated and compared to the results obtained with convectional drying at 60°C. Hawthorn slice samples dried more quickly with microwave drying and the time needed to reach desired moisture content of <10% varied from 36 to 84 min depend on microwave power. The drying rate increased with increasing the microwave power and was found higher than those of convectional drying. Although eight different thin-layer drying kinetic models were found to be fit the experimental data well depending of high R^2 and low $RMSE$ and χ^2 values, Page model was found as the best described the microwave drying data. Microwave drying of hawthorn slices at 600 W exhibited lower total color difference and higher rehydration characteristics, when compared to other microwave treatments. However, the highest bioactive properties were obtained after microwave drying at 360 W power. As a result, microwave drying at 360 W can be a potential for drying of hawthorn slices considering the optimal drying characteristics and high quality products.

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