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Research Article/Araştırma Makalesi

Rehydration and drying kinetics of ultrasound pretreated microwave dried olive slices using peleg's model

Ultrason önişlemi uygulanmış mikrodalgada kurutulan zeytin dilimlerinin peleg modeli kullanılarak kuruma ve rehidrasyon kinetikleri

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ABSTRACT

The objective of present research was to determine the ultrasound and microwave mechanisms involved in the improvement of the drying and rehydration of black and green olive slices. Aydın Kaba variety of olive slices in 5 mm diameter were pretreated for 15 min sonication using an ultrasonic bath (32±5 kHz, 420 W). The microwave drying was conducted at 3 different power level for each sample (180, 450 and 800 W). The Peleg model was used to investigate the drying and rehydration kinetics of olive slice samples. The color properties (L*, a*, b*, C and H°) of olive slices were also evaluated in microwave dried samples. The L values of olives increased from 45.36 to 50.05 and from 38.69 to 39.80 for green olive slices and black olive slices, respectively after microwave drying at 180 W and 800 W. An increase was observed for a* and b* values from 0.71 to 0.99 and from 4.37 to 5.11 in black olive slices. While the K_1 constant decreased with the increase in microwave power in both type olives in drying process, the K_2 constants in the drying of black olive slices and green olive slices increased from 0.56855 to 0.84379 and from 0.68680 to 0.77682, respectively. It was concluded that ultrasound pretreatment improves the both rehydration process and quality parameters of olive slices.

Key Words: Ultrasound, Microwave, Drying, Olive, Rehydration model

ÖZ

Mevcut araştırmanın amacı, siyah ve yeşil zeytin dilimlerinin kurutulması ve rehidrasyonunun iyileştirilmesinde ultrason ve mikrodalga mekanizmalarını belirlemektir. Aydın Kaba çeşidi zeytin dilimleri ultrasonik bir banyo (32 ± 5 kHz, 420 W) kullanılarak 15 dakika sonikasyon ön işlemine tabi tutulmuştur. Mikrodalgada kurutma her numune için (180, 450 ve 800 W) 3 farklı güç seviyesinde gerçekleştirilmiştir. Zeytin dilimi numunelerinin kurutma ve rehidrasyon kinetiklerini incelemek için Peleg modeli kullanılmıştır. Zeytin dilimlerinin renk özellikleri de (L*, a*, b*, C ve H°) mikrodalgada kurutulmuş numunelerde değerlendirilmiştir. 180 W ve 800 W' da mikrodalgada kurutulmalarının ardından zeytinlerin L değerleri, yeşil zeytin dilimleri ve siyah zeytin dilimleri için sırasıyla 45.36'dan 50.05'e ve 38.69'dan 39.80'e yükselmiştir. Siyah zeytin dilimlerinin a* ve b* değerlerinde sırasıyla 0.71'den 0.99'a. ve 4.37 ila 5.11'a yükselmiştir. Kurutma işleminde her iki tip zeytinde de mikrodalga gücünün artması ile K_1 sabiti düşerken, siyah zeytin dilimleri ve yeşil zeytin dilimlerinin K_2 sabitleri sırasıyla 0.56855'ten 0.84379'a ve 0.68680'den 0.77682'ye yükselmiştir. Ultrason ön işleminin zeytin dilimlerinin hem rehidrasyon yeteneğini hem de kalite parametrelerini iyileştirdiği sonucuna varılmıştır.

Anahtar Kelimeler: Ultrason, Mikrodalga, Kurutma, Zeytin, Rehidrasyon modeli

Introduction

Olives, which can be processed as table olives or olive oil in Mediterranean countries, is also one of the products consumed for thousands of years. According to 2018 report of International Olive Oil Council, table olive consumption has been increased from 2754.5 thousand tons to 2978 thousand tons in worldwide and from 85 thousand tons to 160 thousand tons in Turkey in last decade (International Olive Oil Council, 2018). Due to high phenolic properties of olives different processed olives such as dried olives are used on pizza, salads, appetizers and snacks (İçier et al., 2015).

Drying is an old and commonly applied process used in the food industry to produce food products with a longer shelf life. It also has benefits such as lower transport and storage costs, and longer food consumption. The quality of final product can be deteriorated mostly by conventional drying methods such as vitamin and mineral degradation and/or undesirable food color and taste (Kaymak-Ertekin, 2002). The external an internal resistance are responsible for water movements between air and solid surface and water movement inside food, respectively. These two types of resistance control the moisture transfer in drying process. While the internal resistance is a feature of the food, the external resistance based on the thickness of the diffusion boundary layer (Ricce et al., 2016). Thus, different drying methods including microwave, vacuum, electric pulses and pretreatments such as sulphiting, blanching and ultrasound are applied to change drying characteristics of foods to increase mass transfer which is prevailed by internal and external water resistances during drying process (Belgacem Mahdhaoui, 2014; Rodrigues-Fernandes, 2007; Wiktor et al., 2016; Yildiz and İzli, 2019).

The ultrasound an emerging technology is used mostly to improve mass transfer processes including extraction and drying (Aydar et al., 2017; Jerman et al.,2010; Kadam et al., 2015). When ultrasound is applied to a medium, both external and internal resistances are influenced and this causes to mass transfer to accelerate. It also causes to structural changes on food and micro agitation in solid-liquid interfaces by mechanical waves which decrease the extremal resistance and increase the mass transfer in liquid (Xu et al., 2014). Ultrasound pretreatment has been recently used in drying of many fruit and vegetables such as tomato (Horuz et al., 2017), garlic (Bozkir et al., 2018), melon (Rodrigues-Fernandes, 2007), apple (Fijalkowska et al., 2015), kiwi (Wang et al., 2019), mulberry (Tao et al., 2016), orange peel (Garcia-perez et al., 2012), onion (Karaaslan et al., 2016) and mushroom (Zhang et al., 2016). However there are limited numbers of studies investigates the combine effect of microwave and ultrasound technologies during drying of foods. Recently, an ultrasound pretreatment time of up to 10 minutes has been investigated in drying olives (Aydar, 2021), but the effect of higher ultrasound treatment time in an ultrasonic bath with lower concentration has not been studied in previous studies. Peleg's model was also successfully applied to describe rehydration/hydration behavior of foods including carrot (Planinic et al.,2005), cowpea (Yildirim and Atasoy, 2017) and chickpea (Yildirim et al., 2010). Thus, the purpose of the study was to determine the drying and rehydration kinetics and change in color parameters of 15 minutes ultrasound pretreated green and black olive slices using Peleg's model.

Material and Method

Raw material

Olives (*Olea europea* cv. Aydın Kaba) were obtained from a local olive company (Aydar Food Company, Akhisar, Manisa) and processed at the same day. The olives used in this study were approximately 22 mm± 2 mm wide and 31.20 mm±3 mm lengths. The seeds of olives were removed by pitting machine, and then they were cut in slices of 5 mm thickness (TM02 Model Tutkun Machine, İzmir).

Ultrasound pretreatment

The olive slices (15 g/replicate) were put in 250 mL beaker and 135 mL of distilled water added (1:9, olive slices: water), and then the beaker placed into an ultrasonic bath (Alex, Turkey, 4L, frequency of 35 kHz, power 420 W). The green and black olive slices were sonicated for 15 min. The process temperature during ultrasound did not reach to 25±1 °C. After the pretreatment was completed, the samples were dried with paper towel to remove excess water on surface. All treatments were conducted in triplicate.

Microwave drying

Drying was performed at 180, 450 and 800 W power levels in a microwave (GE83X, Samsung, Turkey, 2450 MHz and 23 L capacity). 15 gram of olive slices (6 slices per replicate) were placed on a glass tray and microwaved. Then microwave was stopped and weight of samples was recorded in every 1 minute during drying. The weighed olives were not put back in the microwave and the heating was continued with the new olive samples (15 g) to the time when final moisture content of olive slices was reached to % 20 (wet basis). The codes of all samples were shown in Table 1.

Table 1. Codes for treatments

Treatment	Olive	Ultrasound pretreatment time (min)	Microwave Power (Watt)
G+15US+180W	Green	15	180
G+15US+450W	Green	15	450
G+15US+800W	Green	15	800
B+15US+180W	Black	15	180
B+15US+450W	Black	15	450
B+15US+800W	Black	15	800

Rehydration and mathematical modelling

Rehydration was performed at 23 ± 2 °C. The dried olive slices (6 pieces) were rehydrated by replacing in 250 mL of distilled water, and change in weight in every 15 minutes was recorded during 180 minutes of rehydration time. The rehydration kinetics of olive slices dried at different microwave power levels were investigated by Peleg's model which is calculated with the equation (1):

$$X = X_0 \pm \frac{t}{K_{1+}K_2 t} \quad (1)$$

$$X' = X / X_0 \quad (2)$$

Then the equation is simplified as equation 3:

$$X' = 1 \pm \frac{t}{K_{1+}K_2 t} \quad (3)$$

Where X_0 is initial moisture content (g water/g dry matter) and X is the moisture content at time t, t is time, K_1 is the Peleg rate constant, and K_2 is the Peleg capacity constant. When process is an absorption/adsorption ± turns '+' if the process is drying/desorption, ± turns to '-' (Planinic, Bilic, Velic, 2005). Root mean square error (RMSE), reduced chi-squared value (χ2) and coefficient of determination (R^2) were calculated to evaluate the goodness of model fitting. The equations for RMSE, χ2 and R^2 are shown below:

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

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N - z} \quad (5)$$

$$R^2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})}{\sqrt{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2 \sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}} \quad (6)$$

$MR_{exp,i,}$ is the experimental moisture ratio in test i; $MR_{pre,i,}$ is the predicted moisture ratio in test i; N is the observation number and z is the number of constants in the drying model (Sunil et al., 2017).

Color measurements

The color measurements of olive samples in control and after treatments was measured with a Konica Minolta (CR 300 Model, VA) with 5 color coordinates (L*, a*, b*, C and H°). After the calibration of colorimeter against a standard white surface and black one, three replicate measurements were performed for each sample.

Statistical analyses

SAS 9.2. (SAS Institue Inc., Cary, NC, USA) was used to evalaute 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. Coeficient of determination (R^2), χ2 (reduced chi-square parameter) and root mean square error (RMSE) were calculated to interpret the adequacy of each model. Data in tables represents means of three replicates ±standard deviation.

Results and Discussions

The effects of the microwave power on the 15 minutes ultrasound pretreated microwave drying of black and green olive slices were described, and both drying and rehydration kinetics were determined using Peleg's model. The mass transfer through the drying is not only a simple diffusional process; it is also affected by capillarity which cause a rapid moisture removal in the beginning of drying (Ricce et al., 2016). The characteristic drying curves were observed in both two types of olive slices. Moisture removal was high in first stage of drying and it slowed in later stages until reaches the equilibrium moisture as this behavior was similar in other olive drying studies (Erbay et al., 2010; İçier et al., 2015; B. Mahdhaoui et al., 2014). Ultrasound pretreatment and microwave drying increased the drying rate compared to other studies, resulting in a lower drying time. Ultrasound application before drying improved the drying rate and decreased drying time in pineapple, apple and orange peel. The drying time of ultrasound pretreated samples was 35%, 45% and 54% shorter respectively in pineapple, orange peel and apple drying (Corrêa et al., 2017; Garcia-perez et al., 2012; Rodríguez et al., 2014). Microwave drying combined with conventional drying was studied in pomelo slices, and it was found that when microwave power increased from 90W to 160 W drying rate increased and drying time reduced significantly (Yildiz and İzli, 2019).

Drying curves for black and green olive slices were shown in Figure 1 and 2. In both two olive slices drying time decreased as level of microwave power increased. In this study drying time decreased by 29.41% and 33.17% when microwave power increased from 180 W to 800 W, respectively for black and green olives. Drying time at power of 800 W was significantly lower than drying time which is conducted at 180 W ($p \leq 0.05$). Similar to drying, a rapid moisture absorption in the first stage of rehydration results from a capillary absorption process (Lewicki, 1998). Microwave power level shortened the rehydration time of samples can be shown in Figure 3. It was reported that increasing microwave power up to 800 W in 5 and 10 minutes ultrasound pretreated olive samples caused lower rehydration capacity of dried samples (Aydar, 2021). This might be ascribed to the fact that higher microwave power levels enhances the molecular diffusion rate due to increase of temperature. This could also be related to higher microwave power levels result in larger spaces and tunnels in the tissue. It was observed that there was no significant difference between black and green olive slices in terms of rehydration ratio.

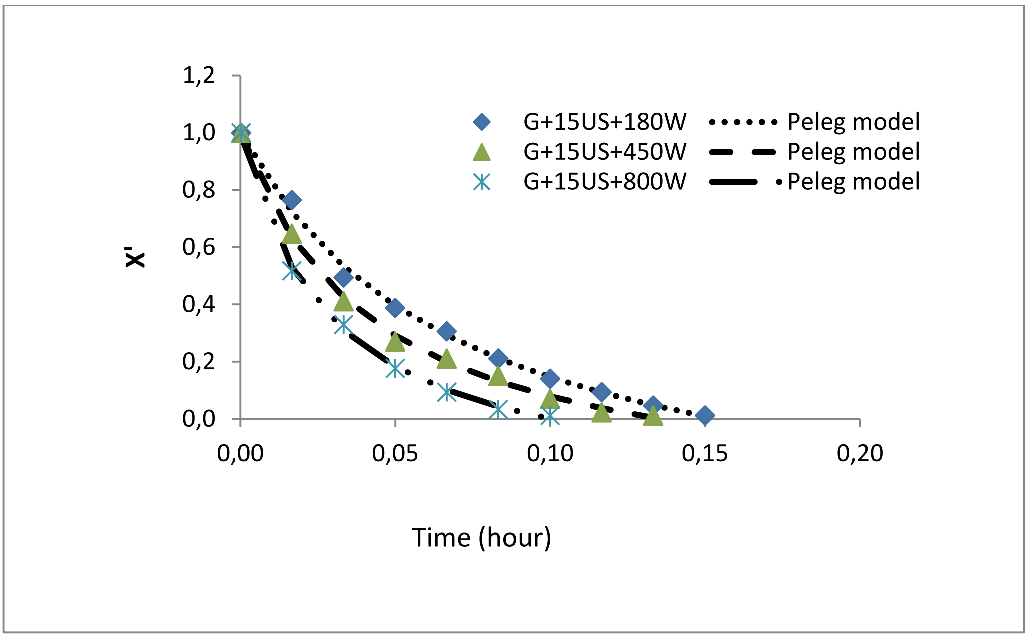

Figure 1. Drying curves for green olive slices

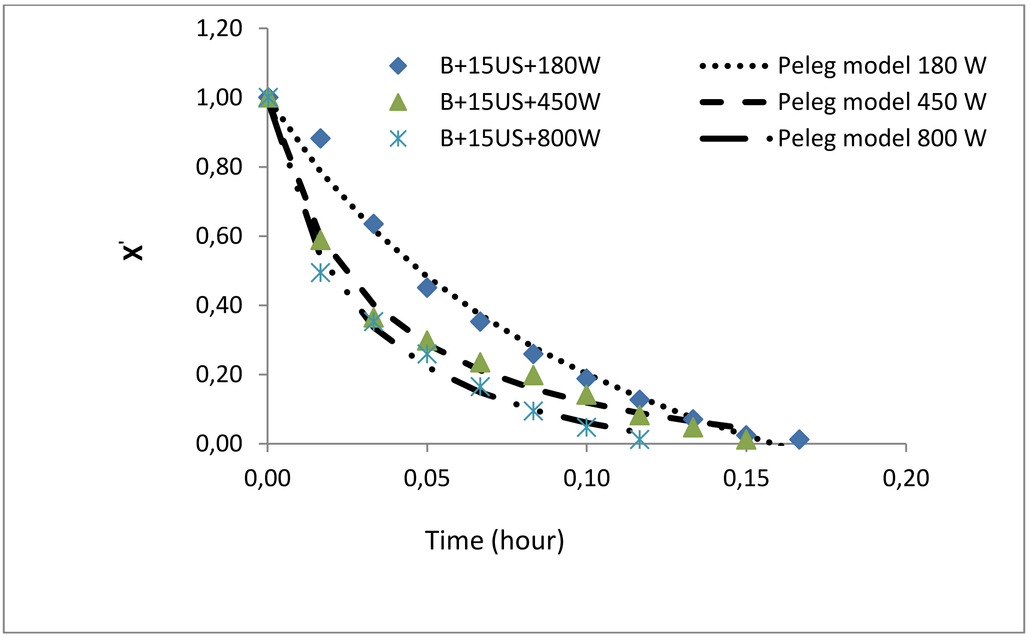

Figure 2. Drying curves for black olive slices

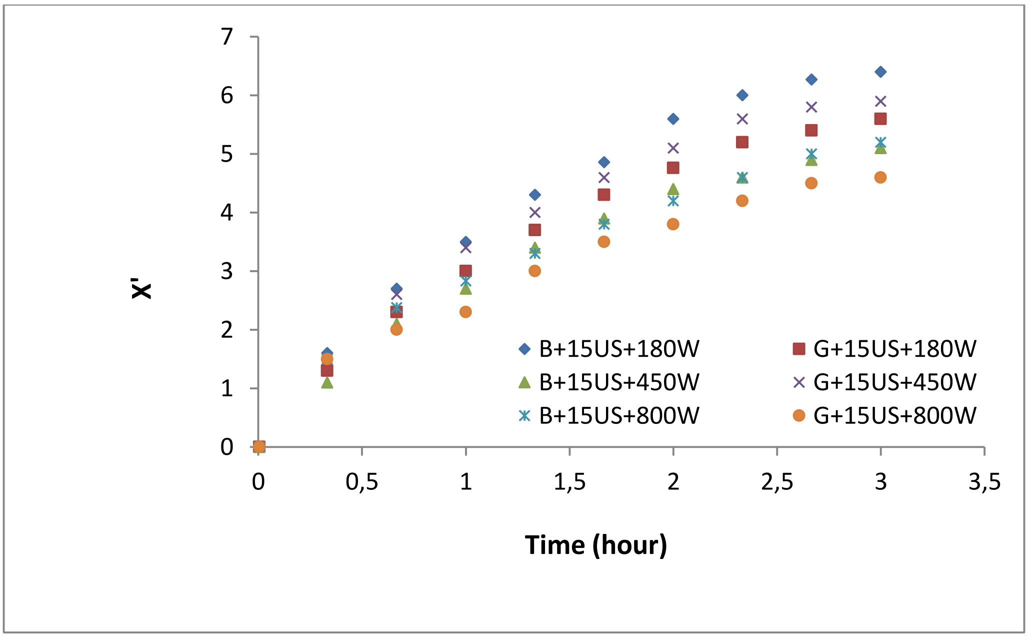

Figure 3. Rehydration curves for black and green olive slices

Table 2. Peleg's model constants and statistical values for model

Treatment	Drying					Rehydration				
	K_1	K_2	χ2	R^2	RMSE	K_1	K_2	χ2	R^2	RMSE
G+15US+180W	0.048389	0.68680	0.000445	0.9979	0.00711	0.272758	0.162209	0.007278	0.9981	0.02697
G+15US+450W	0.032514	0.76002	0.000253	0.9990	0.00562	0.332261	0.183078	0.008349	0.9971	0.02889
G+15US+800W	0.022348	0.77682	0.000165	0.9994	0.00485	0.384711	0.197106	0.012780	0.9946	0.03574
B+15US+180W	0.068265	0.56855	0.001431	0.9951	0.01196	0.270865	0.142069	0.008055	0.9951	0.02838
B+15US+450W	0.026778	0.86761	0.000689	0.9966	0.00992	0.348696	0.146469	0.006192	0.9984	0.02488
B+15US+800W	0.022025	0.84379	0.000665	0.9968	0.01052	0.360499	0.173200	0.003361	0.9989	0.01388

The results of the nonlinear regression analysis both for drying and rehydration were summarized in Table 2. The determination coefficients were very high in two processes. The R^2 differed from 0.9951 to 0.9990 for drying and from 0.9946 to 0.9989 for rehydration. RMSE values were lower than 0.01196 for drying and lower than 0.03574 for rehydration and χ2 values were also lower than 0.001431 for drying and lower than 0.012780 for rehydration.

Peleg's model gave a good prediction in drying process than rehydration with its higher R^2 and lower RMSE and χ2 values. Planinic et al.,(2005) used Peleg's model to determine the drying and rehydration characteristics of carrot slices and they used RMSD and R^2 to evaluate the goodness of model. They also found that Peleg's model well fit with drying and rehydration curves (Planinic et al., 2005).

K_1 values decreased with the increase of the microwave power in both type olives. Lower K_1 values imply a higher drying rate and shorter drying times. K_1 values of green olives were decreased by power level increased in drying, while they increased as power level increased in rehydration process. This pattern was similar in rehydration but it was different in drying. K_2 values of B+15US+800W sample was higher than sample of B+15US+450W. K_2 value, which is related to the equilibrium moisture content, were not affected by microwave power level significantly in black olive slices, while it increased in both drying and rehydration process in green olive slices. The K_2 value increased from 0.56855 to 0.84379 and from 0.68680 to 0.77682 in drying of black olive slices and green olive slices, respectively. Peleg's rehydration constants (K_1 and K_2) decreased with the decrease of the microwave power level in green and black olives which referred an increase rehydration rate with the increase in microwave power in olives.

Table 3. Color parameters of green olive slices during drying

Treatment	L*	a*	b*	C	H°
G+15US+180W	45.36±0.95[a]	0.48±0.03[b]	13.45±0.69[a]	14.22±1.68[a]	88.00±0.20[a]
G+15US+450W	45.45±4.12[a]	1.01±0.03[ab]	9.94±0.92[a]	12.72±1.51[a]	84.73±0.15[b]
G+15US+800W	50.05±1.32[a]	1.09±0.40[a]	12.40±3.69[a]	12.89±1.83[a]	85.00±0.72[b]

Values are the means of the three four different olive sample measurements(n=3) ± standard deviations.
Significant differences in the same column are shown by different letters (p≤0.05).

Table 4. Color parameters of black olive slices during drying

Treatment	L*	a*	b*	C	H°
B+15US+180W	38.69±0.11[a]	0.71±0.04[b]	4.37±0.01[b]	4.46±0.06[b]	81.30±0.14[a]
B+15US+450W	39.46±0.20[a]	0.86±0.01[a]	5.32±0.01[a]	5.41±0.01[a]	80.90±0.17[a]
B+15US+800W	39.80±1.22[a]	0.99±0.04[a]	5.11±0.13[a]	5.20±0.13[a]	79.20±0.15[b]

Values are the means of the three different olive sample measurements (n=3) ± standard deviations.
Significant differences in the same column are shown by different letters (p≤0.05).

Color is one of the most significant characteristic of table olive products which define their quality and also plays a vital role in selection of olive by consumers. The color values of green and black olives during drying treatments were listed in Table 3 and Table 4. The lowest value of L* (lightness) within the dried olives was attained samples dried lowest microwave level and highest value of L* values were observed at dried in 800 W. a* and b* values were also increased as power increased and this tendency was observed in the study of apples pretreated with ultrasound at frequency of 21 kHz and 35 kHz (Fijalkowska et al., 2015). a*(redness-greenness) values of olive slices dried at 800 W power level were significantly higher than those dried at 180 W power level (p≤0.05). Signficant difference in H° value between samples dried at 180 W and 800 W was also observed in both green and black olives (p≤0.05). b* (yellowness-blueness) values of olive samples were not affected by power level in green olive slices, in the other hands b* value of black olives dried at 180 W was significantly lower than those dried at 450 W and 800 W. While C values of green olive slices were between 12.72-14.22, they were 4.46-5.41 for black olive samples. Total color difference was observed lowest in 30 minutes ultrasound pretreated kiwifruits and it is concluded that US pretreatment could prevent browning reaction by inactivation of polyphenoloxidase (Wang et al., 2019).

Conclusions

The Peleg's model gave a reasonable prediction of moisture removal and uptake in all treatments (R^2>0.994). The trend of drying and rehydration K_1 constants with the microwave power was different. Peleg's rate constant (K_1) was influenced mostly by level of microwave power during the drying process. K_1 values decreased with the increase of the microwave power. Rehydration constants (K_1 and K_2 values) increased as microwave power increased. It was concluded that the different power level applied to black and green olive slices showed different dehydration/rehydration behavior. Microwave power increased the drying rate but decreased the rehydration rate of both olives. It can be concluded microwave can be applied in drying olives in mild conditions for a better drying and rehydration process.

Conflict of Interest: The authors declare that they have no conflict of interest.

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