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Kinetic studies for microwave-assisted drying of Oraby date slices

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ABSTRACT

This study was conducted to evaluate the effects of microwave (MW) output power on the drying kinetics and quality of ascorbic acid pretreated and untreated Oraby date slices (2, 4 and 6 mm in thickness and 24 ± 2 mm in diameter) at the end of khalal stage. The initial moisture content was 1.7397 d.b. The drying experiments were carried out using three levels of MW output power 160, 320 and 480 W. The obtained experimental data were fitted with three empirical models. The effect of MW power on drying time and drying rate were determined. Effect of drying on sugars, total phenols, tannins contents and color measurements were studied. Because of occurrence of some charring (burning) when MW drying of 4- and 6-mm slices goes beyond moisture content of 0.3678 kg[H_2O].kg^{-1}dry matter, thereafter MW drying was stopped, then drying was completed using a conventional oven at 60°C to avoid sample discoloration or burning. MW drying of 2 mm slices was completed without showing such burning. The Midilli et al. model was the best fit for the data of MW drying as well as the following convention oven drying. All sensory attributes for the dried Oraby date slices were acceptable by the panelists, however, the 2 mm slices received the highest panelists' scores. MW shortened the time needed for drying.
Keywords: Oraby (El Arabi, Orebi, Oreebi, Eraby) dates, soft dates, microwave, oven drying, snacks, diffusivity, microwave, drying efficiency.

INTRODUCTION

Egypt is the world leading country in production of date palm fruits; 1.56 MT/year (MOALR, 2018) about 45% of which are known soft (fresh) date varieties; Hayany, Zaghloul, Samany, Bent Aisha, Amhat and Oraby. Soft dates cannot be consumed outside their season because they are perishable and suffer great losses (more than 35%) due to lack of cooling facilities and poor post-harvest handling techniques. In addition, there are 427,704 ton of seedling (Meghal) date palms (about 27% of national production) mostly of seedling soft dates i.e. of low marketing potential locally and abroad. Date palm cultivars (*Phoenix dactylifera* L.) are classified into three main types according to fruit moisture content, i.e. Soft (Moisture content >30%), semi-dry (20-30%) and dry cultivars (less than 20%) (Kader and Hussein, 2009). Date fruit passes three stages during ripening: khalal (bisr), rutab and tamar (Kassem, 2012).

Dates have many bioactivity potentials such as antioxidant, antimicrobial, anticancer, antidiabetic, etc. Idowu, et al., (2020) mentioned that dates bioactivities are enhanced by the presence of phytochemicals such as carotenoids, phenolic acid, flavonoids, tocopherol, phytosterols, etc. Processing of date fruits enables production of versatile shelf-stable products, adds a value, and generates new jobs, besides enables consumption of these nutritious products outside the date production season (Rabie *et al.,* 2018a). Oraby cultivar is the main soft date grown at North Delta near Gamasa at Dakahlia governorate where sandy soil and saline water (Hegazi *et al.,* 2008) and at other locations such as Idko, Rasheed and Balteem in Behera, Kafr El-Sheikh and Damietta governorates. Its productivity is high (averaged 145 kg/tree, (MOALR, 2018), and it is a late season cultivar that can withstand harsh environmental and soil conditions (Abul-Soad *et al.,* 2015). Total Production of Oraby date is 28,853 ton/year (MOALR, 2018). Rabie et al., (2018b) reported average values of 3.92 cm, 2.64 cm, 14,55 g and 12.21 cm^3 for length, diameter, weight, and volume for Oraby fruit, respectively. Flesh/pit weight ratio and apparent density were 10.4 and 1.038 g/cm^3, respectively). Eissa et al., (2009) described Oraby fruit as ovate in shape, having obtuse apex and retuse base. The skin is smooth and shiny, and its color is pale red at khalal stage and dark red at maturation. Its skin is united firm with the flesh as compared with Amhat, Bent Eisha and Hayany whose skin is loose from flash. Its flesh is whitish yellow in color having firm texture of poor flavor as compared with Bent Eisha which has soft texture and excellent flavor. Oraby date cannot be consumed at Khalal (fresh) stage of ripening due to poor eating quality (fibrous, astringent taste due to high tannins and low reducing sugars contents) which make its texture and taste unpleasant. After it turn to the Rutab stage (naturally on the tree or artificially by processing), it is delicious with sweet taste and soft texture. Hegazi *et al.,* (2008) reported that tannins content in Oreabi (Oraby) dates was higher at Khalal stage than that at Rutab stage.

Fresh Oraby date has 22.53% total sugars content at end of khalal stage (Rabie, et al., 2018b) which comprised of 9.01% and 13.52% reducing and non-reducing sugars content, respectively. The amount of non-reducing sugars (mainly sucrose, which is less sweet) is higher than the amount of reducing sugars (mainly glucose and fructose). Al-Farsi and Lee, (2008) reported an average for total of sugars in fresh dates of 43.4 g/100g and for dried dates of 64.1 g/100g. Ahmed et al., (2014) reported a range of 38.8-50.2 and 44.4-79.8 g/100g for total sugar contents of fresh and dried dates, respectively. The reducing sugars of fresh and dried dates are in a range of 17.6-26.1 and 17.6-41.4 g/100g, respectively for glucose and 13.6-24.1- and 14.1-36.8 g/100g, respectively for fructose (Ahmed et al., 2014). There are different drying techniques; sun, solar, oven, vacuum, osmotic and infra-red drying to mention a few. Microwave drying is instantaneous and enable quick internal heating of food product making the drying time very short. Rao et al., (2012) mentioned that moisture content of date can be reduced and brought to safe limits by dehydration or drying. Oven drying of soft dates at 65°C and 40-60% relative humidity was recommended for economical cost and to avoid case hardening of date berry. The fruits of same variety grown in arid areas are dry and may require rehydration. Moisture content of 23-25% is adjusted for Deglet Noor variety of dates to be desirable and acceptable to the consumer with soft texture (Rygg, 1975). Boubekri et al, (2009) stated that naturally fresh humid Deglet-Nour dates variety is collected at about 35% (w.b) equivalent to a water content of approximately 0.54 kg/kg on dry basis. However, the date standard moisture content of 26% w.b or 0.35 kg/kg d.b is recommended by the international standards for the marketing of Deglet-Nour.

Studying drying kinetic of date fruits enables explain changes of moisture contents within the fruits, explain changes in quality of the final products, and help in process operation control. Air drying characteristics of Nigerian dates was studied by Falade and Abbo (2007) in the temperature range of 50-80°C. The authors reported that most of the moisture migration took place in the falling rate period. They modeled moisture migration using Fick's law and effective diffusivities were reported. Thin layer drying model for drying of Sukkari and Sakie date cultivars at 70, 80, and 90 °C was studied by Hassan and Hobani (2000). They found that Page equation was better for predicting moisture ratio as a function of drying time and drying temperature for the two date cultivars. Thin layer drying models for Khalas date variety were also studied (Abdalla and Al-Amri, 1999; Boubekri et al, 2009). Amellal and Benamara, (2008) used vacuum drying for pulp cubes from three Algerian common date varieties. They reported that the Henderson and Pabis model better described drying kinetic of Mech-Degla and Frezza pulps at 60 and 80°C.

Microwave drying has some advantages over other dying methods of food products. Khraisheh, et al. (2004) reported that MW drying produced less shrinkage, less destruction in V.C, and higher rehydration potential as compared with convective air drying of potatoes. Haghi and Amanifard, (2008) listed some of the advantages of MW drying as short drying time, improved product quality, and producing a wide variety of dried products. Rayaguru. and Routray, (2011) reported that microwave drying as compared to conventional oven drying is mor efficient, saves time and improved sensory attributes of the final products

Heating by Microwave takes place by generation of heat from inside the food material resulting in migration of moisture i.e. it is a process of a simultaneous heat and mass transfer. The dielectric properties of the food materials are dependent on the water content (in addition of salts and siliceous materials present in foods), and they also determine the absorption of microwave energy in the electric field (Young, 1969; Tong et al., 1992).

Rao et al., (2012) reported that their microwave dried dates developed a flavor similar to that of a fruit toffee with soft texture and good mouth feel, which are desirable attributes of a fruit toffee. Most of the panelists preferred the toffee flavor that has been developed. Mechlouch et al., (2015) found significant differences of fructose and glucose contents were observed between drying methods and especially between date dried at MW 3w/g (62°C and 100°C) and all other drying methods. The use of MW 3w/g had remarkably decreased the fructose and glucose contents. This may be explained by the fact that during the drying process, the development of sugar degradation products provides a characteristic flavor to the product (Ziegleder, 1991).

Izli, (2017) reported that Midilli et al. model was found to be the best model for convective and microwave drying of Date slices. The microwave-dried samples were recorded as having the highest total phenolic content and the highest antioxidant capacity. The author concluded that microwave drying can produce high quality date slices and reduce drying times compared to convective and freeze drying. Izli and Isik (2015) compared between microwave, convective and microwave-convective hybrid drying methods. The authors indicated that using the microwave saves time and enable less moisture content at the end of drying. Differences in the moisture ratio and drying rates could be due to variation in initial moisture, composition (dry matter contents) and surface area of the date palm fruits. Studying the kinetic of microwave drying technique can be useful in process engineering design and food processing operations to enable selection of best processing conditions, reduce production cost and to increase the productivity. Producing popular snacks from Oraby dates and other soft date varieties will increase consumption of nutrition rich food products by increasing consumer choice for food selection and convenience.

The aim of this study was to evaluate kinetics of drying Oraby date slices using a microwave and to produce a shelf stable product which can be consumed as snacks having acceptable sensorial attributes.

MATERIAL AND METHODS

Materials:

Fresh Oraby date fruits, season 2020 were bought from a farm at Balteem, Kafr El-Shaikh gevernorate. Sound fruits at end of khalal stage of maturity were selected. Manually, the top and bottom tips of each fruit were cut using a sharp knif and the stone was ejected along the fruit horizontal axis using a wooden article leaving the fruit as a hollow cylender which was then cross-sectionally sliced (2, 4 and 6 mm in thickness). Oraby date slice samples (24 ± 2 mm in diameter) were either dipped into ascorbic acid solution (1 %), or left without dipping (a control). After10 min, dipped slices were removed and excess solution was drained.

Methods:

Drying procedures:

1. Microwavedrying stage:

A microwave (LG model MS3043BARS) was described and modified by Younes et al., (2016) by installing an electric suction fan having electric power of (90 W) on one aspect of the microwave to withdraw internal air carrying the generated vapors during heating. The microwave oven (100 to 800 W) has an operating area of (50 × 34× 27) cm, a digital clock for time control, and a rotating glass plate at the bottom of the oven which rotates 5 times per min. Three microwave power levels 160, 320 and 480 W were selected to dry Oraby slices. Three drying trials were conducted at each power level on 50 g samples. After 10 s radiation (power on), moisture loss was determined by weighing sample boats at end of a 20 s rest (power off) period. The average values were used for estimation of the drying parameters. Due to some scorching of samples having 4 and 6 mm (at sample weight about 25 - 26 g) i.e. after sample moisture goes beyond 0.3678 kg[H_2O].kg^{-1} dry matter, therefore microwave drying was stopped earlier and a second drying stage was applied using a conventional oven at 60°C till reaching about 23 g final weight. The 2 mm slices reached complete dryness and were in good conditions without any burning or change in color.

2. Conventional oven drying stage:

A conventional oven drying was conducted at 60°C to complete drying of the 4- and 6-mm slices till samples reach a final moisture content less than 10%,w.b. Also, values of moisture loss during oven drying were averaged and used for calculation of drying parameters.

Mathematical* Modeling *of the Drying Curves

The obtained experimental data were fitted to three drying models (Table 1) to determine the best fitting drying equation. Moisture ratio (MR) can be calculated as follows:

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

Where, M_o, M_t and M_e (kg [H_2O] kg^{-1} [DM]) are the initial, instantaneous and equilibrium moisture contents of the sample. The equilibrium moisture content (M_e) was neglected by many authors for being very small at the end of drying, therefore, the moisture ratio (MR, dimensionless) was simplified to M_t/M_0. The experimental data of microwave drying of Oraby date slices were fitted to three empirical drying models (Table 1) using Nonlinear Regression to calculate model constants. The estimated parameters (Eq. 2-5; Al-Awaadh, et al., 2015); coefficient of determination (R^2), root mean square error (RMSE), reduced chi-square (χ^2) and mean percent error (PE) were used for model fitness evaluation and were calculated as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{pre,i} - \overline{MR_{exp,i}}\right)^2} \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N - z} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N}} \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

$$\text{PE} = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|MR_{exp,i} - MR_{pre,i}\right|}{MR_{exp,i}} \dots\dots\dots\dots\dots\dots\dots\dots\dots.. \dots (5)$$

Where: ***$MR_{exp,}$i*** is the moisture ratio observed experimentally for instant *i* and ***MRpred,i*** is the predicted moisture ratio by the applied model for same instant *i*. $MR_{exp,i}$.$\overline{MR_{exp,i}}$ is the average for the experimental values. The parameters N and z are the number of observations and number of model constants, respectively. A fit was considered good when high values of R^2 and low values of χ^2, RMSE, and PE were obtained. Relative percent errors (PE) below 10% indicate a good fit **Table (1).** Thin-layer drying models being used to mathematically model the date drying kinetics.

No	Model name	Model	References
1	Logarithmic	*MR = a exp(-kt) + c*	Yagcioglu, et al. (1999)
2	Midilli et al.	*MR = a exp(-kt^n) +bt*	Midilli, et al. (2002)
3	Page	*MR = exp(-kt^n)*	Agrawal and Singh (1977)

Calculation of drying rate (DR, g/min):

$$DR = \frac{M_{t+\Delta t} - M_t}{\Delta t} \dots\dots\dots\dots\dots\dots\dots\dots (6)$$

Where: $M_{t+\Delta t}$ and Mt are the moisture contents (%, d.b) at t+Δt and t, respectively, and Δt is the drying time period (min).

Calculation of the Effective Moisture Diffusivity (D_{eff}):

The effective moisture diffusivity (Deff) values were interpreted by using Fick's second diffusion equation. The general solution of Fick's Equation for slab geometry with the assumptions of diffused moisture migration, insignificant shrinkage, constant diffusion coefficients and temperature is given below [Crank, 1975]:

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2} exp\left(-(2n+1)\pi^2\frac{D_{eff}t}{4L^2}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (7)$$

where MR is the moisture ratio, Deff is the effective moisture diffusivity (m^2s^{-1}), L is the half thickness of the samples (m), i is a positive integer and t is time (s). For the long drying process, Equation (7) can be simplified as follows [Wang, et al., 2007]:

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2}{4L^2} D_{eff}\ t\right) \ldots\ldots\ldots\ldots\ldots (8)$$

The Deff values were calculated by plotting experimental ln(MR) data against drying time, so the plot provides a straight line with $Slope = \frac{\pi^2 D_{eff}}{4\,L^2} \ldots\ldots\ldots\ldots (9)$

Evaluation of microwave performance:

These parameters were estimated according to equations (10-13) used by Darvishi (2012) for process evaluation of potato slices process drying by microwave and applied by Hassan (2016) for microwave drying of Some Egyptian dates:
Energy consumption in the microwave oven is calculated as:

$$Q_t = P\ \frac{t}{60} \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where Qt presents the total energy consumption, kWh; P is the microwave power, t is the power-on time in min.
While Q_s is the specific energy consumption (Energy needed to evaporate a unit mass of water from the product, Sharada, 2013), MJ/kgH_2O is calculated as follows:

$$Q_s = \frac{60 \times 10^{-6} Pt}{m_w} \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

While η is the microwave drying efficiency (%) is calculated as follows:

$$\eta = \frac{m_w \times \lambda_w}{P \times t} \times\ 100 \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where; mw is the mass of evaporated water (kg); λw is the latent heat of vaporization of water (kJ/kg); P is the average microwave power (kW); and t is the time interval (s). The cumulative drying efficiency values were calculated as the average energy consumption for water evaporation divided by the supplied microwave energy in power-on time in s.

Physical and chemical evaluation:

Moisture content: The average moisture content of fresh date pulp samples was determined by drying samples in a vacuum oven at 75ºC until constant weight was reached (AOAC, 1995). The initial moisture content was found to be 63.5% w.b (1.7397d.b.).

Total polyphenols (TPC): The Folin-Ciocalteu method was used to measure total phenolic compounds (Elfalleh et al., 2009). Absorbance was measured at 765nm. The results were compared to a gallic acid calibration curve, and the total phenolic compounds were determined as mg gallic acid equivalents per 100g dry weight (GAE mg/ 100g DW).
Tannins contents: Total tannins were determined according to the method of (AOAC, 1995) using the Indigo carmine indicator.
Sugar content: Total sugars were extracted using 70% neutral ethanol for 6-8 hr under reflux according to the method of Kawamura (1966). Reducing sugars were determined directly in the extract using the 3, 5-dinitro-salicylic acid (DNS) method according to Miller (1959). Total sugars were measured after hydrolysis. Non-reducing sugars were calculated by difference.
Color measurement: Minolta CR300 series Chroma Meters which offer different color systems including the CIELAB system. The three coordinates of CIELAB represent the lightness of the color; *L** = 0 yields black and *L** = 100 indicates diffuse white; *a**, where negative values indicate green and positive values indicate red) and *b**, where negative values indicate blue and positive values indicate yellow. Color measurements, along with fruit dimensions have been recommended by Ibrahim et al. (2014) for quality grading of Saudi dates.

Sensory evaluation:

Seven trained panelists were asked to evaluate color, taste, texture and general acceptability attributes of the dehydrated Oraby slices. An evaluation sheet was used by the panelist, and each attribute was given a value from 0 to 10 where 0 means dislike most and 10 means like most.

Statistical analysis:

Nonlinear regression analyses (SPSS, 2008) were used for calculation of coefficients of these models using SPSS Statistical Package v.17 program. The coefficient of determination (R^2), Reduced Chi-square (χ^2), Root mean square error (RMSE) and percent error (PE) were utilized to select the best equation. These parameters were computed using Excel Package of Microsoft.

RESULTS AND DISCUSSION

1. Microwave drying of Oraby date slices:

1.1. Drying curves of microwave drying:

Drying curves of untreated control of Oraby date slices or pretreated with ascorbic acid and dried at 160, 320 and 480 W power in a microwave oven are illustrated in Fig. (1). It is noticeable that moisture content decreased as drying time was increased and the thinner the slice the steeper was the curve i.e. less time is needed for drying. Also, the higher was the microwave power the shorter was the drying time.

Because some scorching (burning) was observed for the 4 and 6mm date slices when drying passed moisture of 0.3678 $kg[H_2O].kg^{-1}$ dry matter, therefore, MW drying was stopped earlier to avoid caramelization. A second stage of drying was conducted using a conventional oven at 60°C. Drying of the 2mm slices did not show any discoloration, thereby only

MW drying stage was used satisfactory for completion of drying (10.5 – 18.5 min to reach 7.11 - 10.81%, w.b moisture). Kinetics of each stage of drying Oraby slices were evaluated separately, and evaluation of quality of all dried slices will follows.

Ismail, et al., (2017) utilized different microwave powers to dry nectarine slices till the moisture was reduced to about 0.18 g water/g dry matter. Beyond this point the nectarine slices burned due to burning of the sugar content (7-12%) inside the nectarines. On increasing microwave output power level, excessive browning of the nectarine slices (burning) occurred.

Benamara, et al., (2009) reported that the MW drying could be considered instantaneous, but it involves a few scorched spots on pulp pieces which was explained by either the non-uniformity of the initial date pulp color or to the inadequacy of the chosen power. In practice, the temperature in the later stages of MW and hot air drying can easily involve caramelization and scorching in high sugar material (Zhang, et al.,2006). Benamara, et al., (2009) stated that scorching limits the date pulp equilibrium moisture content to 7% (d.b) in MW drying against less than 5% for hot air drying. Nonetheless, to reach 7% moisture content, the drying time was reduced by about 95% when the microwave drying was used.

1.2. Estimation of model constants and evaluation parameters for microwave drying:

The experimental data of microwave drying of Oraby date slices were fitted to three empirical drying models (Table 1). The calculated model constants and estimated evaluation parameters [Coefficient of determination (R^2), root mean square error (RMSE), reduced chi-square (χ^2) and percent error (PE)] were summarized in Table (2).

The moisture contents of date fruits at different drying powers were calculated as moisture ratio (MR, Eq. 1) and fitted to the three selected thin-layer drying models listed in Table (1). Table (2) summarizes the results of model statistical evaluation parameters (R^2, χ^2, RMSE, and PE) performed for the suggested models. The values of those parameters were in the range of 0.9787-0.9998 for R^2, 0.0000-0.0016 for χ^2 , 0.0036-0.0373 for RMSE and 0.24-9.83 for PE. Based on the criteria of the highest R^2 and the lowest RMSE, PE and χ^2, the model of Midilli et al. (2002) was selected as the most suitable model to represent the MW thin-layer drying behavior of date fruits.

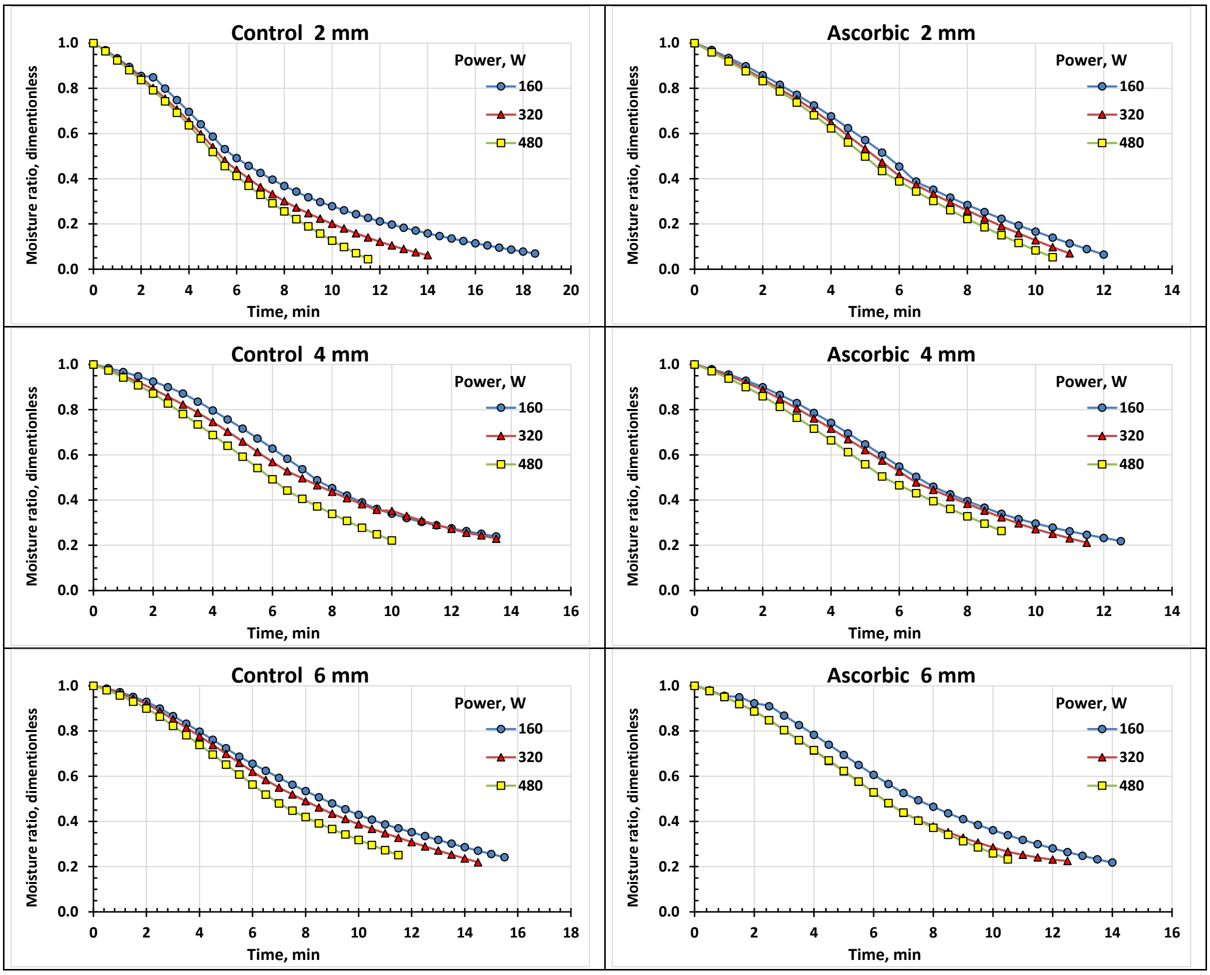

Fig. (1). Drying curves of Oraby date slices of 2-, 4- and 6-mm thickness pretreated with ascorbic acid and untreated control dried at 160, 320 and 480 W power of a microwave oven.

Table (2). Model fitting parameters and constants of drying Oraby date slices at different microwave powers.

Model name	Microwave Power, W	Slice Treatment	Thickness mm	Model constants				R^2	χ^2	RMSE	PE
Logarithmic				**k**	**A**	**c**					
	160	Control	2	0.117	1.169	-0.071		0.9943	0.0005	0.0224	4.37
	160	Control	4	0.051	1.809	-0.720		0.9860	0.0010	0.0302	5.66
	160	Control	6	0.058	1.431	-0.360		0.9964	0.0002	0.0144	2.17
	160	Ascorbic	2	0.059	2.039	-0.968		0.9940	0.0006	0.0228	0.24
	160	Ascorbic	4	0.069	1.562	-0.478		0.9903	0.0007	0.0251	4.80
	160	Ascorbic	6	0.059	1.590	-0.505		0.9907	0.0007	0.0245	3.91
	320	Control	2	0.103	1.360	-0.279		0.9954	0.0004	0.0196	5.41
	320	Control	4	0.077	1.332	-0.264		0.9937	0.0004	0.0192	3.21
	320	Control	6	0.059	1.501	-0.429		0.9960	0.0003	0.0156	2.42
	320	Ascorbic	2	0.051	2.355	-1.298		0.9962	0.0004	0.0177	4.86
	320	Ascorbic	4	0.055	1.875	-0.809		0.9949	0.0004	0.0179	3.25
	320	Ascorbic	6	0.087	1.357	-0.272		0.9913	0.0006	0.0235	4.65
	480	Control	2	0.063	2.013	-0.953		0.9968	0.0003	0.0166	5.23
	480	Control	4	0.035	2.898	-1.846		0.9965	0.0002	0.0145	2.63
	480	Control	6	0.049	1.937	-0.873		0.9949	0.0003	0.0170	2.78
	480	Ascorbic	2	0.048	2.564	-1.510		0.9964	0.0004	0.0175	5.37
	480	Ascorbic	4	0.041	2.572	-1.523		0.9967	0.0002	0.0130	2.07
	480	Ascorbic	6	0.032	2.970	-1.914		0.9958	0.0003	0.0157	2.79
Page				**k**	**n**						
	160	Control	2	0.066	1.277			0.9962	0.0004	0.0183	5.44
	160	Control	4	0.030	1.532			0.9938	0.0004	0.0201	4.24
	160	Control	6	0.037	1.345			0.9981	0.0001	0.0103	1.95
	160	Ascorbic	2	0.043	1.628			0.9981	0.0002	0.0126	3.93
	160	Ascorbic	4	0.043	1.450			0.9960	0.0003	0.0162	3.56
	160	Ascorbic	6	0.035	1.451			0.9957	0.0003	0.0166	3.14
	320	Control	2	0.062	1.425			0.9992	0.0001	0.0082	2.54
	320	Control	4	0.051	1.314			0.9966	0.0002	0.0141	2.98
	320	Control	6	0.039	1.376			0.9984	0.0001	0.0099	1.90
	320	Ascorbic	2	0.049	1.605			0.9975	0.0002	0.0144	4.90
	320	Ascorbic	4	0.046	1.458			0.9990	0.0001	0.0077	1.48
	320	Ascorbic	6	0.053	1.372			0.9954	0.0003	0.0170	3.73
	480	Control	2	0.052	1.588			0.9973	0.0003	0.0153	8.00
	480	Control	4	0.048	1.497			0.9995	0.0000	0.0056	0.75
	480	Control	6	0.042	1.441			0.9986	0.0001	0.0088	1.64
	480	Ascorbic	2	0.051	1.638			0.9966	0.0003	0.0171	7.31
	480	Ascorbic	4	0.057	1.436			0.9994	0.0000	0.0056	0.84
	480	Ascorbic	6	0.042	1.514			0.9995	0.0000	0.0054	0.96
Midilli et al				**k**	**A**	**b**	**n**				
	160	Control	2	0.062	1.009	0.003	1.352	0.9976	0.0002	0.0146	4.85
	160	Control	4	-3.400	0.035	-0.060	-0.008	0.9787	0.0016	0.0373	7.67
	160	Control	6	0.036	1.004	0.007	1.453	0.9998	0.0000	0.0038	0.67
	160	Ascorbic	2	-0.509	0.809	-0.401	0.508	0.9986	0.0001	0.0109	0.93
	160	Ascorbic	4	-0.593	0.767	-0.420	0.474	0.9989	0.0001	0.0083	1.35
	160	Ascorbic	6	-0.533	0.785	-0.364	0.484	0.9987	0.0001	0.0090	1.59
	320	Control	2	0.056	0.987	0.001	1.475	0.9993	0.0001	0.0077	2.80
	320	Control	4	0.040	0.981	0.010	1.557	0.9993	0.0001	0.0066	1.34
	320	Control	6	0.037	1.001	0.006	1.480	0.9996	0.0000	0.0051	1.05
	320	Ascorbic	2	0.042	0.973	-0.005	1.613	0.9995	0.0001	0.0065	1.92
	320	Ascorbic	4	0.038	0.981	0.008	1.626	0.9998	0.0000	0.0038	0.65
	320	Ascorbic	6	0.038	0.976	0.012	1.683	0.9998	0.0000	0.0036	0.55
	480	Control	2	-0.369	0.884	-0.348	0.580	0.9994	0.0001	0.0075	2.66
	480	Control	4	-2.316	0.101	-0.080	-0.006	0.9947	0.0004	0.0178	3.54
	480	Control	6	-3.205	0.042	-0.065	-0.009	0.9907	0.0006	0.0229	4.26
	480	Ascorbic	2	-3.346	0.035	-0.087	-0.011	0.9932	0.0007	0.0239	9.83
	480	Ascorbic	4	-2.556	0.079	-0.083	-0.007	0.9948	0.0003	0.0164	2.93
	480	Ascorbic	6	-2.057	0.132	-0.077	-0.005	0.9940	0.0004	0.0188	3.67

R^2 is the coefficient of determination, RMSE is the root mean square error, χ^2 is the reduced Chi-square and PE is the percent error.

The Logarithmic model recorded a range of 0.9860 to 0.9968 for R^2, a range of 0.0002 to 0.0010 for χ^2, a range of 0.0130 to 0.0302 for RMSE and a range of 0.24 to 5.66 for PE. The Midilli et al. model recorded a range of 0.9787 to 0.9998 for R^2, a range of 0.0000 to 0.0016 for χ^2, a range of 0.0036 to 0.0373 for RMSE and a range of 0.55 to 9.83 for PE. The Page model achieved such fitness for data at 320 and 480 W but not at 160 W. Therefore, the Midilli et al. model best fit the experimental data and can be recommended to describe moisture change within the slices during microwave drying. Izli, (2017) reported that Midilli et al. model was found to be the best model for convective and microwave drying of date slices. Darvishi and Hazbavi (2012) found that Page model to best fit the experimental data of microwave drying of pitted whole semi-dry dates.

The degree of model fitness according to cut off values of **R^2> 0.994, χ^2** <0.0003, RMSE < 0.020 and PE < 3.0 were totaled for each model. The Midilli et al. model scored the highest among other models with respect to all the evaluation parameters at 160 and 320 W power. The Page model showed better fit than Midilli et al. model at 480 W for the 6mm slices data. Logarithmic model comes third for overall scores of fitness. So, Midilli model is recommended to describe moisture change during microwave drying of Oraby slices.

The predicted (estimated) values of moisture ratio using the Midilli et al. Model were plotted against their corresponding values of measured (experimental) moisture ratio to illustrate model fitness (Fig., 2). All Data points were scattered in a straight-line relationship confirming fitness. The same trend was obvious for all slice thickness, pretreatment, and applied MW power level.

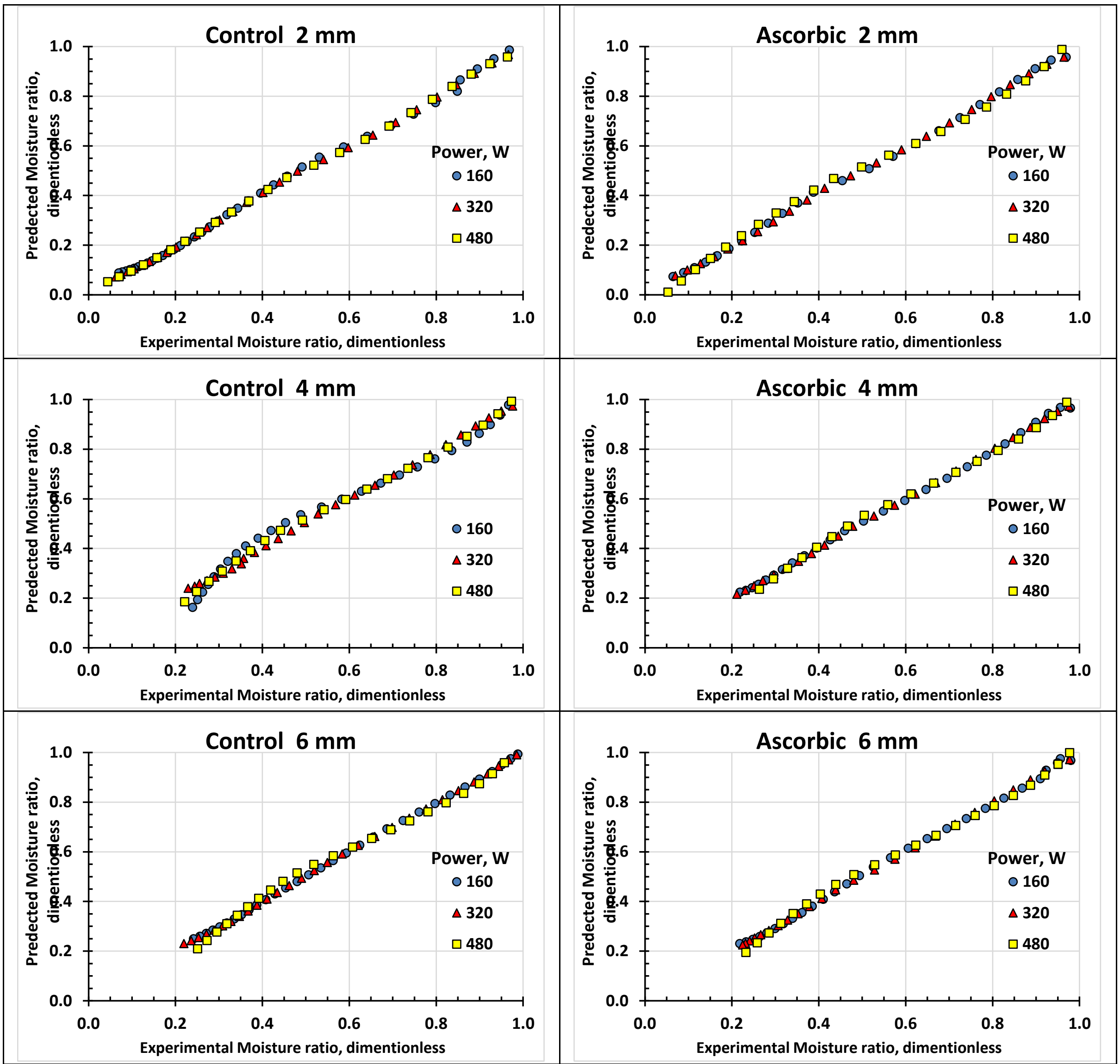

Fig. (2). Experimental versus predicted Moisture ratios calculated using Midilli et al. Model equations for 2, 4 and 6 mm ascorbic acid pretreated Oraby date slices and the control after microwave drying at 160, 230 and 480 W.

1.3. Drying rate of Oraby slices using different microwave power levels:

The drying rates were determined from the amount of water removed per unit time and per unit dry base. The drying rate curves for date slices dried at different microwave powers are given in Fig. 3 and 4. It can be observed that the drying rates of different thickness of date slices were very high during the initial phase of the drying, which resulted in a high rate of water removal due to a high rate of moisture diffusion. As the drying progressed, the loss of moisture in the three thickness of the date slices was dominated by internal moisture diffusion. The results indicated that mass transfer within the sample was more rapid during the first minuets of microwave drying because more water, which absorbed more microwave energy, was readily available for evaporation within the sample surface. As drying progressed, less water was available and less microwave energy was absorbed resulting in a decline in drying rates.

Falade and Abbo (2007) stated that drying rate of date palm fruit declined rapidly until equilibrium was reached. It was noted that there was no constant rate drying period during drying of date palm fruits. Drying took place predominantly in the falling rate period. This indicated that diffusion was the main physical mechanism governing moisture movement in date palm fruits. This trend is typical for most fruits (Sankat and Castaigne, 2004). Depending on the drying conditions, average drying rates of Oraby date slices ranged from 0.130 to 0.231 kg (H_2O) kg^{-1}d.b.min^{-1} for the applied three MW powers. A constant rate period was not observed in drying of date fruit samples. The entire drying process for the samples occurred in the range of falling rate period. This indicated that diffusion is the dominant physical mechanism controlling moisture movement in date samples. Similar results have been reported for drying of different fruits and vegetables: apple (Wang et al., 2007), kiwifruit (Femenia et al., 2009), Amelia mango (Dissa et al., 2009), pineapple, mango, guava and papaya (Marques et al., 2009) and carrot pomace (Kumar et al., 2011).

The following figures illustrate the relationship between drying rate and time of drying (Fig. 3) and moisture content (w.b) during drying (Fig. 4). It can be observed in Fig. (3) that drying rate increased gradually until reaching a maximum then decreased gradually till end of the drying period. The maximum drying rate ranged from 0.130 to 0.231 $kgH_2O.kg^{-1}$d.b.min^{-1} for 6mm Oraby control slices and 2mm Oraby slices treated with ascorbic acid, when dried at 160 W. The value of maximum drying rate increased with decreasing slice thickness and with increasing MW power level. Maximum drying rates were higher for ascorbic treated slices compared with the control. The time to reach maximum drying rate ranged from 330 to 450 seconds. The 4 mm control slices recorded the highest value (7.5 min) while the other slices recorded 5.5 – 6.5 min to reach maximum drying rate. It is expected that the higher the microwave power the more heat generated within the sample i.e. higher drying temperature. Drying rate increases with the increase in drying power, and thereby, higher drying power results in a higher drying rate and faster reduction in moisture content. These findings were also observed by Hassan and Hobani, (2000) for conventional drying of semi-dry dates and by Hassan (2016) for microwave drying of soft dates.

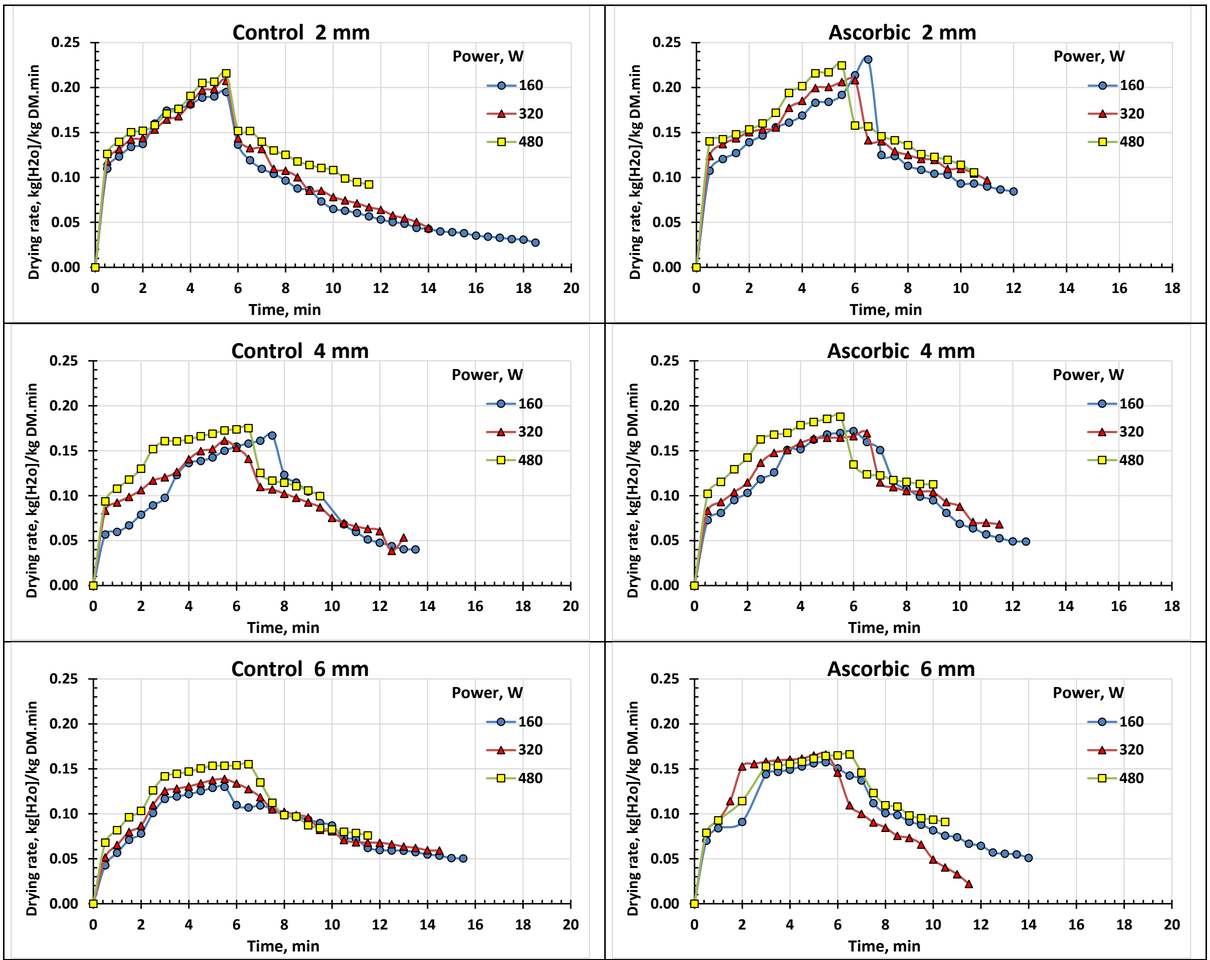

Fig. (3). Drying rates vs. drying time (s) for microwave drying of Oraby date slices

Figure 4 illustrates the effect of MW power on moisture ratio (MR) of the samples during drying. The differences among samples with respect to drying rate at same moisture content of the samples were not obvious at the begin of drying then they become obvious as drying proceeded. Cheraghi and Hamdami, (2010) used a laboratory hot-air dryer for drying skinned and skinless Barhi date at khalal stage and indicated that drying took place in the falling rate period. Although the drying rate after removing the skin was faster, the rehydration rates of both forms were the same. The authors found that the best fit models were Wang model for drying of dates with skin and the Verma model for drying of skinless dates.

Darvishi and Hazbavi (2012) utilized a microwave oven at 200 W power level to study the kinetic of thin layer drying pitted whole dates of initial moisture content of 18% w.b until final moisture content of less than 7.5% w.b. The authors found that Page model best fit the experimental data. They reported that k; the model drying rate constant to range from 0.052 to 0.142 min^{-1}, and effective diffusivity of 2.72 x 10^{-6} to 4.73 x 10^{-6} m^2s^{-1}. The authors reported that the power density (microwave Power/ sample mass) to have great effect on drying rate. The microwave drying of 4 and 6 mm slices was ended at moisture content of about 28.6%, w.b (i.e. about 0.402 kg[H_2O].kg^{-1} dry mater) in order to avoid caramelization which takes place beyond 0.3678 kg[H_2O].kg^{-1} dry matter. Then, a second drying step using a conventional oven at 60 °C was applied in order to complete the drying process. The 2 mm slices did not show such effect; therefore, MW drying was completed.

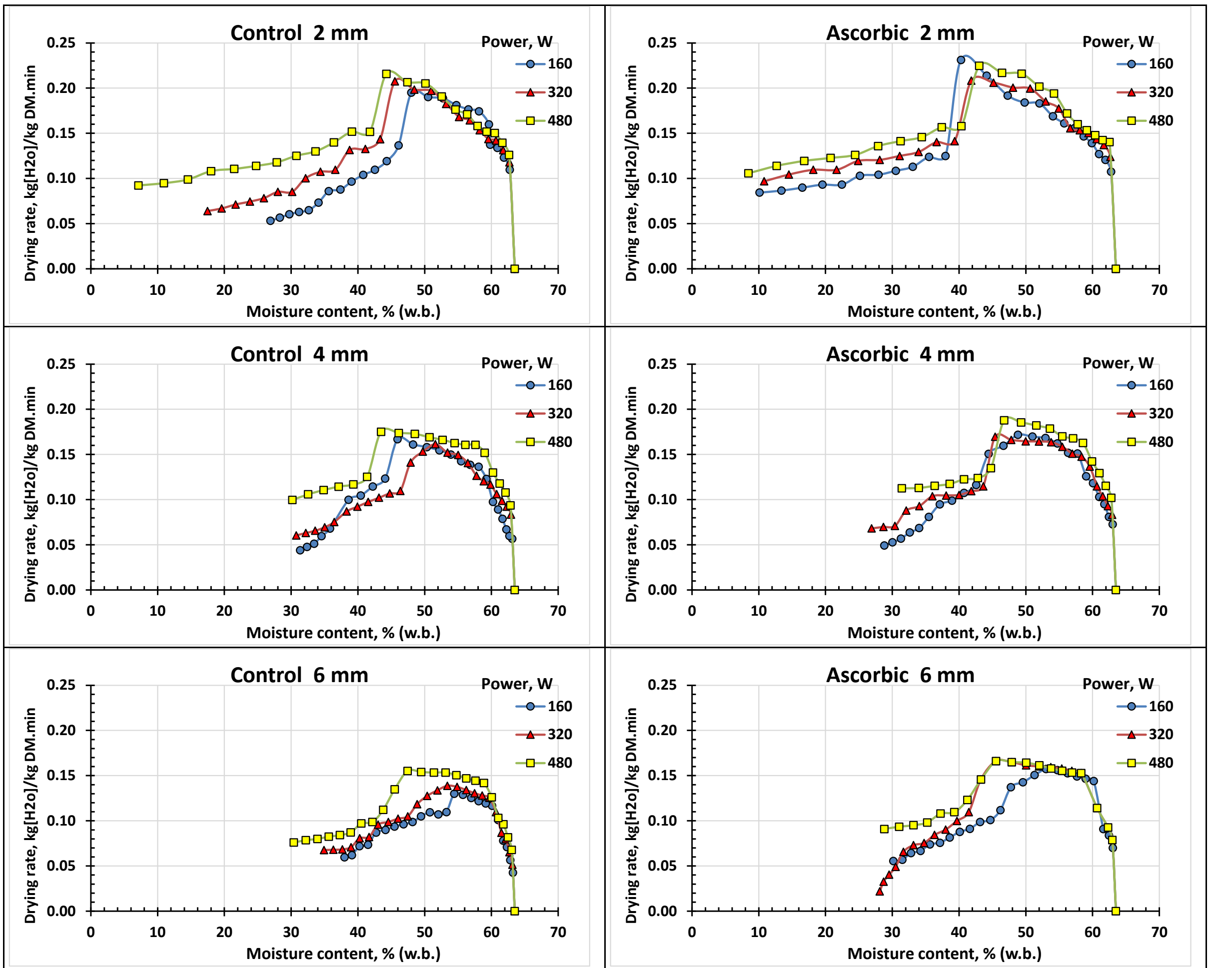

Fig. (4). Drying rate (DR) vs Moisture ratio (MR) of Oraby date slices (2-, 4- and 6-mm thickness) pre-treated with ascorbic acid (A) and the Control (C) at different microwave powers

1.4. Estimation of moisture diffusivity (D_{eff}) for microwave drying of Oraby slices:

Figure (5) illustrates the straight line relationship between ln(MR) and drying time. The equation of each treatment combination is depicted along with its R². The D_{eff} can be estimated from the slope of each straight line. The R² values were 0.9226 or higher (0.9955).

The calculated D_{eff} values are summarized in Table (3). For the Effective Diffusivity, the Control samples showed a range of 5.89E-08 to 4.59E-07 with an average value of 2.31E-07 m^2/s. The Ascorbic acid showed a range of 8.71E-08 to 5.23E-07 with an average value of 2.67E-07 m^2/s for the Effective Diffusivity. D_{eff} increases as MW power level was increased. Ascorbic pretreated slices showed high D_{eff} than the control. As slice thickness was increased D_{eff} increased.

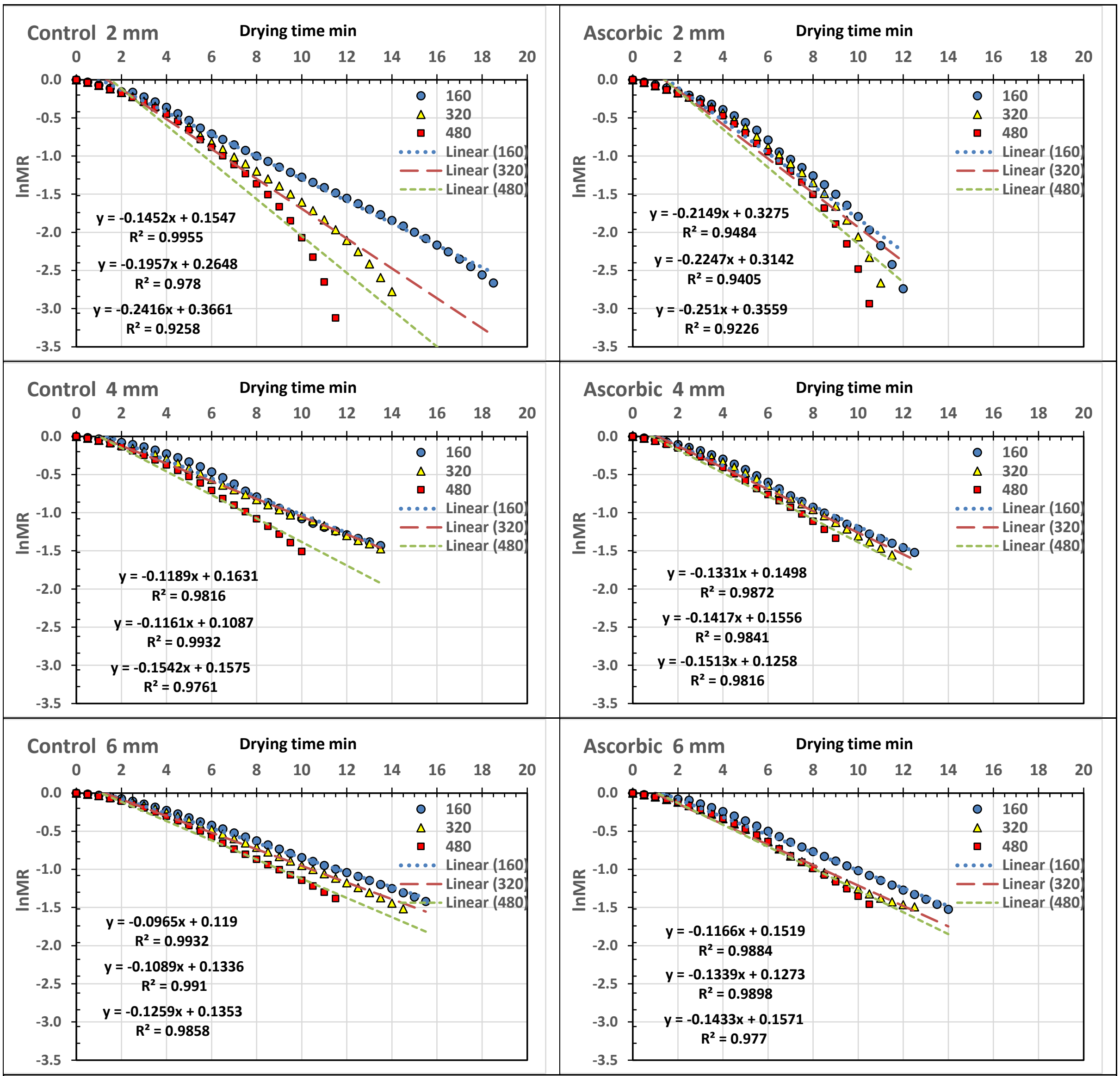

Fig. (5). Ln(MR) vs. Drying time (s) curves of Oraby date slices of 2, 4, and 6 mm thickness pretreated with ascorbic acid and untreated control using 160, 320 and 480 W power of a microwave oven.

Table (3). Effective Diffusivity, m^2/s of drying Oraby date slices using a microwave oven

Pre-treatment	Thickness, mm	Effective Diffusivity, m^2/s		
		Microwave Power, W		
		160	320	480
Control				
	2	5.887E-08	7.930E-08	9.790E-08
	4	1.927E-07	1.883E-07	2.500E-07
	6	3.521E-07	3.971E-07	4.591E-07
Ascorbic acid				
	2	8.709E-08	9.107E-08	1.017E-07
	4	2.158E-07	2.297E-07	2.453E-07
	6	4.252E-07	4.884E-07	5.225E-07

1.5. Evaluation of the microwave drying performance:

MW drying of 2mm slices was continued till final drying without any sign of burning or brown color, but MW drying of 4- and 6-mm slices was stopped before reaching certain moisture level and a conventional oven was used to complete the drying process. To make a fair comparison, only data collected before reaching this moisture level were used for evaluation of MW performance among all treatment combinations of samples. It can be noticed in table (4) that slice thickness had great effect on the time to reach a particular moisture content (about 0.402 kg[H_2O]/kg dry matter) without brown color to appear or sample burning to take place when using the microwave oven for drying products having high sugar content such as date slices. The time to reach such moisture content varies according to sample thickness and applied MW power.

Oraby date slices of 2, 4, and 6 mm in thickness when dried in microwave oven at 160, 230 and 480 W required from 140 – 290 seconds (Table 4) of radiation (Power-on time) to reach moisture contents of 0.4583 to 0.5249 kg[H_2O]/kg dry matter. The shortest time was recorded for 480 W drying of 2 mm slices pretreated with ascorbic acid and the longest time was recorded for 160 W drying of 6 mm control slices. In general, the slices pretreated with ascorbic acid recorded shorter time than those of the control. Also, the required time to reach such moisture level increased as slice thickness was increased and power was decreased. However, to produce dry slices that can be used as snacks, it was necessary to use a conventional oven to complete drying to reach far less moisture content.

The MW drying efficiency η, % ranged from 46.8 to 188.9% with an average value of 92.8%. It decreased as MW power or slice thickness was increased. The η, % values for the ascorbic acid pretreated slices were higher than the control. The high values of η may be explained by the high pressure generated within the samples as a result of heating and evaporation of entrapped water by the absorbed MW power. The 160 W has more penetration depth than 320 and 480 W.

The Energy consumption (Q_t, kWh) ranged from 0.0071 to 0.0293 kWh with an average value of 0.0173 kWh. It increased as MW power or slice thickness was increased. The Q_t values for the ascorbic acid pretreated slices were lower than the control. The Specific energy consumption, Q_s ranged from 1.13 to 4.57 with an average value of 2.71 MJ/kg H_2O. It increased as MW power or slice thickness was increased. The Q_s values for the ascorbic acid pretreated slices were lower than the control.

These results are in agreement with those reported by Hassan, (2016) who utilized the microwave power for drying two soft date varieties: Hayany and Zaghloul to a final moisture level of less than 20% d.b. The author reported minimum total energy consumption, minimum specific energy and maximum drying efficiency of 0.08 kWh, 5.7 MJ/kgH_2O and 40%, respectively for drying Hayany date, while the maximum total energy consumption, the minimum drying efficiency and maximum specific energy were 0.14 kWh, 32% and 7.15 MJ/kgH_2O, respectively for Zaghloul date (Hassan, 2016).

Table (4). Time, s to reach a moisture content of about 0.402 kg[H_2O]/kg dry matter, Energy consumption, Q_t kWh, Drying efficiency, η %, and Specific energy consumption, Q_s MJ/kg H_2O of microwave drying of Oraby date slices.

	Pre-treatment	**Ascorbic acid**			**Control**		
	Power, W	**Slice thickness, mm**					
Attributes		**2**	**4**	**6**	**2**	**4**	**6**
Time*, s							
	160	160	210	250	200	240	290
	320	150	200	210	170	240	260
	480	140	180	190	150	180	220
Qt, kWh							
	160	0.0071	0.0093	0.0111	0.0089	0.0107	0.0129
	320	0.0133	0.0178	0.0187	0.0151	0.0213	0.0231
	480	0.0187	0.0240	0.0253	0.0200	0.0240	0.0293
η, %							
	160	188.9	147.5	127.5	154.7	130.4	110.1
	320	97.4	77.2	74.5	90.2	65.0	60.3
	480	68.3	57.2	52.9	65.7	56.3	46.8
Qs, MJ/kg H_2O							
	160	1.13	1.47	1.71	1.40	1.67	2.00
	320	2.15	2.77	2.88	2.36	3.33	3.60
	480	3.03	3.69	4.02	3.20	3.77	4.57

* **Time, s** is the total radiation time (Power-on time) and is used to estimate the MW efficiency parameters.

2. Second stage of drying using a convention oven:

2.1. Drying curves for convention oven drying of4, and 6 mm Oraby slices:

Oraby date slices of 4mm and 6mm previously dried by MW at 160, 320 and 480 W were subjected to second stage of drying using a convention oven at 60 °C in order to reach the desired dryness. Figure (6) illustrate the drying curves for oven dried Oraby slices. It can be observed from Figure (6) that the moisture ratio of Oraby slices decreased as drying time was increased and the curves of ascorbic acid pretreated slices were steeper than those of the control. Differences with respect to previous applied MW power levels were minimal.

The collected data from oven drying were subjected to the three models for evaluation using a nonlinear regression approach. Model constants and calculated evaluation parameters were tabulated (Table 5).

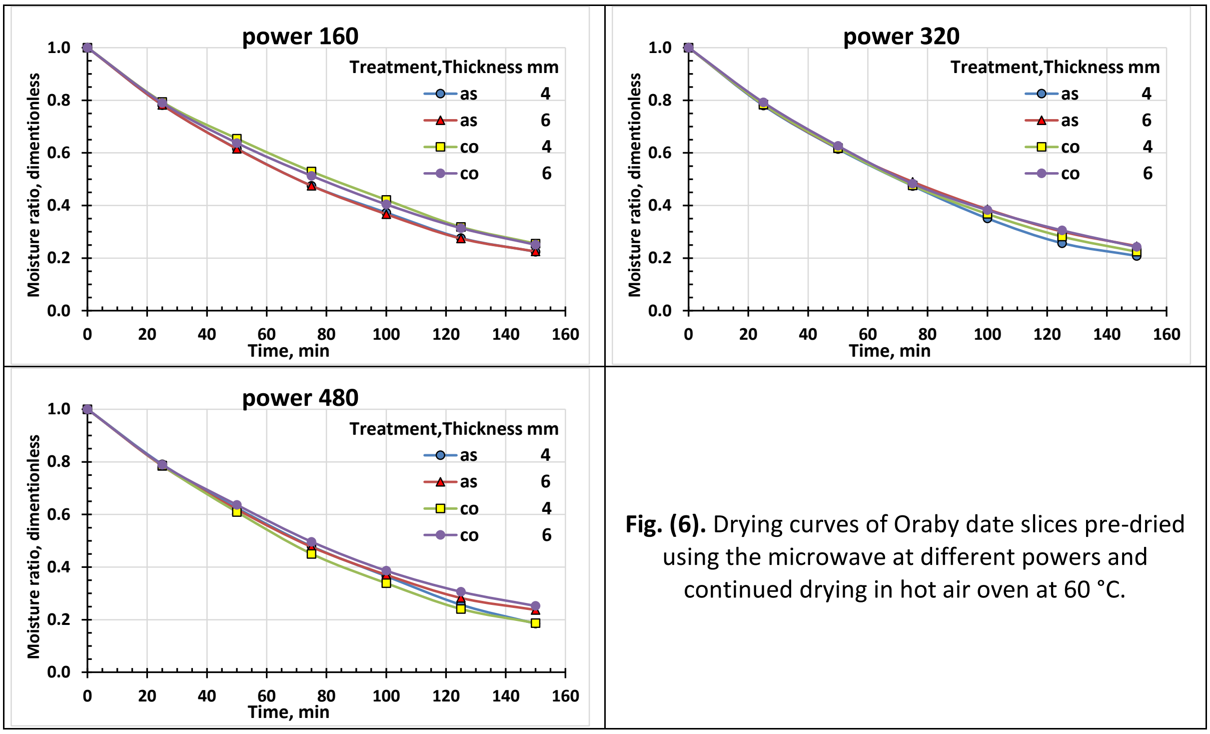

Fig. (6). Drying curves of Oraby date slices pre-dried using the microwave at different powers and continued drying in hot air oven at 60 °C.

The final moisture contents (w.b.) were 7.89 and 8.89% (w.b) which correspond to 0.086 and 0.098 kg[H_2O]/kg dry mater, for the 4 and 6 mm date slices, respectively within the drying time of 150 min. The ascorbic acid pretreated slices reached less final moisture contents than the control slices within the same drying period of 150 min.

2.2. Estimation of model constants and evaluation parameters for convention oven drying:

Data in table (5) summarize the NLR outputs for estimation of model coefficients. Cut off values were used to select the best fit model that explain changes in slices moisture content during drying. Cut-off values were arbitrary set as R^2> 0.9995, χ^2< 0.00004, RMSE< 0.0045 and PE< 1.0. For the three models, four parameters, three microwave powers, two pre-treatments and two slice thicknesses i.e. 144 possible cases. Midilli et al. model scored the highest, followed by the Logarithmic model and the Page model. When the overall scores were compared, there was no difference between the two pretreatments, the 6 mm slice thickness scored slightly higher than the 4 mm slice thickness, and the 320 W power scored better than the 160 W and 480 W power. Table (5) shows that R^2 ranged from 0.9972 to 1.0000, $\chi 2$ ranged from 0.0000 to 0.0002, RMSE ranged from 0.0004 to 0.0099 and PE ranged from 0.07 to 2.42. In general, the Midilli et al. model recorded highest values for R^2 and the lowest values for χ^2, RMSE and PE as compared to other two models. It can be concluded that the Midilli et al. model best fits the experimental data for oven drying after samples were pre-dried using the microwave and, hence can be used to describe moisture loss as a function of time during drying. This conclusion was confirmed as plotting the experimental moisture ratios against those predicted by using Midilli et al. model which resulted in points lined in a straight line making a 45 degree angle with the X-axis (Fig. 7).

Table (5). Model constants and parameters for 4 and 6 mm Oraby slices dried in a conventional oven after MW drying.

Model	MW power	Pre-treatment	Thick-ness, mm	Model constants				Model parameters			
								R^2	χ^2	RMSE	PE
Logarithmic				**k**	**A**	**c**					
	160	**Control**	4	0.364	1.196	-0.232		0.9993	0.00005	0.00499	1.13
			6	0.464	1.064	-0.086		0.9998	0.00001	0.00270	0.63
		Ascorbic	4	0.570	1.031	-0.029		0.9994	0.00005	0.00492	1.29
			6	0.592	1.022	-0.014		0.9993	0.00005	0.00519	1.28
	320	**Control**	4	0.585	1.025	-0.017		0.9997	0.00003	0.00357	0.86
			6	0.621	0.984	0.035		0.9997	0.00002	0.00315	0.50
		Ascorbic	4	0.553	1.078	-0.072		0.9985	0.00013	0.00791	2.34
			6	0.584	0.981	0.015		0.9998	0.00001	0.00235	0.52
	480	**Control**	4	0.606	1.095	-0.060		0.9991	0.00008	0.00620	1.66
			6	0.570	0.997	0.007		0.9991	0.00007	0.00578	1.25
		Ascorbic	4	0.436	1.225	-0.230		0.9997	0.00003	0.00366	1.05
			6	0.629	0.994	0.024		0.9991	0.00007	0.00582	1.39
Page				K	n						
	160	**Control**	4	0.522	1.031			0.9972	0.00015	0.00993	2.02
			6	0.545	1.007			0.9992	0.00004	0.00516	1.01
		Ascorbic	4	0.592	1.025			0.9994	0.00004	0.00488	1.22
			6	0.594	1.026			0.9993	0.00004	0.00498	1.24
	320	**Control**	4	0.589	1.028			0.9997	0.00002	0.00328	0.80
			6	0.570	1.006			0.9995	0.00003	0.00425	0.95
		Ascorbic	4	0.603	1.064			0.9985	0.00009	0.00774	2.04
			6	0.577	0.983			0.9998	0.00001	0.00247	0.57
	480	**Control**	4	0.619	1.105			0.9994	0.00004	0.00514	1.47
			6	0.559	1.006			0.9991	0.00005	0.00578	1.31
		Ascorbic	4	0.584	1.123			0.9981	0.00012	0.00908	2.42
			6	0.587	1.013			0.9990	0.00006	0.00619	1.63
Midilli et al				K	A	b	n				
	160	**Control**	4	-0.441	0.907	-0.806	0.799	0.9997	0.00003	0.00311	0.66
			6	0.483	0.938	0.007	1.156	0.9999	0.00001	0.00206	0.46
		Ascorbic	4	0.555	0.938	0.019	1.212	0.9996	0.00005	0.00392	0.93
			6	0.561	0.926	0.028	1.273	0.9997	0.00003	0.00321	0.80
	320	**Control**	4	0.561	0.937	0.024	1.233	1.0000	0.00000	0.00105	0.24
			6	0.586	0.977	0.021	1.117	0.9998	0.00002	0.00259	0.54
		Ascorbic	4	0.531	0.889	0.034	1.442	0.9996	0.00004	0.00385	0.99
			6	0.565	0.966	0.014	1.087	0.9999	0.00001	0.00201	0.49
	480	**Control**	4	0.583	0.934	0.022	1.323	0.9997	0.00004	0.00342	0.90
			6	0.527	0.903	0.044	1.371	1.0000	0.00000	0.00035	0.07
		Ascorbic	4	0.494	0.952	-0.017	1.170	0.9998	0.00003	0.00320	0.81
			6	0.571	0.919	0.040	1.319	0.9998	0.00002	0.00271	0.64

- R^2 is the coefficient of determination, RMSE is the root mean square error, χ^2 is the reduced Chi-square and PE is the percent error.

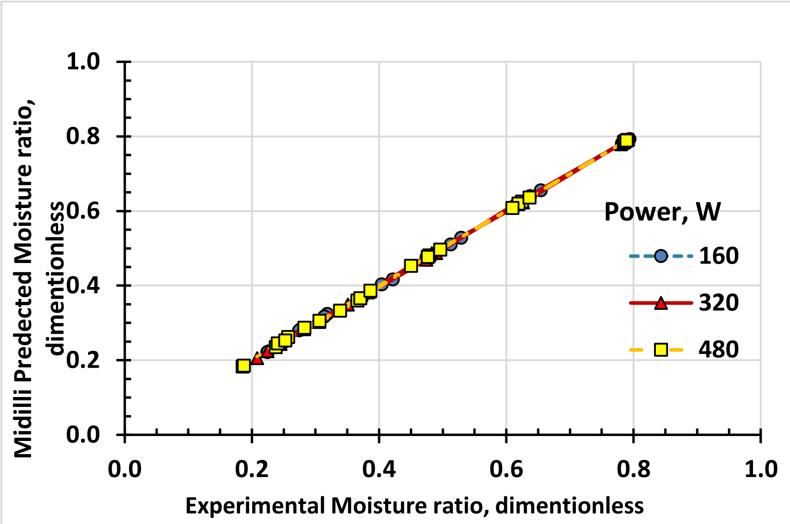

Fig. (7). Experimental versus predicted Moisture ratios calculated using Midilli et al. Model equations for 4 and 6 mm ascorbic acid pretreated Oraby date slices and the control after microwave drying at 160, 230 and 480 W.

2.3. Drying rate for convention oven drying:

The drying rates were determined from the amount of water removed per unit time and was illustrated against drying time (Fig. 8) and against moisture content (Fig. 9). The drying rate of 4 and 6 mm Oraby slices increased quickly to reach a maximum in a narrow range of 0.0032 to 0.0038 kg[H_2O].kg^{-1} Dry matter.min^{-1} within 25 min then decreased gradually. The moisture contents at these maxima ranged from 0.2869 to 0.3623 kg[H_2O]kg^{-1}dry matter. The lower values were recorded for 4mm slices as compared 6mm slices and for the ascorbic acid treated samples as compared with the control. The drying rate versus moisture content, w.b. for Oraby date slices during convention oven drying is illustrated in Figure (9). Convention oven drying for the 6 mm samples started at 0.9 %, d.b. moisture contents whereas drying the 4 mm slices starts near 0.7%, d.b. moisture contents, as the result from previous drying step using the microwave oven at different power levels. As illustrated before (Fig. 8), the maximum drying rate was reached in about 25 min from the start of drying, however, all sample were dried till final moisture content of about 0.25%, d.b.

2.4. Estimation of moisture diffusivity of convention oven drying:

A straight-line relationship was found when the logarithm of moisture ratio versus drying time was depicted in Figure (10). This enabled calculation of effective diffusivity for 4, 6 mm Oraby date slices after pre-drying using the microwave. Effective moisture diffusivity (D_{eff}) was calculated from the slope of the curves. The relationship recorded R^2 range of 0.9537 to 0.9996 which reflects good fit for most samples.

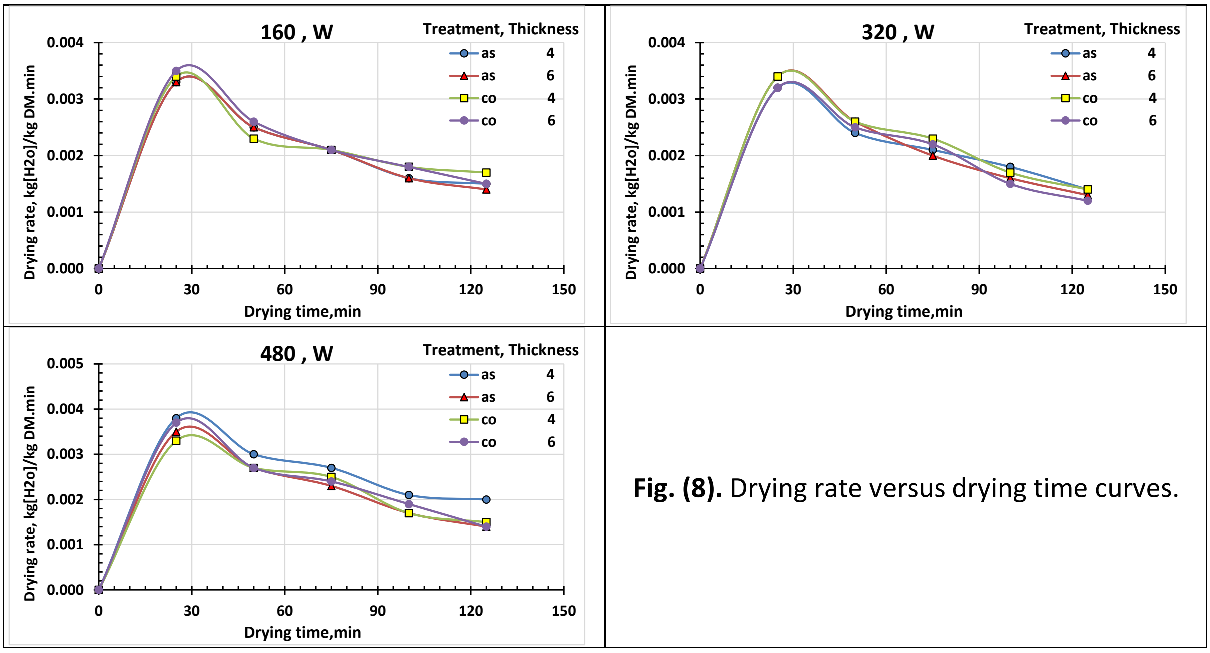

Fig. (8). Drying rate versus drying time curves.

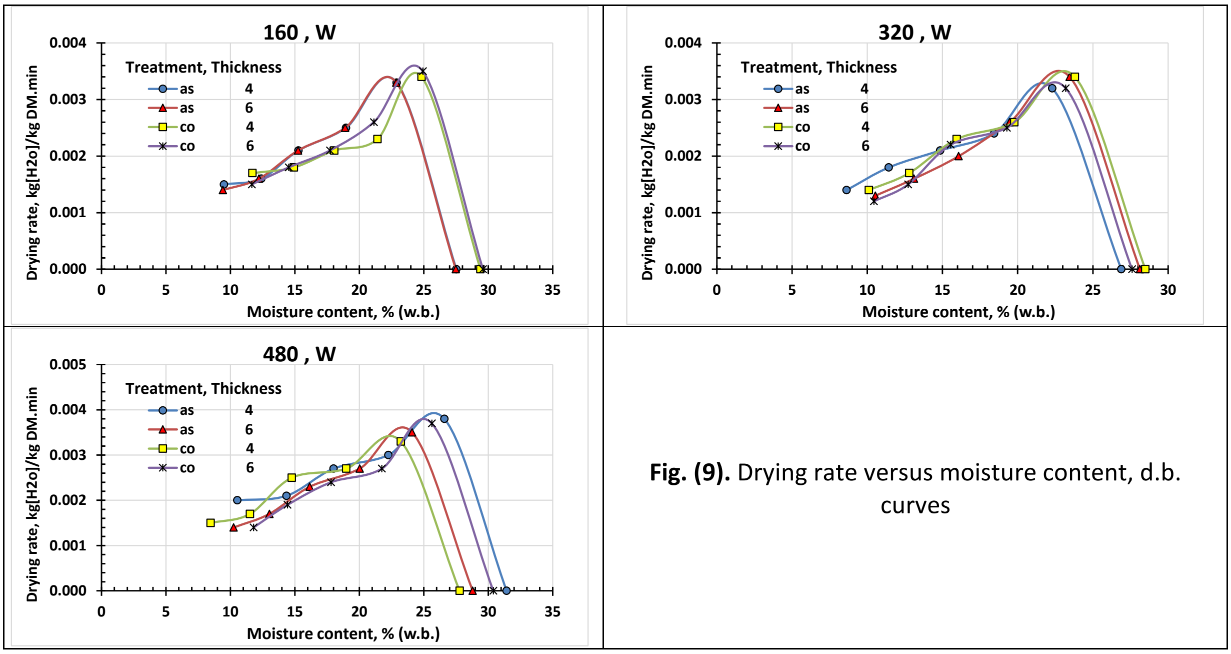

Fig. (9). Drying rate versus moisture content, d.b. curves

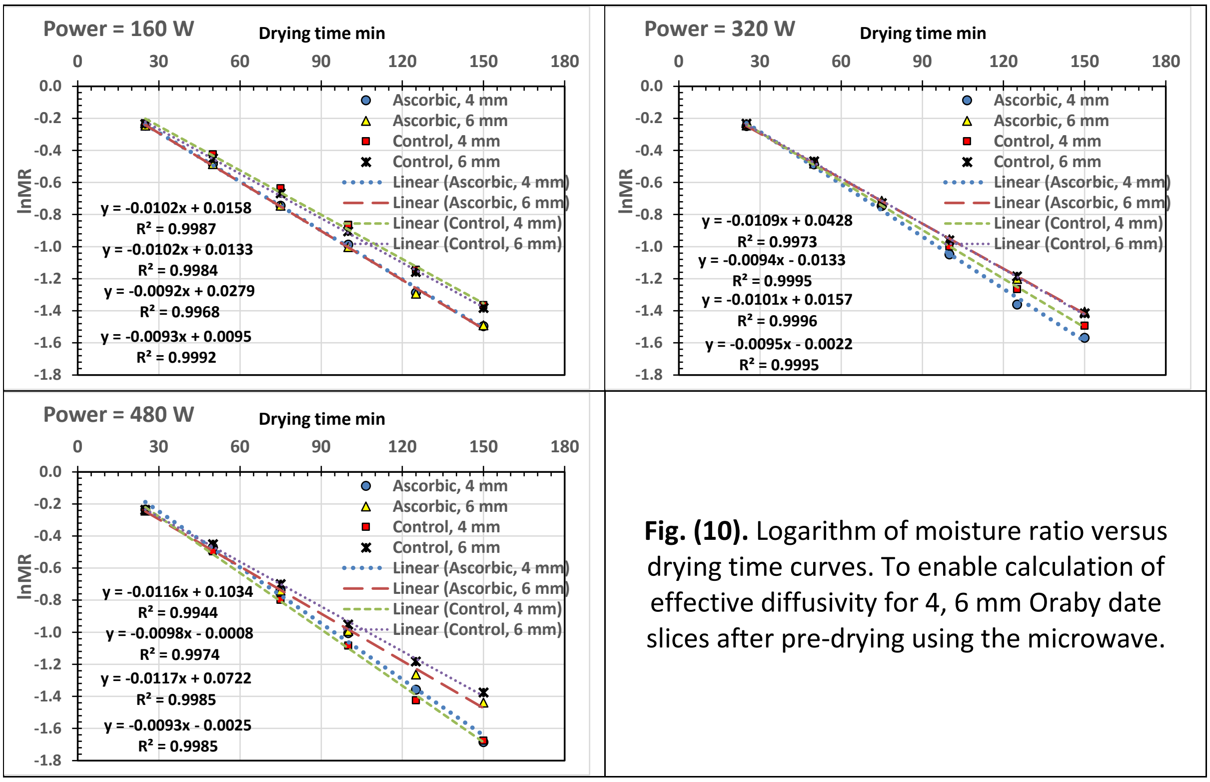

Fig. (10). Logarithm of moisture ratio versus drying time curves. To enable calculation of effective diffusivity for 4, 6 mm Oraby date slices after pre-drying using the microwave.

Effective Diffusivity (D_{eff}) estimated values are summarized in Table (6). D_{eff} ranged from 8.81E+05 to 2.91E+06 with an average value of 1.58E+06. The minimum value was recorded for the control 4 mm slice pre-dried using MW at 160 W. The maximum value was recorded for the ascorbic acid pretreated 6 mm slices pre-dried using MW at 320 W. The 6mm slices recorded higher D_{eff} values than the 4mm slices. The control samples recorded higher D_{eff} values compared with the control. The differences among D_{eff} values of Oraby date slices regarding the applied microwave powers were small except for the 6mm control slices.

The results of Falade and Abbo (2007) showed that the diffusivity coefficient (D_{eff}) varied from 5.89×10^{-10} to 1.78×10^{-9} m^2/s, 3.22×10^{-9} to 8.16×10^{-9} m^2/s and 7.53×10^{-9} to 2.98×10^{-8} m^2/s for Red soft type, Tempo 2 and Tempo 3, respectively. Tempo 3 consistently showed higher D_{eff} than Red soft type and Tempo 2 at all drying temperature. D_{eff} values mostly lie within general range of $10^{-12} – 10^{-8}$ m^2/s reported for most food materials (Babalis and Belessiotis, 2004; Zogzas, et al., 1996). Effective moisture diffusivity increased with increasing drying air temperature.

Table (6). Effective Diffusivity, m^2/s of drying Oraby date slices using a convention oven at 60 C after microwave drying

Pre-treatment	Thickness, mm	Effective Diffusivity, m^2/s		
		Microwave Power, W		
		160	320	480
Control				
	4	1.493E-08	1.642E-08	1.900E-08
	6	3.375E-08	3.459E-08	3.394E-08
Ascorbic acid				
	4	1.649E-08	1.765E-08	1.887E-08
	6	3.712E-08	3.419E-08	3.581E-08

3. Physical, chemical and sensory evaluation of dried Oraby date slices:

3.1 Color measurements:

Table (7) presents the color measurements of Oraby slices after MW drying. The *L** values which indicate the degree of lightness of the samples ranged from 27.85 to 38.00 with an average value of 33.56. It is noticed that *L** values decreased as MW power was increased and as sample thickness was increased i.e. sample color becomes darker (lower *L** values). The *a** values which are all positive numbers indicate the degree of redness ranged from 5.04 to 9.21 with an average value of 7.81. It is noticed that *a** values increased as MW power was increased and as sample thickness was increased i.e. sample becomes more reddish in color (higher *a** values). The *b** values which are all negative numbers which indicates the degree of blueness of the samples ranged from -0.50 to -0.20 with an average value of -0.38. It is noticed that *b** values decreased as MW power was increased and as sample thickness was increased i.e. sample color becomes more blueish in color (lower *b** values).

As slice thickness and the MW power used for drying were increased, the sample color becomes darker and more reddish. The thick slices require more time for drying and thereby more chance for oxidation and color change. Also, using higher MW power apply much heat to the samples which may accelerate reactions responsible for color changes. It is recommended to apply the 160 W power for the thin date slices (2 mm) to produce a product having bright color. The organoleptic evaluation of dried Oraby slices indicated more preference towards the 2mm slices with respect to color and general acceptability. As a pretreatment, microwave can be used along with other drying methods to take advantage of its benefits. Krokida, et al., (2000) studied the effect of pretreatment on color of convective dried products (namely apple, banana, potato and carrot). The authors found that osmotically and microwave pretreated samples suppressed browning compared to the untreated samples. Benamara, et al., (2009) indicated 95% of time saving by using microwave drying as a pretreatment of date pulp followed by convective drying. Al-Awaadh, et al., (2015) reported that drying affected Sukkari date fruit color and texture. Proper selection of drying temperature and air velocity can minimize such changes.

Table (7). Color measurements, total phenols and tannins contents of dried Oraby date slices.

	Pre-treatment	Control			Ascorbic acid		
	Power, W	Thickness, mm					
Attributes		2	4	6	2	4	6
Color measurements							
*L**	160	37.5	36.2	34.0	38.0	37.0	35.6
	320	34.0	33.6	33.0	35.0	34.2	33.7
	480	31.0	29.5	27.9	33.5	31.2	29.3
*a**	160	6.53	8.26	9.03	5.04	6.44	7.14
	320	7.28	7.55	8.10	7.03	7.53	8.23
	480	8.18	9.03	9.21	8.02	8.84	9.16
*b**	160	-0.30	-0.48	-0.50	-0.20	-0.36	-0.40
	320	-0.36	-0.36	-0.45	-0.31	-0.32	-0.36
	480	-0.41	-0.41	-0.49	-0.33	-0.37	-0.42
Polyphenols	160	19.94	7.55	3.74	27.56	8.75	4.85
	320	15.22	5.00	2.49	24.18	6.33	3.00
	480	12.82	2.11	0.87	20.38	3.33	1.47
Tannins, %	160	1.32	1.23	1.04	1.85	1.57	1.43
	320	1.26	1.15	0.88	1.51	1.31	1.22
	480	1.20	0.95	0.72	1.37	1.25	1.10

3.2. Tannins and total phenol contents of dried Oraby slices:

Because of the importance of tannins and total phenolic contents of date slices (Table 7) to consumer acceptability, measurements were made after drying of sample to produce crispy slices that can be used as ready to eat snacks. It was noticed from table (7) that the tannins content values for MW dried Oraby slices decrease as slice thickness was increased at the same power level, while they increase as MW power was decreased for samples of the same thickness. These values are very low compared with previously reported levels for tannins in Oraby dates at the khalal stage before drying. It is well known that heat treatments precipitate tannins into condensed form which is not astringent and thereby the taste was improved.

According to table (7), the polyphenol contents of MW dried Oraby slices decrease as slice thickness was increased at each MW power. Also, the polyphenol contents of the slices decreased as microwave power was increased for the same slice thickness.

3.3. Total, reducing, and non-reducing sugar contents of dried Oraby slices:

Table (8) presents classes of sugar contents of dried Oraby slices. It was found that total sugars, the reducing sugars and the non-reducing sugars decreased with a decrease in the intensity of the microwave radiation and increased with the increase in the thickness of the dried date slices. These values are in the ranges reported by Al-Farsi and Lee, (2008) and Ahmed et al., (2014) for sugar contents in dried date fruits.

Table (8). Total, reducing and non-reducing sugar contents of dried Oraby date slices.

Pre-treatment		Control			Ascorbic acid		
Thickness, mm	**Power, W**	**Reducing sugars, %**	**Non-reducing sugars, %**	**Total sugars, %**	**Reducing sugars, %**	**Non-reducing sugars, %**	**Total sugars, %**
2	**160**	32.91	20.48	53.39	48.00	10.88	58.88
	320	33.00	21.00	54.00	48.48	11.18	59.66
	480	33.75	21.25	55.00	49.74	10.42	60.16
4	**160**	36.54	19.46	56.00	48.84	11.16	60.00
	320	37.00	19.87	56.87	49.55	11.21	60.76
	480	37.59	20.35	57.94	50.17	11.28	61.45
6	**160**	36.58	20.42	57.00	49.72	11.76	61.48
	320	37.62	20.17	57.79	50.11	11.89	62.00
	480	38.48	20.18	58.66	51.00	11.67	62.67

3.4. Sensory evaluation of dried Oraby slices:

Sensory evaluation of the dried Oraby slices (Table 9) indicated acceptance of the new product. Panelists' scores for all the organoleptic attributes were 7 or above. Slices pretreated with ascorbic acid received higher scores than the control which reflect that the pretreatment with the ascorbic acid preserved color and texture of the slices during the drying process. It was observed that the panelists' scores were higher for the 2mm slices while differences between the 4- and 6-mm slices were minimal. Also, the microwave power showed minimal differences among samples with respect to all attributes. It can be concluded that microwave drying of Oraby slices produced acceptable food products particularly when the slice thickness was 2 mm.

Table (9). Panelists' scores of sensory attributes of Microwave dried Oraby date slices

Power, W	**Pre-treatment**	**Thickness, mm**	**Color**	**Taste**	**Texture**	**overall acceptability**
160	Ascorbic acid	2	9.5	9.5	9.5	9.5
		4	8.5	8.5	8.5	8.5
		6	8.5	8.5	8.5	8.5
	Control	2	8.0	8.0	8.0	8.0
		4	7.0	7.0	7.0	7.0
		6	7.0	7.0	7.0	7.0
320	Ascorbic acid	2	9.5	9.5	9.5	9.5
		4	8.5	8.5	8.5	8.5
		6	8.5	8.5	8.5	8.5
	Control	2	8.0	8.0	8.0	8.0
		4	7.0	7.0	7.0	7.0
		6	7.0	7.0	7.0	7.0
480	Ascorbic acid	2	9.5	9.5	9.5	9.5
		4	8.5	8.5	8.5	8.5
		6	8.5	8.5	8.5	8.5
	Control	2	8.0	8.0	8.0	8.0
		4	7.0	7.0	7.0	7.0
		6	7.0	7.0	7.0	7.0

CONCLUSION

Drying Oraby date slices (at one stage using MW drying for the 2 mm thickness, and at two stages for the 4 and 6 mm thickness using Microwave followed by oven drying at 60°C) produced consumer acceptable snacks with good sensory characteristics and low tannins contents. The Midilli et al Model showed best fit to the experimental data for moisture changes during MW drying and second stage oven drying. This was judged by the higher R^2 and lower values of reduce chi-square (χ^2), root mean square error (RMSE) and mean percent error calculated parameters for the Midilli model as compared to those for the other two models. The 2mm slices required only one stage drying by microwave. Calculated energy consumption and efficiency indicated that utilization of microwave drying at 160 W for thin date slices is economical and efficient. For thicker samples, MW assisted-drying efficiently aids to reduce time of conventional oven drying.

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الملخص العربي

دراسات على حركيات التجفيف بمساندة الميكروويف لشرائح البلح العرابي

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استهدفت الدراسة تقييم تأثير شدة اشعة الميكروويف على حركيات التجفيف وجودة شرائح البلح العرابي (في مرحلة الخلال) والمعاملة بحمض الاسكوربيك او بدون معاملة (كنترول). وكانت رطوبة الابتدائية للعينات 1.7397على أساس الوزن الجاف. وتم استخدام ثلاث مستويات أشعة وهي 160 و320 و480 وات لتجفيف الشرائح بسمك 2، 4، و 6 مم وقطر 24 ± 2 مم. وباستخدام معادلات الانحدار الغير خطي لدراسة مدي موائمة ثلاثة من النماذج الرياضية المتعارف عليها في وصف التغير في رطوبة المواد الغذائية اثناء التجفيف. وقد تم حساب الزمن اللازم للتجفيف ومعدل التجفيف. وتراوح معامل نفاذية الرطوبة للعينات من 1.86× 10^{-9} الى 1.47 ×10^{-8} م^2/ث. ونظرا لحدوث تلون بني او كرملة في شرائح البلح سمك 4 و 6 مم عندما تقل رطوبة العينة عن 0.3678 كجم ماء/كجم مادة جافة، لذا يتم التوقف قبل الوصول لهذه النقطة، وتنقل العينات إلى الفرن المعملي لاستكمال التجفيف على 60°م ، بينما استمر تجفيف العينات سمك 2 مم بفرن الميكرويف لعدم حدوث هذه الظاهرة. وكان نموذج ميديللي (Midilli) هو انسب النماذج الرياضية في وصف التغير في الرطوبة بالعينات عند التجفيف بالميكروويف وكذلك بالفرن المعملي. وقد تم تقييم المنتجات النهائية من ناحية اللون والمحتوى من السكريات والتانينات والفينولات الكلية. واظهرت نتائج التقييم الحسي تقبل المحكمين للمنتج كنوع من الوجبات الخفيفة (اسناكس) وخاصة الشرائح سمك 2مم. وقد ساهم استخدام الميكروويف في تقليل زمن التجفيف.

الكلمات الدالة: البلح العرابي (العربي) – التمور الرطبة – فرن الميكروويف - التجفيف – المقرمشات – الخواص الحسية – تصنيع التمور – التلون البني– معامل نفاذ الرطوبة - كفاءة التجفيف.