QUALITY PARAMETERS AND DRYING KINETICS OF ULTRASOUND PRETREATED FERMENTED BLACK TABLE OLIVES

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***Abstract*— The effect of ultrasound (US) pretreatment on microwave drying parameters including drying rate, moisture ratio and effective diffusivity and quality properties such as total phenolic and color parameters (L*, a*, b*, C, ΔE and H°) of black table olive slices were determined. 10 minutes ultrasound pretreatment decreased drying time of black table olive slices by 31.81%, 41.37% and 42.85% compared to control samples dried at 180, 450 and 800 W, respectively. Weibull and Diffusion models could precisely fit the drying behavior of black table olive slices (R^2 > 0.9950). Microwave drying had a negative effect on phenolic compounds of olives, whereas US pretreatment preserved phenolics and color parameters of samples. Higher effective diffusivity (D_{eff}) values were obtained when the drying was combined with US pretreatment. Microwave drying with ultrasound pretreatment could improve drying process, since it accelerated drying rate and preserved the phenolic compounds and color parameters.**

Keywords*— Ultrasound, microwave, drying, olive, kinetic model

I. INTRODUCTION

Olive fruit (*Olea europaea* L) is one of the most significant agricultural products in Mediterranean countries and mostly consumed as olive oil and table olives throughout the world (Kailis, 2016). Olive consumption has been increased from 2110 thousand tons to 2667 thousand tons from 2009 to 2019 in whole world and its consumption is risen in every year (International Olive Oil Council & Council, 2019). It contains many phenolic compounds including tyrosol, hydroxytyrosol and oleuropein, in which anticarcinogenic, antioxidant, antimicrobial and anti-inflammatory effects on humans have been proven in many studies (Aydar *et al.*, 2017a). Drying is one of the oldest process applied to fruits and vegetables which provides long-term storage by removing moisture to a desired concentration that guarantee microbial safety of the food using heat energy (Wang *et al*. 2019; Lewicki, 1998). Hot air, spray, solar, microwave, osmotic dehydration and freeze drying are some of the commonly used drying methods used in food industry (Yildiz and İzli, 2019). Microwave drying has been proved to decrease drying time with less energy consumption (İçier *et al.*, 2015).

Pre-treatments including ultraviolet, blanching, ultrasound, pulsed electric, osmotic dewatering, immersing in solutions and sulfiting have been applied to fruits and vegetables to enhance qualitative and drying properties of foods (Bozkir *et al.*, 2019). Ultrasound, a novel technology, is composed of mechanical sound waves that is generated from molecular movements has been used mostly for extraction (Aydar *et al.*, 2017b; Lianfu and Zelong, 2008) and pre-treatment of a drying process (Wang *et al.*, 2019; Seidi *et al.*, 2016; Bozkir *et al*., 2019) to enhance the product quality and improve the drying rate.

Although microwave drying of black olives have been determined in recent studies (İçier *et al.*, 2015; Mahdhaoui *et al*., 2014), and ultrasound as a pretreatment has been used for microwave drying of kiwifruit (Wang *et al.*, 2019), garlic (Bozkir *et al*., 2019), melon (Rodrigues and Fernandes, 2007), apple (Fijalkowska *et al.*, 2016), mushroom (Zhang *et al*., 2016) and tomatoes (Horuz *et al*., 2017) and fresh green olives (Aydar, 2020) there are limited numbers of study in literature evaluated the effect of ultrasound combined microwave drying on total phenolic compounds, color changes and kinetic modelling of fermented black table olive slices. Therefore, this work aimed to evaluate ultrasound as a pretreatment in microwave drying of fermented black table olives by investigating the qualitative and drying properties during drying including drying rate, moisture ratio and moisture effective diffusivity.

II. METHODS

A.Olive samples

The fermented Aydın Kaba variety of olive samples (*Olea europaea* L.) was obtained from Aydar Olive Company, Akhisar, Turkey. Before the olives were sliced into the thickness of 5 mm the seeds of olives were removed by pitting machine (TM02 Model Tutkun Machine, İzmir). The olive slices had the outside diameter of 14.5±0.5 mm and the inside diameter of 0.9±0.2 cm. Olives were kept at +4 °C before drying process.

B. Ultrasound pretreatment

The black olive slices were put in a 250-mL glass beaker. The distilled water was used as the medium and the ratio of olive slices to water was 1:5 (w/w). It was studied with fresh green olives in these parameters and it was observed increasing the ultrasound time up to 15 minutes, TPC of olives were decreased. Therefore 5 and 10 minutes were applied in this study to determine the effect of ultrasound in fermented black table olives (Aydar, 2020). The 5 and 10 minutes of ultrasound were applied to samples using ultrasonic bath (Alex Machine, PR-6711, Turkey, 150kW and ultrasonic frequency 25

KHz; Tank volume 4.5 L) in this study. An infrared thermometer (Benetech, GM300, China) was used to measure the surface temperature of the olive slices and ultrasonic bath for 1 minute intervals during sonication process. The temperature inside the bath and surface of olive slices did not exceed to 25 °C during sonication.

C. Microwave Drying

A microwave oven (GE83X, Samsung, Turkey, 2450 MHz and 23 L capacity) was used for drying of black olive slices. 5 g of sliced olives were weighted and put on a glass drying tray (10 cm diameter). Then they were left to dry at 180, 450, and 800 W microwave power levels. The weight of olive slices were recorded in every 1 min during microwave drying until the final moisture content of samples reached approximately 20% (weight/weight). In previous studies conducted with fresh green olives it was observed that samples burned at high microwave power level, therefore the weight of olive slices were recorded in every 1 min during microwave drying until the final moisture content of samples reached approximately 20% (weight/weight). The experiments were performed in triplicate.

D. Moisture Rate

The moisture ratio (MR) of black table olive slices was calculated from Eqs. (1) (Wang *et al.*, 2019)

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

where M_t is the moisture at a specific time (weight/weight), M_o is the initial moisture content (w/w), M_e is the equilibrium moisture content (weight/weight), When moisture at a specific time and initial moisture content are compared with equilibrium moisture content, M_e value approaches to a very small number. Therefore, MR is simplified by many researchers and MR of fermented black table olives were calculated as this simplified Eq. 2 (Midilli *et al.*, 2002):

$$\mathrm{MR}=\frac{\mathrm{M_t}}{\mathrm{M_0}} \quad (2)$$

Drying rates of different drying processes were computed according to equation below (Akpinar *et al.*, 2003):

$$\mathrm{DR}=\frac{\mathrm{M_{t1}}-\mathrm{M_{t2}}}{\mathrm{t_2}-\mathrm{t_1}} \quad (3)$$

where t_1 and t_2 are the different drying times and M_{t1} and M_{t2} are the moisture contents of olive slices at time t_1 and t_2, respectively.

E. Modeling

Weibull, Newton, Henderson and Pabis, Logarithmic, Wang and Sing, Midilli *et al*. and Diffusion are models have been applied to describe the changes in moisture content and physicochemical degradation of olive slices during drying are shown Table 1 (Simal *et al.*, 2005; Aregbesola *et al.*, 2015; Wang *et al.*, 2019). A graph of moisture ratio (MR) and drying rates (DR) against time (t) at the different microwave power levels and ultrasound times was plotted. Drying data of the black olive slices were fitted to seven thin drying models (Table 1. SAS 9.2. (SAS Institute Inc., Cary, NC, 2009) was used to perform regression analyses. To identify the goodness of fit coefficient of determination (R^2), χ2 (reduced chi-square parameter) and root mean square error (RMSE) between the predicted and experimental values were applied (Wang *et al.*, 2007).

Table 1. Thin-layer drying models used for the study

No	Model name	Model	References
1	Weibull	$\mathrm{MR}=\exp[-(t/\beta)^{\alpha}]$	(Wang *et al.*, 2019)
2	Newton	MR=exp(-kt)	(Akwasi, 1997)
3	Henderson & Pabis	MR=*a*exp(-kt)	(Akpinar *et al.*, 2003)
4	Logarithmic	MR=*a*exp(-kt)+*c*	(Aregbesola *et al.*, 2015)
5	Wang & Singh	MR=1+*a*t+*b*t^2	(Yildiz and İzli, 2019)
6	Midilli *et al.*	MR=*a*exp(-kt^n)+*b*t	(Midilli *et al.*, 2002)
7	Diffusion	MR=*a*exp(-kt)+ (1-*a*)exp(-k*b*t)	(Yaldiz *et al.*, 2001)

F. Effective diffusivity

Effective diffusivity of olive slices was calculated by using the Fick's second diffusion law for slab geometry:

$$\frac{\partial M}{\partial t} = D_{eff}\nabla^2 \mathrm{M} \quad (4)$$

where D_{eff} is the effective moisture diffusivity (m^2/s) , M is the moisture content (dry basis), t is the time(s) (Yağcıoğlu *et al.*, 2014). Fick's second diffusion law presumes that moisture removal is caused by diffusion, temperature, shrinkage and constant diffusion coefficients (Aregbesola *et al.*, 2015; Sun, 2014)

$$\mathrm{MR}=\frac{\mathrm{M_t}-\mathrm{M_e}}{\mathrm{M_0}-\mathrm{M_e}}=\frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\,exp\left[-\frac{(2n+1)^2\pi^2 D_{eff}}{4L^2}\right] \quad (5)$$

Where t is time (s), L is half thickness of samples (m) and *n* is a positive integer. For longer drying times, Eq. 5 can be converted to a further formula consisting of only the first set of terms without significant influence on the correctness of the supposition.

$$\mathrm{MR}=\frac{8}{\pi^2}\,exp\left[-\frac{\pi^2 D_{eff}}{4L^2}\right] \quad (6)$$

$$\ln(\mathrm{MR})=\ln\left(\frac{8}{\pi^2}\right)-\left[\frac{\pi^2 D_{eff}}{4L^2}\right] \quad (7)$$

From Eq. 7, moisture effective diffusivity can be determined by plotting ln(MR) versus drying time (*t*); which provides a linear line and the slope of this line is explained as below:

$$\mathrm{Slope}=\left[\frac{\pi^2 D_{eff}}{4L^2}\right] \quad (8)$$

G. Total Phenolic Compounds (TPC)

Total phenolic compounds of black olive slices were determined using Folin-Ciocalteau method (İçier *et al.* 2015). According to this method, 2 gr of olive slices extracted in an 50 mL of methanol solution (80:20, volume/volume), then extract was filtered. 50 µl of filtered extract was reacted by 250 µl Folin-Ciocalteau reagent for 5 minutes. After 750 µl of Na2CO3 was added the volume was completed with 3.95 ml of distilled water. Final solution was kept at 2 h in dark and the absorbance value was measured using an UV-VİS spectrophotometer at 760 nm. A calibration curve (R^2 =0.9899) of standard solution of gallic acid was prepared and results

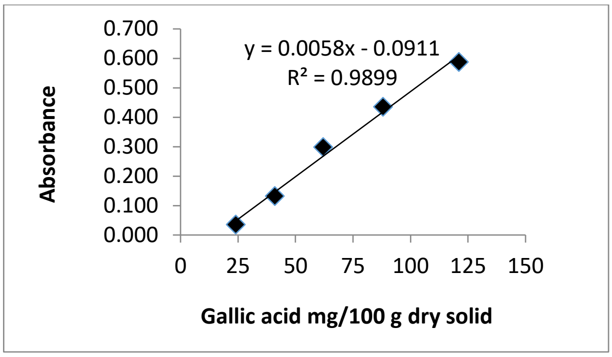

Fig. 1 Calibration curve of standard gallic acid for determination of TPC.

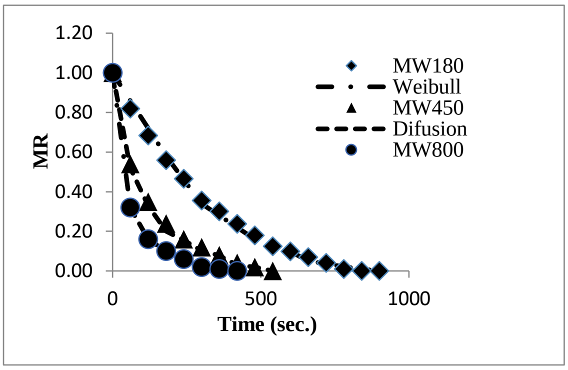

Fig. 2. Drying curves of microwave dried olive slices.

were expressed as mg gallic acid equivalents per 100 g of dried fruit (Fig 1).

H. Color Parameters

The color parameters of black olive slices was measured with a Chroma Meter(Konica Minolta, CR 300 Model, VA) based on 5 color coordinates (L*, a*, b*, C, h°). After the calibration of colorimeter against a standard white surface and black one, six replicate measurements were performed for each sample To illustrate the color changes between control sample and samples after drying treatments total color variance (ΔE) values were calculated by using the formula:

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^{*2})]^{1/2} \qquad (9)$$

Where: ΔL*, Δa*, and Δb* are the differences of these values between the control sample and samples after drying treatment

I. Statistical Analysis

The data was shown as means ± standard deviation (SD). SAS 9.2. (SAS Institute Inc., Cary, NC, USA) was used to determine the effect of the microwave power level and ultrasound time on the qualitative parameters of olive samples by one-way ANOVA. Tukey's honestly significant differences (HSD) test (α=0.05) was applied as post-hoc test. Coefficient of determination (R^2), χ^2 (reduced chi-square parameter) and root mean square error (RMSE) were calculated to interpret the adequacy of each model.

III. RESULTS

A. Drying Kinetics

Figure 2 shows thin layer microwave drying curves of olive slices at the different power levels and Fig. 3

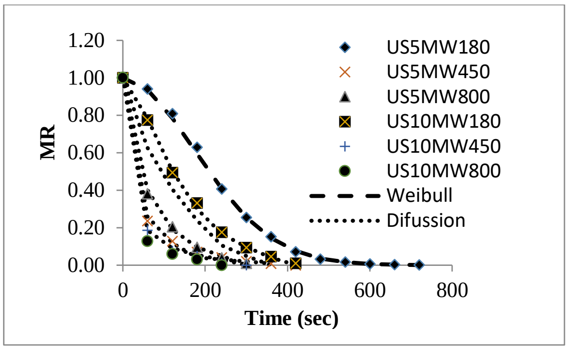

Fig. 3. Drying curves of olive slices pretreated with ultrasound.

shows thin layer microwave drying combined with different ultrasound pretreatment times

The total drying times for olive slices were 880, 580 and 420 seconds at microwave drying levels of 180, 450 and 800 W respectively. Drying times of olive slices decreased to 280, 240 and 180 seconds when 10 minutes of sonication applied before microwave drying at power levels 180, 450 and 800 W respectively. This shows that longer drying times are required to dry the olives when they are nontreated with ultrasound.

Horuz *et al.* (2017) also observed that application of ultrasound pre-treatment reduced the drying time of tomato slices by 7.38% when they were dried at 120 W microwave power. It was also determined by the researcher that ultrasound pre-treatment caused shorter drying times (Rodrigues and Fernandes, 2007; Seidi *et al.*, 2016; Bozkir *et al.*, 2019)

The results of nonlinear analysis of the fitting of seven selected models to the drying data of black olive slices at the different ultrasound pretreatment times (5 and 10 min.) and microwave power levels (180, 450 and 800 W) are shown in Table 2. According to the evaluation criteria (R^2, $\chi 2$ and RMSE), most of models well fitted with the thin layer drying characteristics (R^2>0.94, RMSE<0.11 and $\chi 2$<0.02) of olive slices which are subjected to 5 minute of ultrasound before being dried at 180 W power level in microwave.

Weibull and the Midilli *et al.*, were the best fitted models in describing the thin layer drying characteristics of olive slices which are not pretreated with ultrasound with the lowest RMSE and X^2 values and highest R^2 values. In a similar study by İzli *et al.* (2019), Page and Midilli *et al.* models were best fitted in describing the thin layer microwave drying kinetics of lime slices.

On the other hand, in ultrasound pretreated black table olive slices Distribution and Midilli *et al.* models well described the experimental data with R^2 value higher than 0.992, RMSE and χ^2 values lower than 0.029 and 0.002, respectively.

Figure 2 and Fig. 3 demonstrate the comparison between the experimental and predicted data using the best fitted models with drying interval at different ultrasound combined microwave drying treatments. As it can be seen in these figures, the Weibull and Diffusion models well predicted the experimental values in most treatments.

Table 2. Coefficients of selected drying models and sta statistical computations on model equations.

	No	Model Coefficients	R^2	RMSE	X^2
US 5 MW 180	1	a:2.0029, b:258.3136	0.9997	0.0070	5.35 x10^{-5}
	2	k: 0.0041	0.9582	0.1080	0.0127
	3	a:1.1472, k: 0.0046	0.9484	0.0931	0.0104
	4	a:1.3173, k:0.0062, c:-0.0213	0.9668	0.0697	0.0065
	5	a:-0.0025, b:1.36 x10-6	0.9540	0.0844	0.0086
	6	a:1.0797, b:-0.0006, k:0.0052 n:0.4851	0.9717	0.0545	0.0045
	7	a:-6.8062, b:0.0014, k:1.1684	0.9659	0.0777	0.0080
US 5 MW 450	1	a: 7.7631, b: 0.3248	0.8468	0.1139	0.0181
	2	k: 1.8402	0.9534	0.1044	0.0127
	3	a:0.9998, k:1.8402	0.9534	0.1045	0.0153
	4	a: 0.9170, k:2.6537, c:0.0828	0.9534	0.0709	0.0088
	5	a: -0.0086, b: 1.75 x10-5	0.8576	0.1326	0.0235
	6	a:0.5277, b:-0.0018, k:0.014 n:0.02	0.9924	0.0290	0.0020
	7	a:0.4179, b: 33.4809, k:0.0003	0.9999	0.0099	4.12 x10^{-6}
US 5 MW 800	1	a:2.8883, b: 0.2372	0.8520	0.3665	0.1791
	2	k: 1.5001	0.9872	0.0957	0.0106
	3	a: 0.9998, k:1.5001	0.8551	0.1568	0.0328
	4	a:0.8764, k: 0.5412, c:0.1234	0.8554	0.1155	0.0214
	5	a:-0.0080, b: 1.52 x10-5	0.9423	0.3601	0.1729
	6	a:0.9926, b:3.01 x10-5, k:0.0212 n:0.6887	0.9968	0.0181	0.0007
	7	a:0.0156, b:25.9013, k:0.0005	0.9972	0.0172	0.000472
US 10 MW 180	1	a:24.9433, b:63.1013	0.9023	0.2217	0.0655
	2	k: 0.3801	0.8325	0.3528	0.1422
	3	a:1.0202, k:0.3817	0.8942	0.0968	0.0125
	4	a: 0.7250, k:0.4072, c:0.2749	0.8964	0.2415	0.0933
	5	a:-0.0042, b: 4.10 x10-6	0.9917	0.0330	0.0015
	6	a:1.0226, b:3.7 x10-5 k:0.0612, n:0.0845	0.9994	0.0239	0.0011
	7	a:-3.7790, b:1.2269, k:0.0025	0.9951	0.0250	0.0010
US 10 MW 450	1	a: 3.8825, b: 50.1796	0.9214	0.0603	0.0042
	2	k: 1.7804	0.8836	0.0739	0.0062
	3	a:0.9954, k:1.7412	0.8946	0.3464	0.1600
	4	a: 0.9460, k: 2.7756, c:0.0538	0.9681	0.0601	0.0063
	5	a:-0.0093, b: 1.97 x10-5	0.8343	0.1483	0.0293
	6	a: 0.9981, b: 4.16 X 10-5, k:0.0287, n: 0.933	0.9971	0.0199	0.0009
	7	a:0.3683, b:4.9695, k:0.0127	0.9996	0.0064	5.86 x10^{-5}
US 10 MW 800	1	a: 3.8481, b:10.7672	0.8656	0.2814	0.1055
	2	k: 0.4805	0.8457	0.2796	0.0893
	3	a:0.9988, k:0.4814	0.9546	0.0790	0.0087
	4	a: 0.9631 , k: 0.5187, c: 0.0367	0.9835	0.0399	0.0026
	5	a:-0.0058, b: 9.15 x10-6	0.7334	0.2639	0.0907
	6	a:0.9991, b:3.08 x10-5, k:0.1548 n: 0.2135	0.9977	0.0167	0.0006
	7	a:0.2949, b:10.8769, k: 0.0137	0.9998	0.0047	3.50 x10^{-5}

K. Effective Diffusivities and Drying Rates

Table 3. demonstrates the effective moisture diffusivity (D_{eff}) values for each different treatment. Among all the dried samples, D_{eff} value observed highest at 10 min ultrasound – 800 W microwave drying combination (1.13 × 10^{-7} m^2/s) and lowest at 180 W microwave drying (2.53 × 10^{-9} m^2/s). A higher D_{eff} value revealed that the moisture removal rate in the black olive slices was greater, which would reduce the drying time to obtain the final moisture content. It was observed that the D_{eff} values increased with increase in ultrasound pretreatment time and microwave power level. Since, high microwave power levels cause an increase in the water molecule activity at elevated drying temperatures, moisture diffusion increases in samples.

Table 3. Effective Diffusivities of Different Drying Experiments

Treatment	Moisture Effective Diffusivity (m^2/s)
MW180	2.53 X 10^{-09}
MW450	3.80 X 10^{-09}
MW800	4.56 X 10^{-09}
US5MW180	2.35 X 10^{-08}
US5MW450	3.09 X 10^{-08}
US5MW800	3.70 X 10^{-08}
US10MW180	2.61 X 10^{-08}
US10MW450	4.43 X 10^{-08}
US10MW800	1.13 X 10^{-07}

MW180: Microwave dried samples at 180 W, MW450: Microwave dried samples at 450 W, MW800: Microwave dried samples at 800 W, US5MW180**:** 5 minutes of ultrasound pretreated and microwave dried samples at 180 W, US5MW450**:** 5 minutes of ultrasound pretreated and microwave dried samples at 450 W, US5MW800**:** 5 minutes of ultrasound pretreated and microwave dried samples at 800 W, US10MW180**:** 10 minutes of ultrasound pretreated and microwave dried samples at 180 W, US10MW450**:** 10 minutes of ultrasound pretreated and microwave dried samples at 450 W, US10MW800**:** 10 minutes of ultrasound pretreated and microwave dried samples at 800 W.

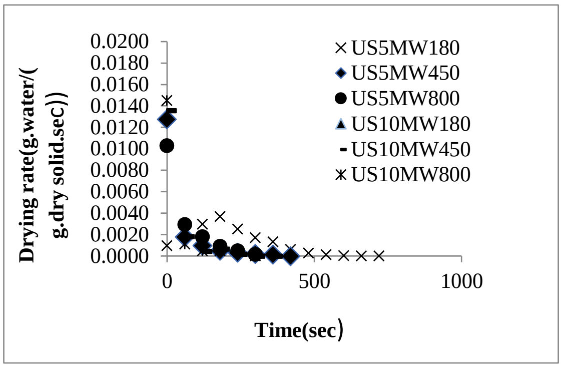

Fig. 4. Drying rate of ultrasound pretreated microwave dried olive slices.

Highest drying rates were observed the 10 minutes ultrasound pretreatment combined with microwave drying at 800 and 450 W power levels, respectively (Fig. 4 and Fig 5). The drying rate of ultrasound non-treated samples was lower in comparison to pretreated samples.

L. Color Parameters and Total Phenolic Content

L* (lightness) values of olive slices dried at 450 W and 800 W power level were significantly different from control sample and it decreased as microwave level increased. The decrease in L* value could be explained by non-enzymatic oxidation reaction. In all other drying conditions which are pretreated by ultrasound, L* value was not significantly different from control. Bozkır *et al*. (2019), who studied the ultrasound pretreatment effect on quality and drying parameters and found that

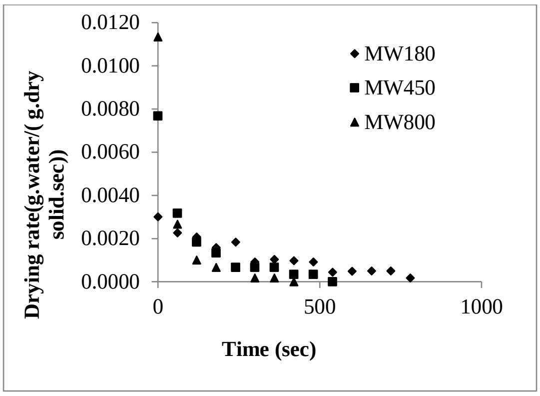

Fig. 5. Drying rate of microwave dried olive slices.

lightness was lowest at microwave dried samples and highest at hot air dried samples.

Significant difference in a*(redness-greenness) value was only observed in ultrasound treated samples (p<0.05). b* (yellowness-blueness) values of all non-treated samples and 10 minutes ultrasound treated olives dried at 450 W power level were different than control. While total color difference values of ultrasound treated olive slices were between 2.21-4.15, it was 5.03-10.34 for nontreated samples. Horuz *et al.* (2917) also reported that ΔE values of all microwave drying conditions combined by ultrasound was not higher than 10 in tomato samples. It was found that the color of olive slices did not differ significantly compared to control sample when exposed to ultrasound. The changes in L* and C values of olive slices were more clearly observed than in Hue angle.

TPC of black table olive slices reduced significantly in all microwave and ultrasound pretreated drying treatments compared to control sample ($p < 0.05$). The decrease in phenolic compounds might be related to deterioration of these compounds by electromagnetic waves of the microwave. In addition, microwave power induced to the internal temperature of food to rise due to the friction of the water molecules. Thus, thermal degradation and irreversible oxidative reactions caused phenolic compounds to be damaged during drying. Ultrasound pretreatment also influenced the total phenolic compounds of olive slices significantly ($p < 0.05$). It can be explained by the cavitation phenomena which allows the release of phenolic compounds and improves the mass transfer by disrupting the cell walls (Aguilar-Hernández *et al.*, 2019) But when ultrasound treatment time exceeds, degradation could be due to sonochemical and oxidation reactions, increased interaction with free radicals during sonication (Aydar, 2018). Therefore optimum treatment time for an ultrasound processing should be well decided in extraction studies. It can be seen from Table 4 ultrasound pretreated samples preserved phenolics better compared to non-treated samples at each microwave power levels. Highest loss in phenolic compounds were observed when samples were dried at 800 W microwave power level. When olive slices were dried at 800 W microwave power, total phenolic compounds were decreased by 49.92%. However when samples subjected to 5 and 10 minutes of sonication before microwave drying at 800 W, the decrease in phenolic contents was 38.51% and 44.23%, respectively. It can be explained by when ultrasound was applied to samples drying time decreased and thus sample were exposed to microwave shorter time, therefore TPC of ultrasound pretreated samples were found higher than nontreated samples.

IV. CONCLUSIONS

The aim of this study was to evaluate a continuous ultrasonic microwave drying procedure for the table olive slices means of drying and quality parameters. The drying time decreased significantly as microwave power and ultrasound pretreatment time increased by enhancing the moisture effective diffusivity. Weibull and Distribution models gave good fit for the samples dried at different power levels ($R^2 > 0.99$). D_{eff} value was highest at 10 min ultrasound – 800 W microwave drying combination (1.13×10^{-7} m²/s) and lowest at 180 W microwave drying (2.53×10^{-9} m²/s). L* values of ultrasound treated olive slices were not significantly different compared to control sample. It was found that total phenolic compounds of ultrasound pretreated black table olive slices were higher than those which are not subjected to sonication and increasing microwave power decreased total phenolic compounds. This study reveals that ultrasound has a positive effect not only in color parameters and phenolic compounds of black table olive slice, but also it improves drying properties by increasing the drying rate.

NOMENCLATURE

a, b, k, n: Dimensionless drying constants
M: Moisture content of sample (g water/g dry matter)
M_e: Equilibrium moisture content (g water/g dry matter)
M_0: Initial moisture rate (g water/g dry matter)
M_t: Moisture content at actual t (g water/g dry matter)
MR: Dimensionless moisture ratio
D_{eff}: Effective moisture diffusivity (m^2/s)
DR: Drying rate (s^{-1})
L: half thickness of slab (m)
R^2 : Coefficient of determination
$\chi 2$: Reduced chi-square parameter
RMSE: Root mean square error
t:Time (sec)
T:Temperature (°C)
L^*: L value (CIE)
a^*: a value (CIE)
b^*: b value (CIE)
C: chroma (CIE)
H: hue angle (CIE)

REFERENCES

Aguilar-Hernández, G., García-Magaña, M.D.L., Vivar-Vera, M.D.L.A., Sáyago-Ayerdi, S.G., Sánchez-Burgos, J.A., Morales-Castro, J., Anaya-Esparza, L.M. and González, E.M. (2019) Optimization of ultrasound-assisted extraction of phenolic compounds from annona muricata byproducts and pulp. *Molecules*, **29** (904), 1–15.

Akpinar, E.K., Bicer, Y. and Yildiz, C. (2003) Thin layer drying of red pepper. J*ournal of Food Engineering*, **59**, 99–104.

Akwasi, A. (1997) Dehyration of food crops using a solar dryer with convective heat flow. *Solar Energy*. **59**, 121–126.

Aregbesola, O.A., Ogunsina, B., Sofolahan, A.E. and Chime, N.N. (2015) Mathematical modeling of thin layer drying characteristics of dika (Irvingia gabonensis) nuts and kernels. *Nigerian Food Journal*. **33**, 83–89.

Aydar, A.Y., Öncü Öner, T. and Ücok, E.F. (2017a) Effects of Hydroxytyrosol on Human Health. *EC Nutrition,* **11**, 147–157.

Aydar, A.Y., Bağdatlıoğlu, N. and Köseoğlu, O. (2017b) Effect of ultrasound on olive oil extraction and optimization of ultrasound-assisted extraction of extra virgin olive oil by response surface methodology (RSM). *Grasas y Aceites. International Journal of Fats and Oils,* **68**(2), 1-11.

Aydar, A.Y. (2018) Physicochemical Characteristics of Extra Virgin Olive Oils Obtained By Ultrasound Assisted Extraction from Different Olive Cultivars Physicochemical Characteristics of Extra Virgin Olive Oils Obtained By Ultrasound Assisted Extraction from Different. *International Journal of Scientific and Technological Research*, **4**(3), 1–10.

Aydar, A.Y, (2020) Investigation of Ultrasound Pretreatment and Microwave Power Level on Drying Kinetics of Green Olives. *Food Science and Technology,* In Press.

Bozkir, H., Ergun, A.R., Tekgul, Y. and Baysal, T. (2019) Ultrasound as pretreatment for drying garlic slices in microwave and convective dryer. *Food Science and Biotechnology*, **28,** 347–354.

Fijalkowska, A., Nowacka, M., Wiktor, A. and Witrowa-Rajchert, D. (2016) Ultrasound as a pretreatment method to improve drying kinetics and sensory properties of dried apple. *Journal of Food Process Engineering*, **39**, 256-265.

Horuz, E., Jaafar, H. J. and Maskan, M. (2017) Ultrasonication as pretreatment for drying of tomato slices in a hot air – microwave hybrid oven. *Drying Technology*. **35**, 849–859.

İçier, F., Baysal, T., Taştan, Ö. and Özkan, G. (2015) Microwave Drying of Black Olive Slices: Effects on Total Phenolic Contents and Colour. *Gida/the Journal of Food*, **39**, 323–330.

International Olive Oil Council and Council (2019) *World Table Olive Consumption Statistics*.

Izli, N., Taskin, O. and Izli, G. (2019) Drying of lime slices by microwave and microwave combined convective methods. *Ital. J. Food Sci*., **31**, 487–500.

Kailis, S.G. (2016) Olives. *Encyclopedia of Applied Plant Sciences*, **3**, 236–245.

Lewicki, P.P. (1998) Effect of pre-drying treatment, drying and rehydration on plant tissue properties: A review. *International Journal of Food Properties*, **1**, -1–22.

Lianfu, Z. and Zelong, L. (2008) Optimization and comparison of ultrasound/microwave assisted extraction (UMAE) and ultrasonic assisted extraction (UAE) of lycopene from tomatoes. U*ltrasonics sonochemistry*, **15**, 731–737.

Mahdhaoui, B., Mechlouch, R.F., Mahjoubi, A. and Ben Brahim, A. (2014) Microwave drying kinetics of olive fruit (Olea europeae L.). I*nternational Food Research Journal*, **21**, 67–72.

Midilli, A., Kucuk, H. and Yapar, Z. (2002) A new model for single-layer drying' *Drying Technology*, **20**, 1503–1513.

Rodrigues, S. and Fernandes, F.A.N. (2007) Use of ultrasound as pretreatment for dehydration of melons, .*Drying Technology*. **25**, 1791–1796.

Seidi, M., Niakousari, M. and Jamal, M. (2016) Ultrasound pretreatment impact on Prangos ferulacea Lindl and Satureja macrosiphonia Bornm. Essential oil extraction and comparing their physicochemical and biological properties. *Industrial Crops & Products*, **87**, 105–115.

Simal, S., Femenia, A., Garau, M.C. and Rosselló, C. (2005) Use of exponential, Page's and diffusional models to simulate the drying kinetics of kiwi fruit. *Journal of Food Engineering*, **66**, 323–328.

Sun, D.-W. (2014) *Emerging technologies for food processing*. Second Ed., Elsevier Inc., Dublin.

Wang, Z., Sun, J., Liao, X., Chen, F., Zhao, G., Wu, J. and Hu, X. (2007) Mathematical modeling on hot air drying of thin layer apple pomace. *Food Research International*. **40**, 39–46.

Wang, J., Xiao, H.W., Ye, J.H., Wang, J. and Raghavan, V. (2019) Ultrasound Pretreatment to Enhance Drying Kinetics of Kiwifruit (Actinidia deliciosa) Slices: Pros and Cons. *Food and Bioprocess Technology.* **21**, 865–876.

Yağcıoğlu, A., Demir, V. and Günhan, T. (2014) Effective Moisture Diffusivity Estimation from Drying Data. *Tarım Makinaları Bilimi Dergisi*, **3**, 249–256.

Yildiz, G. and İzli, G. (2019) Influence of microwave and microwave-convective drying on the drying kinetics and quality characteristics of pomelo. *Journal of Food Processing and Preservation*, **43**, 1–11.

Zhang, Z., Liu, Z., Liu, C., Li, D. and Jiang, N. (2016) Effects of ultrasound pretreatment on drying kinetics and quality parameters of button mushroom slices. *Drying Technology,* **15**, 1791–1800.

Received November 10, 2019
Sent to Subject Editor March 5, 2020
Accepted June 11, 2020
Recommended by Subject Editor Gianfranco Caruso