Total phenolics, antioxidant capacity, colour and drying characteristics of date fruit dried with different methods

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Abstract

Date slices were dried with the three drying methods convective (60, 70 and 80 °C), microwave (120 W) and freeze drying to determine drying characteristics and to compare the dried fruit quality. All colour parameters changed depending on the drying method and colours closest to the fresh sample were obtained with freeze drying. It is interesting to note that the total phenolic content and antioxidant capacity in each sample rose when looked at in relation to the fresh sample. In particular, microwave-dried samples were recorded as having the highest total phenolic content and the highest antioxidant capacity. To explain the drying kinetics of the date slices, nine thin-layer drying models were also attempted. Based on statistical tests, the model developed by Midilli et al. model was found to be the best model for convective and microwave drying, but the Two Term model was the best for freeze drying. This study shows that microwave drying can produce high quality date slices with the additional advantage of reduced drying times compared to convective and freeze drying.

Keywords: drying methods; thin-layer; date slices; colour; total phenolic content.

Practical Applications: Microwave drying at 120W can improve the final quality of dried date slices.

1 Introduction

The date (*Phoenix dactylifera* L.) is a fruit, which is characterized with a middle-stone and plump outer covering. It is a very nutritious fruit that is a product of a date palm. These date palm trees are native to the dry and semi-dry climates of Northern Africa and the Middle East. This fruit is very healthy as it contains many different kinds of minerals (Ca, Fe, Mg, P, K and Zn), dietary fibre (6.40-11.50%), protein (2.3-5.6%), and carbohydrates (44-88%, predominately glucose, fructose and sucrose). It also includes many more natural ingredients like carotenoids and phenolics that are helpful antioxidative compounds (Al-Shahib & Marshall, 2003). This fruit is available on the global market many different forms; dried, processed, or fresh. Dates are available to be eaten in many different growth stages. For example, dates can be eaten in the *khalaal* stage (full-size, crunchy), *rutab* stage (ripe, soft) or *tamer* stage (ripe, sun-dried), but dried dates are the most common way that dates are sold commercially. (Ashraf & Hamidi-Esfahani, 2011).

One of the oldest forms of processing and preserving food is drying. The main aim of drying is to extend the shelf life of certain foods, minimize packaging requirements and reduce shipping weights (Okos et al., 1992). The most common method throughout history for drying dates has been sun drying. This process of sun drying has its challenges in that daytime temperature and humidity cannot controlled, the fruit is in contact with the open environment (a possible source of contamination due to dust, soil, sand particles and insects), and the fact that the process takes too much time. Due to the downsides of this processing method, sun drying does not provide an effective process for quality production (Doymaz, 2005).

To reduce these problems, other forms of processing should be taken into consideration, which may improve quality in terms of colour or nutrients. In today's world, it seems that the most effective and common form of processing is the convective drying method, because of its ability to reduce the moisture content in food and preserved well (Mundada et al., 2010). However, there are many downsides to the convective method that must be observed. For example, the detriments of using this method include the high temperatures and the long drying times that are used. These detriments can have negative effects on the actual flavor and nutrients of the final product produced (Maskan, 2001; Zhang et al., 2006). Another alternative method to consider is the microwave drying. This method provides many advantages in using uniform energy, providing low space utilization, supplying healthy sanitation, and giving better process control (Maskan, 2000). At the same time, as each method is analyzed, it is noteworthy that every method has some drawbacks. For example, the microwave method can cause uneven heating, can be high investment cost, and can cause damage to the final product (Zhang et al., 2006). Freeze drying is a well-known drying process for obtaining high quality products because it reduces nutritional and sensorial degradation. On the other hand, the freeze drying method also requires a lot of time and is known as the most expensive form of food drying process (Ratti, 2001).

According to literature surveys, there is not much work being published about date fruit drying methods. A careful evaluation of all of the methods must take place before selecting a suitable method for commercial drying. Hence, the objectives of this study were to compare the 1) thin-layer drying kinetics 2) colour change parameters, 3) total phenolic content and 4) antioxidant capacity of dried date fruits when using convective-, microwave- and freeze drying methods.

2 Materials and methods

2.1 Date fruits

For this study, date samples were purchased from a local market in Bursa, Turkey. These samples were stored at a temperature of 4 ± 0.5 °C until the drying process was completed. The initial moisture content on a dry basis (d.b.) was determined to be 1.87 (g water/g dry solid) by oven drying (ED115 Binder, Tuttlingen, Germany) at 100 ± 5°C. Fruits that were uniformly matured and undamaged were used for all experiments in this study. Each date sample was sliced with a food slicer (Nicer Dicer, China) to get the following measurements; each sample averaged out to have a 25 ± 0.05 mm diameter and was sliced to have a 5 ± 0.05 mm thickness.

2.2 Equipment and procedures for drying

Three different methods were used in the following experiments. The methods used were; convective drying, microwave drying, and freeze drying. These experiments were implemented in triplicate. *Convective drying*: Date slices were put on a rotating glass plate with a diameter of 400 mm in thin layer and then dried using a laboratory convective oven (Whirlpool AMW 545, Turkey). At the time of the experiment, the air velocity was 1.5 m/s, with air temperatures of 60, 70 and 80 °C. A digital balance (Shimadzu UX-6200H, Tokyo, Japan) with 0.01 g precision was put under the oven in order to mass determination. While the drying took place, the loss of moisture was recorded in 5-min intervals. *Microwave drying*: The drying treatment was performed in a microwave oven (Arçelik MD574, İstanbul, Turkey) at an output power level of 120 W. Date slices were placed in thin layer on a rotating glass plate with a 245 mm diameter. The moisture loss from the sample was recorded at 2-min intervals by removing the sample with the glass plate and weighing it on the digital balance (Radwag PC 4500/C/2, Radom, Poland) with a precision of 0.01 g. *Freeze drying*: A laboratory freeze dryer (Alpha 1-2 LD Plus, Osterode am Harz, Germany) was used in this experiment at a processing temperature of −50 °C with a constant pressure in the drying chamber of 48 Pa. During drying, moisture loss from the sample was recorded every 2 h with an accuracy of ±0.01 g (Radwag PC 4500/C/2, Radom, Poland).

2.3 Mathematical modelling of drying data

There were nine common drying models used in this experiment. The best model for describing the drying characteristics of the date slices is displayed in Table 1. During the drying process, the moisture ratios (*MR*) were calculated with the following Equation 1:

Table 1. Thin-layer drying models being used to mathematically model the date drying kinetics.

No	Model name	Model	References
1	Henderson & Pabis	$MR = a\exp(-kt)$	Westerman et al. (1973)
2	Newton	$MR = \exp(-kt)$	Ayensu (1997)
3	Page	$MR = \exp(-kt^n)$	Agrawal & Singh (1977)
4	Logarithmic	$MR = a\exp(-kt) + c$	Yagcioglu et al. (1999)
5	Two Term	$MR = a\exp(-k_0 t) + b\exp(-k_1 t)$	Madamba et al. (1996)
6	Two Term Exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat)$	Sharaf-Eldeen et al. (1980)
7	Wang & Singh	$MR = 1 + at + bt^2$	Wang & Singh (1978)
8	Diffusion Approach	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	Kassem (1998)
9	Midilli et al.	$MR = a\exp(-kt^n) + bt$	Midilli et al. (2002)

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

M_t represents the moisture at a specific time (g water/g dry solid). M_o displays the initial moisture content (g water/g dry solid). M_e shows the equilibrium moisture content (g water/g dry solid). When compare M_t and M_o with M_e, the values of M_e turn out to be very small. In conclusion to these findings, many researchers simplified the *MR* as follows (Equation 2) (Midilli et al., 2002):

$$MR = \frac{M_t}{M_o} \tag{2}$$

2.4 Colour analysis

Through the usage of a colorimeter (MSEZ-4500L, HunterLab, Virginia, USA), the colour of fresh and dried fruit slices was determined. The results for the colours were as follows: L-values (lightness/darkness), a-values (redness/greenness) and b-values (yellowness/blueness). The colorimeter was calibrated by using a standard white and black plate. A sample inside of a glass cell was placed close to the nose cone of the colorimeter, above the light source, while the L^*, a^* and b^* values measured (Xiao et al., 2012). L_0^*, a_0^* and b_0^* are the colour values of fresh samples. The reading was performed on the surface of sample while ten random locations were chosen for measurement. The L^*, a^* and b^* values were used for calculating Chroma C (Equation 3), hue angle α Equation 4) and total colour differences ΔE (Equation 5) to explain colour changes (Maskan, 2001):

$$C = \sqrt{(a^2 + b^2)} \tag{3}$$

$$\alpha = \tan^{-1}\left(\frac{b}{a}\right) \tag{4}$$

$$\Delta E = \sqrt{(L*-L_0*)^2 + (a*-a_0*)^2 + (b*-b_0*)^2} \tag{5}$$

2.5 Preparation of sample extracts

Date fruit extracts were prepared according to the method described by Turkmen et al. (2005). Briefly, 1 g of sample was mixed with 4.5 mL methanol/water (80/20 v/v) using a mechanical shaker (Biosan OS-20, Latvia) at 140 rpm for 2 h, followed by centrifuged at 10,000 *g* for 15 min (Sigma 3K30, UK). Supernatants were collected, and residues were re-extracted under identical conditions. The obtained supernatants were combined and passed through a 0.45 μm PTFE membrane filter.

2.6 Total phenolic content determination

Total phenolic content of the extracts was quantified according to the Folin–Ciocalteu test by using the method of Igual et al. (2012) with a minor modifications. 1.25 mL of Folin–Ciocalteu reagent (Sigma-Aldrich, Germany) and 15 mL of distilled water were added to 0.25 mL of methanolic extracts and vortexed (WiseMix VM-10, Daihan, Korea) for 15 s. After the 8 min incubation in darkness, 3.75 mL of 7.5% Na_2CO_3 was added to the mixture and the volume was adjusted to 25 mL with distilled water. Absorbance values of samples were measured at 765 nm (Optizen 3220 UV, Mecasys, Korea), followed by a 2 h incubation in the dark at room temperature. The calibration curve was prepared with gallic acid (GA) (Sigma-Aldrich, Germany), and the results were expressed as mg GA/100 g on dry weight (d.w). Three replicates of each date extract were analysed.

2.7 Antioxidant capacity determination

Based on the DPPH (2,2-Diphenyl-1-picrylhydrazyl) free radical scavenging method by Alothman et al. (2009), the antioxidant capacity of the extracts were measured. To 3.9 mL of 25 mM methanolic solution of DPPH radical, 0.1 mL of appropriately diluted extracts was added. The mixture was thoroughly vortexed (WiseMix VM-10, Daihan, Korea), followed by incubation in the dark at room temperature for 30 min. The absorbance of each sample was measured at 515 nm (Optizen 3220 UV, Mecasys, Korea). Results were expressed as μmol Trolox equivalents (TE) (Merck, Germany) per 1 g d.w. of sample. Three replicates of each date extract were analysed.

2.8 Statistical analysis

The experiments were conducted using a randomized plots factorial experimental design. The results were analysed by using the MATLAB (MathWorks Inc., Natick, MA) and JMP (Version 7.0, SAS Institute Inc., Cary, NC, USA). By using a least significant difference (LSD) test at a 5% level of significance, the mean differences were evaluated. The model that best explains the thin-layer drying characteristics of date fruit slices is determine as by the lowest reduced chi-squared (χ^2) and the root mean square error (*RMSE*) values, and the highest coefficient of determination (R^2) (Goyal et al., 2006).

These values are displayed below (Equations 6, 7):

$$\chi^2 = \frac{\sum_{Y=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N-n} \tag{6}$$

$$RMSE = \sqrt{\frac{\sum_{Y=1}^{n}(MR_{pre,i} - MR_{exp,i})}{N}} \tag{7}$$

$MR_{exp,i}$, represents the experimental moisture ratio for test i.

$MR_{pre,i}$, represent the estimated moisture ratio for test i.

N represents the observation number. Lastly, n is the number of constants in the drying model (Wang et al., 2007).

3 Results and discussions

3.1 Drying kinetics

The changes in moisture content of the date slices with drying time, drying temperature (60, 70 and 80 °C), and microwave and freeze drying are presented in Figure 1. The experimental results show that the time required to reduce the moisture content was dependent on the drying method. Drying took longest with freeze drying (1800 min) and was much faster with microwave drying (16 min). A significant reduction in drying time was realized as an increase in temperature from 60 to 80 °C occurred. It has been shown that increasing the temperature speeds up the drying time of date fruit. This result is in good agreement with earlier observations (Garau et al., 2007; Wang et al., 2007; Tunde-Akintunde & Ogunlakin, 2013; Faal et al., 2015). Drying time at 80 °C (75 min) was 95.3% shorter than freeze drying but 78.7% longer than microwave drying at power of 120 W. Microwave drying probably save time because the internal heat generated by the microwave causes rapid evaporation of water. Tavakolipour & Zirjani (2014) showed that microwave drying of banana slices reduced the drying time by 90% compared to hot air drying. In studies done by Maskan (2000) and Albanese et al. (2013), they had very similar findings.

3.2 Fitting of drying curves

The statistical parameters, including drying model coefficients and the comparison criteria used to evaluate the fitting quality, R^2, *RMSE* and χ^2, are given in Table 2 and 3. The R^2 values varied between 0.9247 and 0.9997, *RMSE* values varied between 0.0058 and 0.0957 and χ^2 values varied between 0.2528 x 10^{-4} and 87.7333 x 10^{-4}, indicating good fitting results. It is noteworthy that higher R^2 and lower *RMSE* and χ^2 values were displayed through the use of the Midilli et al. model for all temperatures and at a microwave power of 120 W. Additionally, the Two Term model gave better statistical values than other models for freeze drying. The R^2, *RMSE* and χ^2 values of the Midilli et al. and Two Term models ranged from 0.9970 to 0.9997, 0.0058 to 0.0152 and 0.2528 x 10^{-4} to 2.1221 x 10^{-4}; and 0.9784 to 0.9977, 0.0135 to 0.0513 and 1.6582 x 10^{-4} to 25.8357 x 10^{-4}, respectively.

The experimental and predicted moisture ratios of the most appropriate models are presented in Figure 2 and Figure 3. Overall, there is excellent agreement between the experimental data and the predicted results. Thus, the Midilli et al. and Two Term models were found to be best models to represent the thin-layer
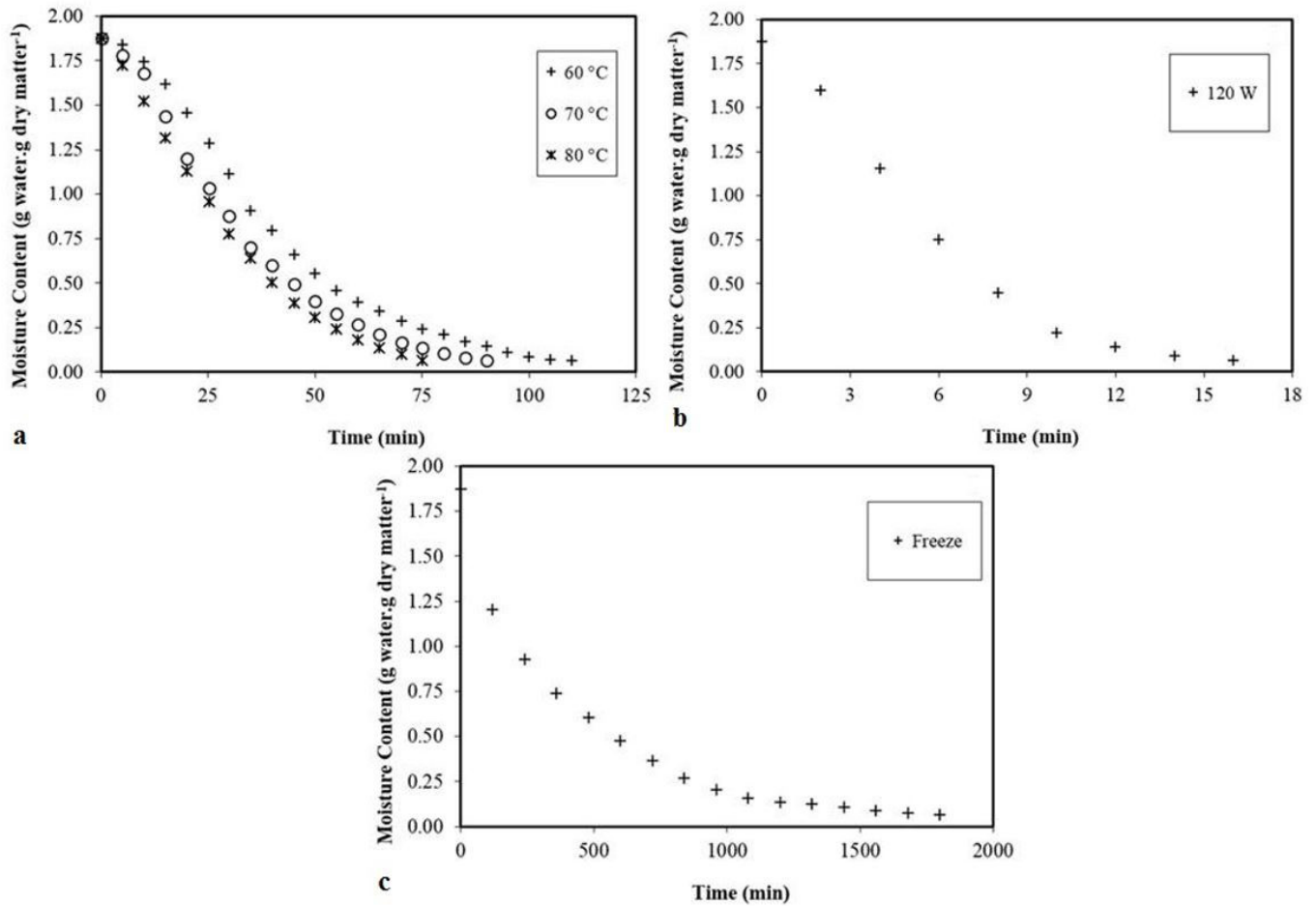
Figure 1. Drying curves of date samples using different convective temperatures (a), microwave power level (b) and freeze drying (c) conditions.

Table 2. Estimated values of coefficients and statistical essentials collected from various thin-layer drying models at different temperatures.

No	60 °C				70 °C				80 °C			
	Model coefficients	R^2	RMSE	$\chi^2(10^{-4})$	Model coefficients	R^2	RMSE	$\chi^2(10^{-4})$	Model coefficients	R^2	RMSE	$\chi^2(10^{-4})$
1	a = 1.16 k = 0.02753	0.9634	0.0667	44.1368	a = 1.125 k = 0.03321	0.9724	0.0567	32.3309	a = 1.096 k = 0.03638	0.9724	0.0559	30.8148
2	k = 0.02401	0.9404	0.0852	72.9711	k = 0.02975	0.9575	0.0704	50.4617	k = 0.03333	0.9632	0.0645	41.6470
3	k = 0.00197 n = 1.652	0.9986	0.0130	1.7176	k = 0.004744 n = 1.504	0.9989	0.0114	1.5244	k = 0.006856 n = 1.448	0.9983	0.0136	1.6537
4	a = 1.322 k = 0.01837 c = -0.2146	0.9833	0.0451	19.8206	a = 1.273 k = 0.02262 c = -0.1962	0.9900	0.0341	12.1484	a = 1.319 k = 0.02219 c = -0.2747	0.9951	0.0235	5.5701
5	a = -0.2754 k_o = 5.323 b = 1.275 k_1 = 0.03012	0.9784	0.0513	25.8357	a = 1.243 k_o = 0.03652 b = -0.2426 k_1 = 4.163	0.9858	0.0407	16.5055	a = 24.01 k_o = 0.06367 b = -22.97 k_1 = 0.06597	0.9943	0.0253	5.9417
6	a = 1.022 k = 0.01932	0.9655	0.0648	41.9409	a = 0.0000059 k = 504.3	0.9549	0.0724	53.4497	a = 0.0000092 k = 360.9	0.9605	0.0668	44.6484
7	a = -0.01746 b = 0.000007491	0.9810	0.0480	23.1766	a = -0.02168 b = 0.0001171	0.9907	0.0329	11.6911	a = -0.02412 b = 0.0001429	0.9966	0.0186	3.6238
8	a = 0.02629 k = 6.366 b = 0.003683	0.9247	0.0957	87.7333	a = 1.646 k = 0.0281 b = 0.9158	0.9531	0.0739	52.4178	a = -13.09 k = 0.06892 b = 0.9352	0.9966	0.0197	3.3102
9	a = 1.014 k = 0.002189 n = 1.631 b = -0.00000498	0.9987	0.0126	1.5324	a = 1.012 k = 0.005768 n = 1.448 b = -0.0001453	0.9990	0.0110	1.4541	a = 0.9972 k = 0.00867 n = 1.356 b = -0.0006357	0.9997	0.0058	0.2528

Table 3. Estimated values of coefficients and statistical essentials collected from various thin-layer drying models microwave and freeze drying conditions.

| No	Model coefficients (Microwave)	R^2	RMSE	$\chi^2(10^{-4})$	Model coefficients (Freeze)	R^2	RMSE	$\chi^2(10^{-4})$
1	a = 1.088 k = 0.1862	0.9550	0.0803	64.4687	a = 0.9519 k = 0.002602	0.9909	0.0268	6.9931
2	k = 0.1731	0.9513	0.0836	70.4025	k = 0.002736	0.9888	0.0296	8.4459
3	k = 0.04973 n = 1.658	0.9994	0.0089	0.5308	k = 0.006943 n = 0.8496	0.9952	0.0194	3.5584
4	a = 1.286 k = 0.1211 c = -0.2311	0.9784	0.0557	31.2405	a = 0.9492 k = 0.002655 c = 0.005606	0.9903	0.0276	7.4329
5	a = -62.45 k_o = 0.3412 b = 63.47 k_1 = 0.3362	0.9910	0.0358	13.3582	a = 0.8359 k_o = 0.002291 b = 0.1641 k_1 = 0.4768	0.9977	0.0135	1.6582
6	a = 2.132 k = 0.2831	0.9960	0.0238	5.6057	a = 0.1518 k = 0.01547	0.9970	0.0154	2.1635
7	a = -0.1251 b = 0.003866	0.9873	0.0427	18.3072	a = -0.001602 b = 0.0006164	0.9692	0.0580	37.2475
8	a = 14.16 k = 0.06767 b = 0.9239	0.9758	0.0589	30.2738	a = 0.1113 k = 0.1841 b = 0.01321	0.9968	0.0157	2.0779
9	a = 0.9987 k = 0.05029 n = 1.645 b = -0.0003728	0.9995	0.0083	0.5088	a = 0.9955 k = 0.01014 n = 0.7787 b = -0.00000219	0.9970	0.0152	2.1221
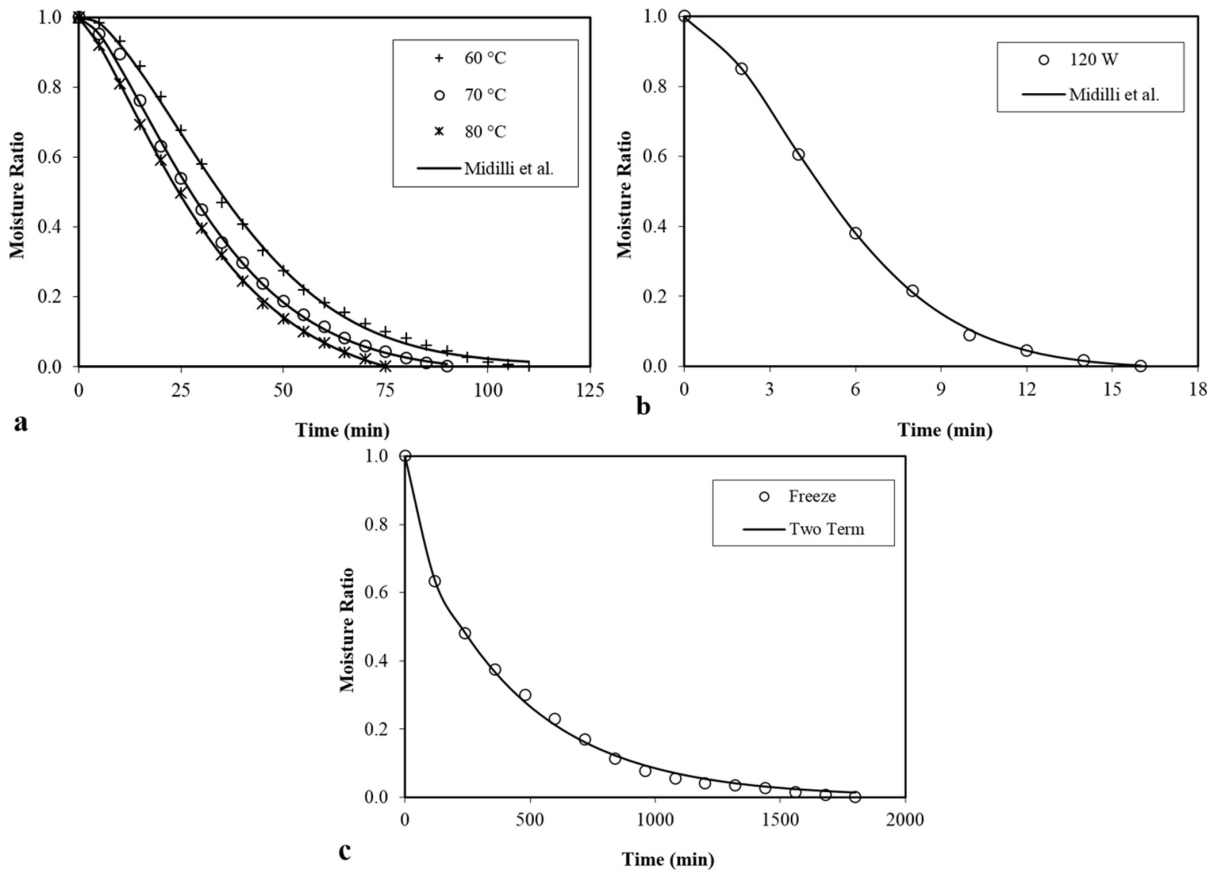
Figure 2. A comparison of the experimental and theoretical moisture ratios that was put forth by the Midilli et al. and Two Term models at specific drying times under three selected drying conditions; convective (a), microwave (b), freeze (c).

drying characteristics of the date slices. These observations are in good agreement with earlier results reported for the Midilli et al. model in describing the thin-layer drying of pear (Doymaz, 2013) and mango ginger (Murthy & Manohar, 2014) and for the Two term model in drying of sultana grapes (Yaldiz et al., 2001) and squash seeds (Chayjan et al., 2013).

3.3 Colour analysis

The colour of a product is an important attribute for quality assessment. The colour parameters of the dried date fruits were influenced by the different drying methods, as shown in Table 4. In comparison to the fresh date fruit, a significant decline in the L^* value was observed ($P < 0.05$). The L^* of the freeze-dried samples was significantly higher than those of convective- and microwave-dried dates ($P < 0.05$). In contrast, a significant increase in a^* values was observed compared to the fresh samples in fruits dried with convective and microwave drying ($P < 0.05$). The changes in L^* and a^* values in dried fruits seemed to follow similar trends, but there were some variations within the b^* values for all drying methods. Of the three drying methods used, the highest b^* value was found with convective drying at 80 °C, and the largest decrease in b^* value was found with microwave drying at 120 W. Generally the b^* value of dried dates was lower than that of fresh samples. However, the b^* value increased with increasing temperature for the convective (80 °C) dried samples. ΔE, which is a function of

L^*, a^* and b^* values, was dependent on drying temperature and drying method. A decrease in L^* value of a sample resulted in higher ΔE. Microwave drying (17.33) produced the highest ΔE, and the lowest ΔE value was obtained with freeze drying (3.42). A good way to recognize the colour intensity was to look at the C value. Compared to fresh sample, the C values of microwave and freeze dried samples were reduced ($P < 0.05$). In contrast, as drying temperature increased from 60 to 80 °C in convective drying, higher C values were obtained, mainly due to the higher b^* values. A reduction was experienced in the values of the dried samples when looked at in relation to the fresh samples ($P < 0.05$), which clearly indicates that more browning occurred. This is probably due to the higher a^* values of all dried samples ($P < 0.05$). Among the all dried date samples, the best colour values were obtained from the non-thermal method of freeze drying. Date fruit colour changes caused by thermal treatment may be strongly related to pigment degradation, especially the degradation of carotenoids and the formation of brown pigments by non-enzymatic reactions (Maillard reaction) and enzymatic reactions (Kammoun Bejar et al., 2011).

3.4 Total phenolic content

The total phenolic content of date fruit and the effects of the drying are displayed within Figure 3. The total phenolic content varied significantly with drying method ($P < 0.05$). The total phenolic content of fresh date slices was 151.79 mg GA/100 g d.w., which is within the range of values found in other studies of dates (Allaith, 2008; Singh et al., 2012). The results show that dried fruits had higher total phenolic content than fresh fruit. The highest total phenolic content (224.52 mg GA/100 g d.w.) was obtained by microwave drying at 120 W, whereas the lowest total phenolic content was obtained by freeze drying (159.23 mg GA/100 g) ($P < 0.05$). During studies using the convective drying method, the total phenolic content declined when the drying temperature was increased from 60 to 80 °C ($P < 0.05$). The decrease in total phenolic with increasing drying temperature has also been reported in studies of pear (Santos et al., 2014) and apple (Vega-Gálvez et al., 2012). The increase in total phenolic content in dried samples may occur because the drying treatments accelerate bound phenolic compounds as part of the breakdown of cellular constituents (Chang et al., 2006). In this study, the increase could be explained by the degradation of complex phenolic tannins by heat and enzymatic or non-enzymatic oxidation, which
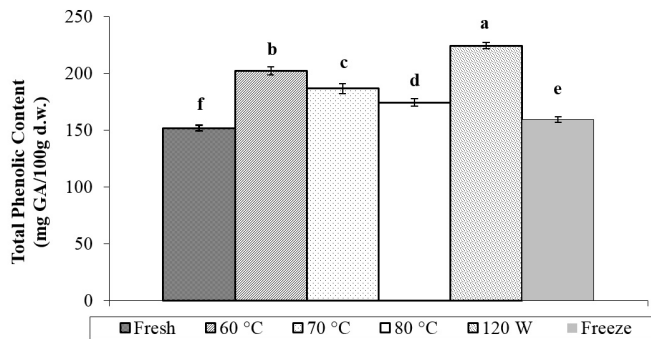

Figure 3. The effects of different drying conditions on the total phenolic content of dates. Bars that display different letters are shown as significantly different ($P < 0.05$).

Table 4. Colour parameters of fresh and dried dates which were determined by using different drying methods.

Drying method	Colour parameters					
	L^*	a^*	b^*	C	$\alpha°$	Δe
Fresh	64.92 ± 1.46[a]	4.18 ± 0.87[e]	35.05 ± 1.56[a]	35.30 ± 1.62[bc]	83.27 ± 1.24[a]	
Convective drying						
60 °C	58.29 ± 1.73[c]	6.05 ± 0.89[c]	31.69 ± 1.58[c]	32.27 ± 1.71[de]	79.28 ± 1.08[c]	7.90 ± 1.50[c]
70 °C	56.61 ± 1.94[d]	7.53 ± 0.73[b]	34.61 ± 1.76[ab]	35.43 ± 1.85[b]	77.78 ± 0.75[d]	9.19 ± 1.75[c]
80 °C	54.25 ± 1.38[e]	10.24 ± 1.45[a]	35.63 ± 1.80[a]	37.09 ± 2.04[a]	74.05 ± 1.67[e]	12.41 ± 1.96[b]
Microwave drying						
120W	49.27 ± 1.85[f]	9.66 ± 0.21[a]	30.33 ± 2.10[c]	31.83 ± 2.01[e]	72.31 ± 1.12[f]	17.33 ± 2.14[a]
Freeze drying	63.11 ± 2.20[b]	5.06 ± 0.48[d]	33.31 ± 1.46[b]	33.70 ± 1.44[cd]	81.38 ± 0.36[b]	3.42 ± 1.45[d]

[a-f]Means that display different letters are shown as significantly different (P <.0.05).

cause more phenolics to be extracted. In addition, the increase in phenolic content could be explained by the formation of Maillard reaction products, which would cause new phenolic compounds to form from precursors during thermal treatments (Que et al., 2008; Sultana et al., 2012). The highest phenolic content in microwave-dried dates might be because of the high temperatures reached in the during microwave treatment, which could cause greater cell disruption and lead to rupturing that releases phenolic compounds. The effects of drying treatments on the phenolic compounds of foods have been studied before. Some previous studies showed that heat treatment is very effective for increasing the total phenolic content in different foods, such as dried apricots (Sultana et al., 2012), tomatoes (Chang et al., 2006) and raisins (Carranza-Concha et al., 2012). Although some authors (Zanoelo et al., 2006; Sultana et al., 2012) note that total phenolics decrease during thermal processing of foods, others (Dewanto et al., 2002) have reported no significant changes. Thus, the effect of drying treatments on phenolic compounds from different materials may not be the same.

3.5 Antioxidant capacity

Figure 4 shows the changes in antioxidant capacity of date samples as affected by drying method. The antioxidant capacity of fresh sample was found to be 1.40 μmol Trolox/g d.w. After drying treatments, this value reached 2.08 μmol Trolox/g d.w. for samples dried by microwave at 120 W ($P < 0.05$). Date slices subjected to freeze drying (1.48 μmol Trolox/g d.w.) had higher values ($P > 0.05$) than fresh sample but were significantly lower ($P \leq 0.05$) than the microwave-dried and convective-dried samples at 60 °C (1.87 μmol Trolox/g d.w.) and 70°C (1.66 μmol Trolox/g d.w.). Additionally, there was not a significant ($P > 0.05$) difference between the antioxidant capacities of fresh sample and freeze and convective dried (80 °C, 1.53 μmol Trolox/g d.w.) samples. Although non-thermal freeze drying is often considered to be the best drying method for preserving heat sensitive compounds, the results show that higher total phenolic content and antioxidant capacity were obtained with thermal methods for date fruit. Que et al. (2008) reported that hot air dried pumpkin flour contained higher total phenolic content and antioxidant activity than freeze dried sample, possibly due to production of Maillard products. The increase in antioxidant capacity as a result
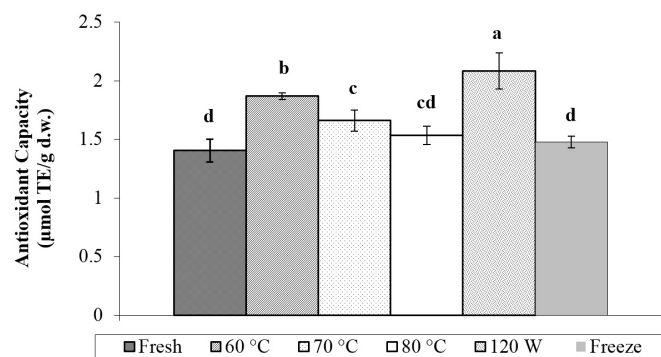
of drying might be caused by the formation of new antioxidant compounds (Albanese et al., 2013). In this study, the antioxidant capacity of samples increases in parallel with the total phenolic content. The antioxidant capacity of convective dried samples decreased as a consequence of increasing the drying temperature from 60 to 80 °C, possibly due to antioxidant compounds being relatively unstable at higher temperatures. The decrease could also be related to interactions between antioxidant compounds and other fruit constituents (Di Scala et al., 2011). These results disagree with some previous studies that reported that drying at low temperatures with long drying times decreases of antioxidant capacity (Garau et al., 2007; Vega-Gálvez et al., 2012).

4 Conclusions

In this study, using microwave power and increasing the temperature of convective drying caused significant decreases in drying time. Freeze drying was found to be the best method for maintaining good colour parameters. However, although freeze drying is often considered to be good for preserving heat-sensitive compounds, findings did not support that claim. The total phenolic content and antioxidant capacity of date slices were higher in dried samples than fresh samples. To model the drying behaviour of date slices, nine different thin-layer drying models were used to describe the drying kinetics. The model of Midilli et al. gave the best fit for the microwave application and all temperatures of convective drying, and the Two Term model showed the best fit for freeze drying. Overall, this study concludes that microwave drying shortens the drying time and can improve the final quality of dried date slices in terms of total phenolic content and antioxidant capacity.

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Figure 4. The effects of different drying conditions on the antioxidant capacity of dates. Bars that display different letters are shown as significantly different ($P < 0.05$).

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