INFLUENCE OF ULTRASOUND PRE-TREATMENT AND CONVECTIVE DRYING ON THE QUALITY PARAMETERS OF CARROTS (*Daucus carota* L.)

A. POLAT, N. IZLI and O. TASKIN

† *Department of Biosystems Engineering, Faculty of Agriculture, University of Uludag, Gorukle Campus, 16059, Bursa, Turkey.*
ahmetpolat@uludag.edu.tr, nazmiizli@gmail.com, onurtaskin@uludag.edu.tr

***Abstract*— In this study, carrot samples with different slice thicknesses (2 and 4 mm) were dried by applying ultrasound pre-treatment at different time periods (0, 20 and 40 min) and the changes in colour, rehydration, pH and °Brix values were evaluated. Besides, microstructures of dried samples under different conditions were observed through scanning electron microscopy images. Drying was carried out in a modified oven at temperatures of 60 and 70 °C with an air velocity of 1 m/s. When compared to fresh potatoes, a decrease in yellowing values (*b**) was observed for the different drying conditions employed. Carrots samples with a thickness of 2 mm, dried at 60 °C and treated with ultrasound for 40 min, presented the highest rehydration ratio (6.930). It was observed that pH and °Brix values changed from 6.705 to 6.120 and from 68.70 to 6.80, respectively. It was observed that the longer the duration of pre-treatment with ultra-sound, the greater the change in the structure of the product. The results showed that the pre-treatment by ultrasound can be used as an alternative method for drying carrot sample.**

***Keywords*— Rehydration, colour, microstructure, ultrasound technology.**

I. INTRODUCTION

Food drying can be defined as a preservation method that reduces the moisture content and water activity, inhibiting the growth of microorganisms and the development of enzymatic and other reactions (Doymaz, 2017). Convective drying is one of the most used drying methods in the industry. The conventional method of convective drying consists of a heater to generate hot air and a protected fan to distribute the hot air. Simple structure and easy control are essential advantages of the convective drying method. However, there are some disadvantages associated with this technique, such as low processing rate, significant losses in product quality, and high energy consumption due to the use of high temperatures. The use of lower drying temperatures can reduce energy consumption and improve the quality of the dry product, but it increases processing time, causing an increase in drying costs (Oliveira *et al*., 2016). Thus, pre-treatment of samples has become an alternative to reduce processing time and costs. Many studies on pre-treatment have been reported in the literature. According to Deng *et al.* (2019), such studies can be divided into two groups: physical pre-treatment and chemical pre-treatment. Physical ultrasound pre-treatment was used in this study. During this application, pressure changes have occurred in the form of contraction and relaxation of the product. This effect is called the sponge effect. Due to the effect of contractions, the microchannel is formed in the product tissues and then these microchannel help discharging of water in the structure. With the accelerated drying process, the samples are exposed to heat for less time and thus, the characteristics and quality of the sample are preserved (Yang *et al.*, 2018). In recent years, the effect of ultrasound pre-treatment on the drying of different agricultural samples such as banana, papaya, melon, apple, barley grass has been investigated by researchers (Azoubel *et al.*, 2010; Azoubel *et al.*, 2015; Da Silva *et al.*, 2016; Fijalkowska *et al.*, 2016; Cao *et al.*, 2018). Ricce *et al.* (2016) studied the mechanisms that play a role in improving the drying and rehydration properties of carrot slices pre-treated using ultrasound technology. In our study, in addition to the determination of the rehydration properties of the ultrasound technology, colour, pH, °Brix, and microstructure factors were also examined.

Carrot (*Daucus carota* L.), one of the most important root vegetables, is cultivated all over the world. According to the Food and Agriculture Organization data, 42.831.958 tons of carrot were produced worldwide in 2017. China is the largest producer country with 20.274.393 tons (FAO, 2019). Carrot is considered a functional food rich in nutrients and important compounds for human health, such as β-carotene, ascorbic acid and tocopherol. It has a significant amount of carotenoid, which is a beneficial antioxidants that can enhance immune system and prevent cardiovascular diseases, muscle diseases, and cataract (Sharma *et al.*, 2012).

This study evaluated quality parameters (color, rehydration, pH and °Brix) obtained during convective drying of carrot slices with different thicknesses, pre-treated with ultrasound. Also, the variation of cell structures in dried samples was examined with the help of scanning electron microscopy (SEM) images.

II. METHODS

A. Sample Preparation

Carrot samples used in the experiments were taken from a local market in Bursa province and stored at a temperature condition of 4 ± 0.5 °C until the experimental trials were completed. The samples were removed from the cooler and allowed to warm at room temperature. The moisture content of carrot samples was 8.75 (g water / g dry matter) on a dry basis (d.b.), determined by drying in an oven at 70 °C for 24 hours. For the drying process,

https://doi.org/10.52292/j.laar.2022.825

mature and undamaged samples were selected. The selected samples were peeled and prepared at the thickness of 2 and 4 mm slices with the help of slicer (Börner, Germany). The drying processes and experiments were carried out in triplicate.

B. Convective Drying

The samples to be dried were placed on a 400 mm diameter glass plate as a thin layer. Drying was carried out in a modified oven (Whirlpool AMW 545) with a sensitivity of 0.1 °C, which can be controlled by a programmable logic controller (PLC) display. The samples were dried at 60 and 70 °C with an air velocity of 1 m/s. The oven was heated for 30 minutes to the level set before drying. The decrease in the moisture content of the samples until reaching the equilibrium moisture content was monitored with the aid of 0.01g precision balance which was placed under the oven.

C. Ultrasonic Pre-treatment Application

Ultrasound pre-treatment was per-formed with a frequency of 25 kHz in a 300 W ultrasonic bath at room temperature. The carrot slices were placed in a metal basket and then placed in an ultrasonic bath filled with distilled water. A 1:4 ratio of sliced carrot-distilled water was used in the ultrasonic bath. The samples, which were not pre-treated with ultrasound were kept in the same amount of distilled water. Ultrasound pre-treatment was applied to the samples at times 0 (control), 20 and 40 minutes. After ultrasonic pre-treatment, samples were filtered and the water was removed with filter paper (Horuz *et al.,* 2017).

D. Changes of Colour Parameters

The colour changes of fresh and dried carrot samples were determined by using a colorimeter (HunterLab, USA). A colour system was used in which L^*, a^* and b^* represented chromatic components of lightness, green/ red and blue/yellow, respectively. The colour parameters for fresh carrot samples were defined as L_0^*, a_0^* and b_0^*. During the experiments, the colorimeter was calibrated via a standard white and black plate prior to each colour measurement. Prior to each use, a glass cell carrying a sample close to the nose cone of the colorimeter was placed on the light source, and then the L_0^*, a_0^*, b_0^*, L^*, a^* and b^* values were recorded. The colour reading process was done in five repetitions. Using the colour parameters obtained, Chroma value (C), and hue angle (α), total colour differences (ΔE) values were calculated by using the Eqs. (1), (2) and (3) (Tian *et al.*, 2016; Zhao *et al.*, 2017).

$$C = \sqrt{(a^2 + b^2)} \quad (1)$$

$$\alpha = \tan^{-1}(b/a) \quad (2)$$

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (3)$$

E. Calculation of Rehydration Ratio

So as to determine the rehydration values, dried carrot slices (10 ± 0.1 g) were placed in a 400 ml beaker containing distilled water at 20 °C for 14 hours. The solid/liquid ratio was adjusted to 1:50 (Vega-Gálvez *et al.*, 2009). The carrot slices were then removed, emptied for 30 seconds, and weighed using an electronic digital balance (Shimadzu, Japan) with an accuracy of ± 0.001 g. This procedure was repeated in triplicate for each run. Finally, the rehydration rate (R) was calculated by using the Eq. (4) (Sunjka *et al*., 2008):

$$R = \frac{M_2 - M_1}{M_1} \quad (4)$$

where $\boldsymbol{M_1}$ and $\boldsymbol{M_2}$ represent sample weights before and after rehydration, respectively.

F. Measurement of pH Values

The pH values of fresh and dried carrot samples were measured using a pH meter (Jenco, USA). The dried samples were soaked in distilled water. The pH meter probe was then immersed in the solution, and the measurement was performed. The pH of fresh samples was measured in the juice extracted from the pulped carrots and filtered with filter paper (Mechlouch *et al.*, 2012).

G. Determination of Water-soluble Dry Matter

Brix values of fresh and dried carrot samples were determined using a digital refractometer (Milwaukee, Romania). The dried carrot samples were soaked in distilled water. Then, the samples were filtered with the help of a multi-layer filter paper. °Brix values of fresh carrot samples were determined after removing the juice of the samples and filtering with the multi-layer filter paper (Meclouch *et al.,* 2012).

H. SEM Analyses

SEM was used to observe the changes in microstructures of carrot samples dried under different conditions. The samples were cut from the center as cross-section and placed into the sample holders. For SEM analyses, samples were coated with a 40-50 nm thick gold-palladium and examined with a SEM device (EVO 40, Carl Zeiss, Oberkochen, Germany) at 20 kV accelerating voltage. Micrographs of samples were taken by using the device (Tian *et al.*, 2015).

I. Statistical Analysis

MS-Excel program was used to process the data collected from different drying conditions. Furthermore, in the statistical analysis of the collected data, a LSD (least significant difference) with analysis of variance (ANOVA) at 95% confidence level ($P < 0.05$), using JMP (Version 7, USA) software, was performed.

III. RESULTS

A. Colour Changes

The colour parameter plays a vital role in the consumer choice of food samples. Homogeneous colour distribution on the product indicates the quality of the product and has significant effects on consumer acceptance (Ozturk *et al.,* 2015). Colour values of fresh and dried carrot samples are demonstrated in Table 1. The value in the parentheses of the results in Table 1 is the standard deviation of the mean value obtained for each color parameter. It was seen from the results that L^* values of carrot samples ranged between 47.796 and 58.110. The lowest L^* value was found in untreated 4 mm thick samples, which were dried at 70 °C (70°C-4mm-US0). The increase in drying temperature and sample thickness de-

Table 1. Colour values of fresh and dried carrots at different drying conditions.

Drying conditions	Colour parameters					
	$L*$	$a*$	$b*$	C	$\alpha°$	ΔE
Fresh	58.110(1.186)^{a}	34.152 (0.454)^{a}	43.686(0.134)^{a}	55.452(0.221)^{a}	52.011(0.433)^{a}	-
US0						
60°C-2mm	53.128(0.696)^{cd}	32.294(0.201)^{cd}	31.976(0.280)^{e}	45.446(0.339)^{c}	44.739(0.078)^{f}	40.237(0.163)^{bc}
60°C-4mm	50.572(1.242)^{ef}	31.086(0.459)^{e}	32.544(0.646)^{de}	45.005(0.784)^{c}	46.334(0.151)^{d}	40.061(0.337)^{cd}
70°C-2mm	50.116(1.164)^{f}	27.634(0.266)^{g}	27.602(0.294)^{h}	39.058(0.395)^{f}	44.989(0.048)^{f}	39.216(0.457)^{ef}
70°C-4mm	47.796(0.561)^{g}	30.756(0.136)^{e}	33.606(0.114)^{b}	45.555(0.174)^{c}	47.560(0.042)^{b}	40.758(0.194)^{b}
US20						
60°C-2mm	57.280(0.323)^{ab}	33.210(0.147)^{b}	32.896(0.560)^{cd}	46.746(0.338)^{b}	44.747(0.579)^{f}	39.456(0.250)^{de}
60°C-4mm	51.896(0.334)^{de}	29.146(0.151)^{f}	32.084(0.176)^{e}	43.346(0.228)^{d}	47.771(0.055)^{b}	37.969(0.072)^{h}
70°C-2mm	53.112(0.862)^{cd}	27.414(0.307)^{g}	29.476(0.359)^{g}	40.254(0.471)^{e}	47.099(0.043)^{c}	36.975(0.251)^{i}
70°C-4mm	50.900(1.533)^{ef}	32.942(0.699)^{bc}	31.168(0.748)^{f}	45.350(1.022)^{c}	43.436(0.083)^{g}	41.940(0.259)^{a}
US40						
60°C-2mm	55.954(0.777)^{b}	31.934(0.316)^{d}	32.602(0.357)^{de}	45.636(0.473)^{c}	45.616(0.071)^{e}	38.771(0.110)^{fg}
60°C-4mm	50.962(0.648)^{ef}	30.874(0.178)^{e}	33.252(0.324)^{bc}	45.375(0.358)^{c}	47.147(0.117)^{c}	39.492(0.225)^{de}
70°C-2mm	53.400(1.753)^{c}	27.654(1.703)^{g}	28.992(1.080)^{g}	40.069(1.937)^{e}	46.404(0.808)^{d}	37.303(1.363)^{i}
70°C-4mm	51.554(1.455)^{e}	27.596(0.444)^{g}	28.164(0.466)^{h}	39.430(0.643)^{ef}	45.607(0.026)^{e}	38.324(0.496)^{gh}

$^{a-i}$ Means superscript with different alphabets in the same column differ significantly ($P < 0.05$).

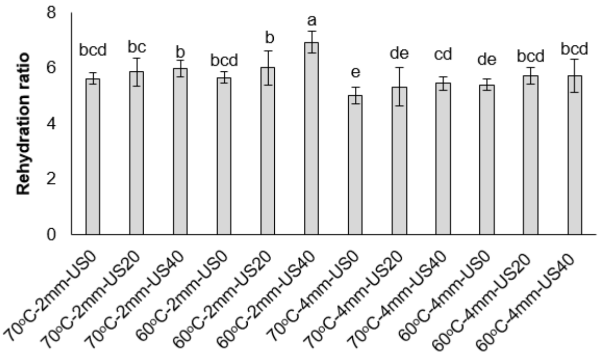

Figure 1: Rehydration rate values of dried carrots at different drying conditions

creased the L^* value. The reason for this can be explained that the products become darker at higher temperature and this is mainly as a result of browning reactions, while the longer drying time, which affects the color parameters of the carrot, can be shown due to the increase in product thickness (Purkayastha *et al*., 2013; Onwude *et al.*, 2018). The use of ultrasound pre-treatment generally increased the L^* value due to decreased product drying time and reduced contact with hot air (Ren *et al.*, 2018). When compared to the fresh product, the ultrasound and drying processes caused a decrease in the a^* values of samples. The a^* values of samples with a thickness of 2 mm dried at 70 °C did not change statistically after the application of ultrasound pre-treatment (US0, US20, and US40) ($P > 0.05$). The highest changes in the b^* value were found between fresh and dry carrots at 70°C (2 mm thick without pre-treatment and 4 mm thick and 40 min pre-treatment) ($P < 0.05$). Total colour change (ΔE), Chroma (C), Hue angle (α^0) were calculated from the values of L^*, a^* and b^*. While the highest C value, which indicates color saturation, was found for the fresh product, the lowest C value was observed in 2 mm-thick carrot samples, dried at 70°C, without pre-treatment, followed by 4 mm-thick samples, dried at 70°C after 40 min of pre-treatment. The values calculated for the hue angle (α^0) ranged from 43.436 to 52.011, while the ΔE values ranged from 36.975 to 41.940. The ΔE values in the 2 mm thick samples decreased with increasing drying temperature from 60 to 70°C, and with increasing duration of pre-treatment ($P < 0.05$). As the reason for these results, Aral and Beşe (2016) reported that increasing the drying time at low temperatures increases the deterioration due to the longer exposure time of the product to heat. In addition, Demiray and Tülek (2015) obtained different results when they studied the color degradation kinetics of carrot slices during hot air drying. They found that ΔE values increased with decreasing L^*, a^* and b^* color values of hot air-dried carrot samples.

B. Rehydration

One of the critical parameters of a product's quality is its rehydration rate (Sumnu *et al.*, 2005). Rehydration can be used as a criterion for defining the exposure of the product to the drying process (Caliskan and Dirim, 2017). Rehydration ratio values of dried carrot samples under different drying conditions are given in Fig. 1. The data showed that the lowest rehydration value (5.010) was observed in 4 mm-thick carrot samples, dried at 70°C, without pre-treatment. In addition, there was no statistically significant difference in the rehydration rate with increasing drying temperature in 2-mm-thick carrot samples not treated by ultrasound ($P > 0.05$). On the other hand, the rehydration rate of the 4 mm samples, without pretreatment, decreased when the drying temperature was increased. The results also showed that the effect of the pre-treatment (US0, US20 and US40) growth of the rate of rehydration under the following experimental conditions: thickness of 2 mm and temperature of 60 and 70°C, and thickness of 4 mm and temperature of 70°C, but it was not ($P > 0.05$) for the thickness of 4 mm and temperature of 60°C. The carrot samples with the highest rehydration values were below the moisture content of the fresh sample, showing that drying causes irreversible damage to the samples (Jambrak *et al.*, 2007)..

C. pH Value

The pH measurement was used as an indicator of the acidity of the samples. An increase in pH value means a decrease in acidity level. The pH results of fresh and

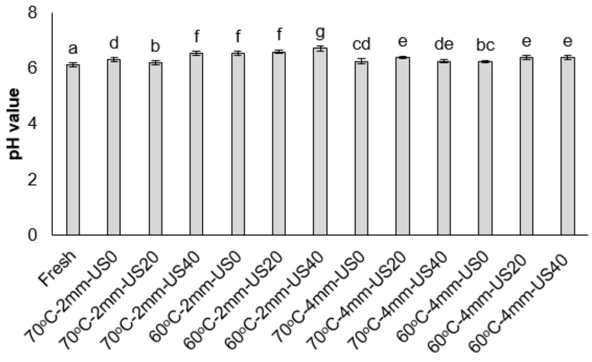

Figure 2: pH values of fresh and dried carrots at different drying conditions.

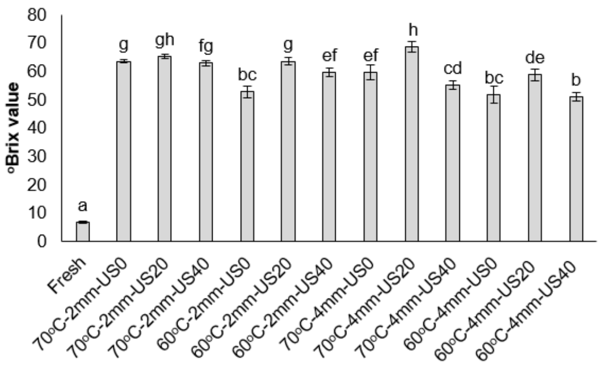

Figure 3: °Brix values of fresh and dried carrots at different drying conditions.

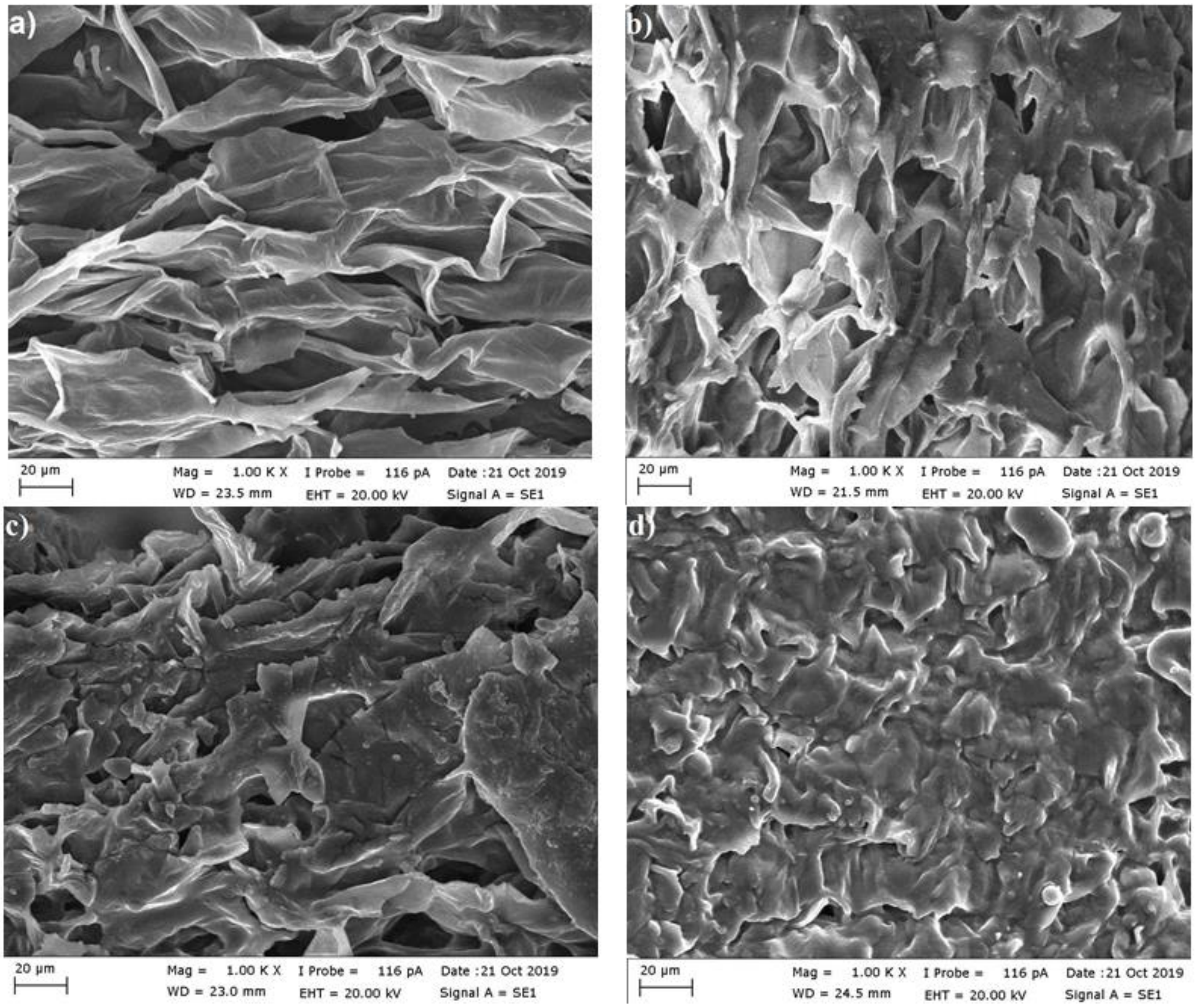

Figure 4: SEM images of dried carrots for US0: a) 60°C-2mm, b) 60°C-4mm, c) 70°C-2mm and d) 70°C-4mm.

dried carrot samples under different drying conditions are given in Fig. 2. According to the data obtained, the pH value of the fresh carrot sample was found to be 6.120. When compared to the fresh product, there were changes in the pH values ($P < 0.05$) of samples subjected to different experimental drying conditions (ultrasonic pre-treatment, temperature and slice thickness). The highest pH value (6.705) was found in 2 mm thick carrot samples, which were pre-treated for 40 minutes and dried at 60 °C (60°C-2mm-US40). The loss of acidity due to the drying process was observed in all samples. Sra *et al.* (2011) found similar results, with the pH of 4 different car-rot varieties subjected to drying ranging between 6.500 and 6.600. Vega-Gálvez *et al.* (2009) when examining the pH change caused by drying red capya pepper, reported that pH values increased after drying. Additionally, Çakmak *et al.* (2016), when studying the drying of mushroom slices at a temperature of 50°C applying pre-treatment and electroplasmolysis, found that the pH of the dried and untreated mushroom samples was lower than the pre-treated mushroom samples. Decreasing of acidity values with pre-treatment was seen. In addition, fresh mushroom samples presented a lower pH value than dried samples. As a result, they concluded that the acidity value decreased with drying. All these works presented results similar to those described here.

D. Water-soluble Dry Matter (°Brix)

Water-soluble dry matter values of fresh and dried carrot samples under different drying conditions are shown in Fig. 3. When the results were examined, the lowest value was found in fresh samples (6.8 °Brix). It was found that the increase in °Brix values occurred due to the drying process ($P < 0.05$). Considering all experimental conditions tested, the highest value obtained for °Brix (68.70) was observed in 4 mm thick carrot samples, with 20 min of pre-treatment and dried at 70°C. Brix values generally increased as the temperature increased ($P < 0.05$). This is explained as the increase in the concentration of solids with the removal of free water (Scher *et al.*, 2009). Alegria *et al.* (2009), Vargas *et al.* (2009) and Lima *et al.* (2001) found for fresh carrots samples ºBrix values of 9.70, 9.20 and 8.48, respectively. The values they obtained were higher than those obtained in this study (6.8 ºBrix). This difference may be due to product type, soil structure, growth conditions, harvest time, and genetic factors (Er and Özcan, 2010). In another study, Uslu (2015) also found that dried kumquat samples exhibited a higher °Brix value than fresh fruit samples.

E. Microstructure

The micrographs showing the changes in the cellular structure of the carrot as a result of different drying conditions are given in Figs. 4-6. Cell structures of carrot samples dried at 70 °C were found to be flatter than those dried at 60 °C under the same conditions. Thus, cell damage of carrot samples was observed to be higher in the case of the application of high temperatures. Vega-Galvez *et al.* (2012) have experienced the same results in the drying process of apples at different temperatures. It was observed that the cell structure of 2 mm thick samples, which was dried at 70 °C without ultrasound pre-treatment (70°C-2mm-US20), was more porous than the 4 mm thick samples dried at the same temperature without ultrasound pre-treatment (70°C-4mm-US0). The drying period of the samples increases as the product thickness increases. Thus, the samples are more exposed to hot air, which causes further deterioration in the product structure. After the pre-treatment with ultrasound, the appearance of microchannels in the cellular structure of the product was observed and the number of microchannels increased with the increase of the ultrasound application

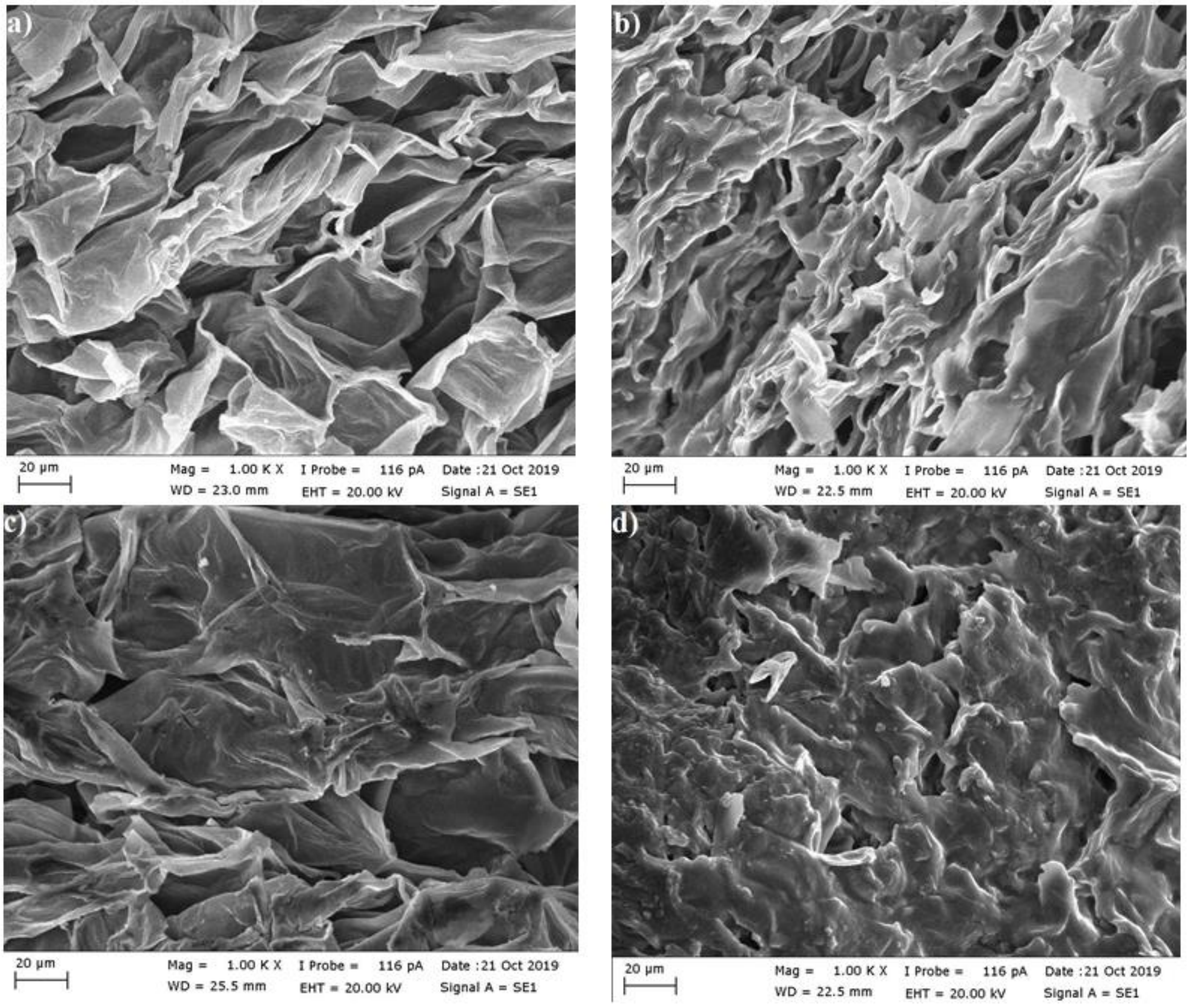

Figure 5: SEM images of dried carrots for US20: a) 60°C-2mm, b) 60°C-4mm, c) 70°C-2mm and d) 70°C-4mm.

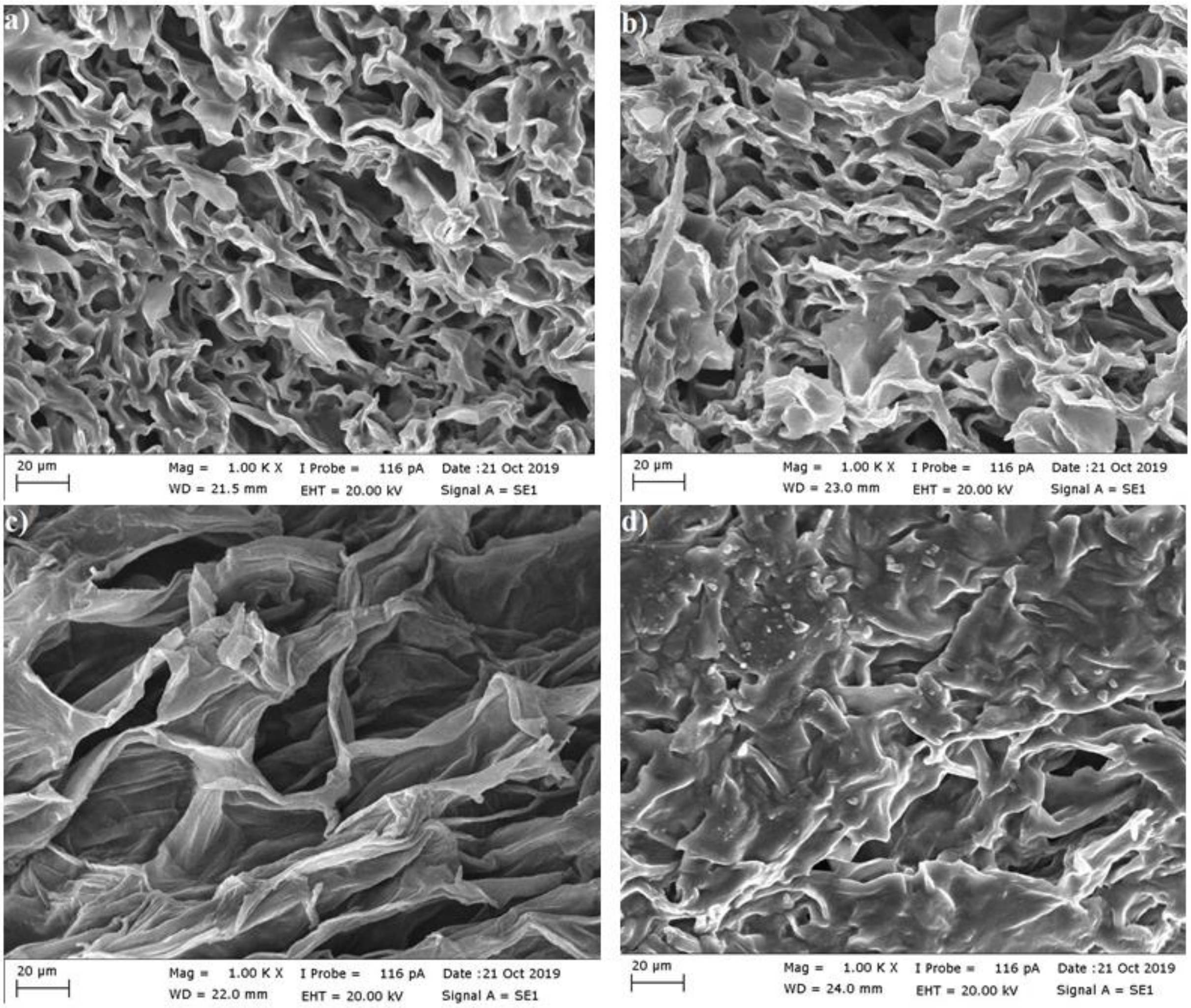

Figure 6: SEM images of dried carrots for US40: a) 60°C-2mm, b) 60°C-4mm, c) 70°C-2mm and d) 70°C-4mm

time. Fernandes *et al*. (2008), obtained similar results when studying the effect of osmotic drying and pre-treatment with ultrasound on the structure of melon.

IV. CONCLUSIONS

The influence that different slice thicknesses (2 and 4 mm) of carrot samples, pre-treated with ultrasound at times of 0, 20 and 40 min, and dried at temperatures of 60 and 70°C, had on the quality parameters was examined. The effects of drying conditions on changes in the cellular structures of the samples were investigated by SEM. The L^* values of the carrot samples dried with ultrasound pretreatment were generally higher than the samples that were not pretreated. The highest value of ΔE was obtained in the 4 mm-thick carrot samples, pre-treated with ultrasound for 20 minutes and dried at 70°C. Except for the 70°C-2 mm applications, the highest ΔE value of the carrot samples was observed in the samples without ultrasound pretreatment. Due to the effects of pre-treatment and drying, the pH and °Brix values of the dried carrot samples increased compared to the fresh samples. When the microstructures of the samples were examined, the increase in temperature and product thickness caused deterioration in the cell structure. The increase in the pre-treatment time with ultrasound caused an increase in the number of microchannels that offer less resistance to water diffusion. The results showed that ultrasound can be used as a physical pre-treatment for the carrot drying process. However, more studies need to be carried out to confirm whether the use of ultrasound allows a reduction in drying times and energy consumption required by the process.

ACKNOWLEDGEMENT

This research was financially supported by the Research Foundation of Bursa Uludag University (Project No. KUAP(Z)-2019/4).

REFERENCES

Alegria, C., Pinheiro, J., Gonçalves, E.M., Fernandes, I., Moldão, M. and Abreu, M. (2009) Quality attributes of shredded carrot (*Daucus carota* L. cv. Nantes) as affected by alternative decontamination processes to chlorine. *Innov. Food Sci. Emerg.* **10**, 61-69.

Aral, S. and Beşe, A.V. (2016). Convective drying of hawthorn fruit (*Crataegus spp*.): Effect of experimental parameters on drying kinetics, color, shrinkage, and rehydration capacity. *Food Chem*. **210**, 577-584.

Azoubel, P.M., Baima, M.D.A.M., da Rocha Amorim, M. and Oliveira, S.S.B. (2010) Effect of ultrasound on banana cv Pacovan drying kinetics. *J. Food Eng.* **97**, 194-198.

Azoubel, P.M., da Rocha Amorim, M., Oliveira, S.S.B., Maciel, M.I.S. and Rodrigues, J.D. (2015) Improvement of water transport and carotenoid retention during drying of papaya by applying ultrasonic osmotic pretreatment. *Food Eng. Rev.* **7**, 185-192.

Çakmak, R.Ş., Tekeoğlu, O., Bozkır, H., Ergün, A.R. and Baysal, T. (2016) Effects of electrical and sonication pretreatments on the drying rate and quality of mushrooms. *LWT - Food Sci. Technol.* **69**, 197-202.

Caliskan, G. and Dirim, S.N. (2017) Drying characteristics of pumpkin (*Cucurbita moschata*) slices in convective and freeze dryer. *Heat Mass Transfer.* **53**, 2129-2141.

Cao, X., Zhang, M., Mujumdar, A.S., Zhong, Q. and Wang, Z. (2018) Effects of ultrasonic pretreatments on quality, energy consumption and sterilization of barley grass in freeze drying. *Ultrason Sonochem.* **40**, 333-340.

Da Silva, G.D., Barros, Z.M.P., de Medeiros, R.A.B., de Carvalho, C.B.O., Brandão, S.C.R. and Azoubel, P.M. (2016) Pretreatments for melon drying implementing ultrasound and vacuum. *LWT - Food Sci. Technol.* **74**, 114-119.

Demiray, E. and Tulek, Y. (2015) Color degradation kinetics of carrot (*Daucus carota* L.) slices during hot air drying. *J. Food Process. Pres.* **39**, 800-805.

Deng, L.Z., Mujumdar, A.S., Zhang, Q., Yang, X.H., Wang, J. and Zheng, Z.A. (2019) Chemical and physical pretreatments of fruits and vegetables: Effects on drying characteristics and quality attributes–a comprehensive review. *Crit. Rev. Food Sci. Nutr.* **59**, 1408-1432.

Doymaz, İ. (2017) Drying kinetics, rehydration and colour characteristics of convective hot-air drying of carrot slices. *Heat Mass Transfer.* **53**, 25-35.

Er, F. and Özcan, M.M. (2010) Chemical compositional properties and mineral contents of some apple cultivars. *South Western J. Hortic. Biol. Env.* **1**, 121-131.

FAO (2019) *Food and Agricultural Organization of the United Nations.* http://www.fao.gov.

Fernandes, F.A., Gallão, M.I. and Rodrigues, S. (2008) Effect of osmotic dehydration and ultrasound pretreatment on cell structure: Melon dehydration. *LWT - Food Sci. Technol.* **41**, 604-610.

Fijalkowska, A., Nowacka, M., Wiktor, A., Sledz, M. and Witrowa-Rajchert, D. (2016) Ultrasound as a pretreatment method to improve drying kinetics and sensory properties of dried apple. *J. Food Process. Eng.* **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. *Dry. Technol.* **35**, 849-859.

Jambrak, A.R., Mason, T.J., Paniwnyk, L. and Lelas, V. (2007) Accelerated drying of button mushrooms, Brussels sprouts and cauliflower by applying power ultrasound and its rehydration properties. *J. Food Eng.* **81**, 88-97.

Lima, K.S.C., Grossi, J.L., Lima, A.L., Alves, P.F., Coneglian, R.C. and Godoy, R.L. (2001) Effect of the gamma ionizing irradiation on after crop quality of Cv. "Nantes" carrots (*Daucus carota* L.). *Food Sci. Technol.* **21**, 202-208.

Mechlouch, R.F., Elfalleh, W., Ziadi, M., Hannachi, H., Chwikhi, M. and Aoun, A.B. (2012) Effect of different drying methods on the physico-chemical properties of tomato variety 'Rio Grande'. *Int. J. Food Eng.* **8**, 1-13.

Oliveira, S.M., Brandão, T.R. and Silva, C.L. (2016) Influence of drying processes and pretreatments on nutritional and bioactive characteristics of dried vegetables: A review. *Food Eng. Rev.* **8**, 134-163.

Onwude, D.I., Hashim, N., Abdan, K., Janius, R. and Chen, G. (2018). Investigating the influence of novel drying methods on sweet potato (Ipomoea batatas L.): Kinetics, energy consumption, color, and microstructure. *J. Food Process Eng*. **41**, e12686.

Ozturk, B., Celik, S.M., Karakaya, M., Islam, A. and Yarilgac T. (2015) Storagetemperature affects phenolic content, antioxidant activity and fruit quality parameters of cherry laurel (*Prunus laurocerasus* L.). *J. Food Process. Pres.* **41**, 1-10.

Purkayastha, M.D., Nath, A., Deka, B.C. and Mahanta, C.L. (2013). Thin layer drying of tomato slices. *J. Food Sci. Technol.* **50**, 642-653.

Ren, F., Perussello, C. A., Zhang, Z., Kerry, J. P. and Tiwari, B. K. (2018). Impact of ultrasound and blanching on functional properties of hot-air dried and freeze dried onions. *LWT*, **87**, 102-111.

Ricce, C., Rojas, M.L., Miano, A.C., Siche, R. and Augusto, P.E.D. (2016) Ultrasound pre-treatment enhances the carrot drying and rehydration. *Food Res. Int.* **89**, 701-708.

Scher, C.F., de Oliveira Rios, A. and Noreña, C.P.Z. (2009) Hot air drying of yacon (Smallanthus sonchifolius) and its effect on sugar concentrations. *Int. J. Food Sci. Technol*. **44**, 2169-2175.

Sharma, K.D., Karki, S., Thakur, N.S. and Attri, S. (2012) Chemical composition, functional properties and processing of carrot—a review. *J. Food Sci. Technol.* **49**, 22-32.

Sra, S.K., Sandhu, K.S. and Ahluwalia, P. (2011) Effect of processing parameters on physico-chemical and culinary quality of dried carrot slices. *J. Food Sci. Technol.* **48**, 159-166.

Sumnu, G., Turabi, E. and Oztop, M. (2005) Drying of carrots in microwave and halogen lamp–microwave combination ovens. *LWT - Food Sci. Technol.* **38**, 549-553.

Sunjka, P.S., Orsat, V. and Raghavan, G.S.V. (2008) Microwave/vacuum drying of cranberries (*Vacccinium macrocarpon*). *Am. J. Food Technol.* **3**, 100-108.

Tian, Y., Wu, S., Zhao, Y., Zhang, Q., Huang, J. and Zheng, B. (2015) Drying characteristics and processing parameters for microwave-vacuum drying of kiwifruit (*Actinidia deliciosa*) slices. *J. Food Process. Pres.* **39**, 2620-2629.

Tian, Y., Zhao, Y., Huang, J., Zeng, H. and Zheng, B. (2016) Effects of different drying methods on the product quality and volatile compounds of whole shiitake mushrooms. *Food Chem.* **197,** 714-722.

Uslu, Ü.H. (2015) *Ultrasound assisted dehydration of kumquat fruit and determination of quality parameters.* MSc Thesis. University of Süleyman Demirel. Turkey.

Vargas, M., Chiralt, A., Albors, A. and González-Martínez, C. (2009) Effect of chitosan-based edible coatings applied by vacuum impregnation on quality preservation of fresh-cut carrot. *Postharvest Biol. Technol.* **51**, 263-271.

Vega-Gálvez, A., Di Scala, K., Rodríguez, K., Lemus-Mondaca, R., Miranda, M. and López, J. (2009) Effect of air-drying temperature on physico-chemical properties, antioxidant capacity, colour and total phenolic content of red pepper (*Capsicum annuum*, L. var. Hungarian). *Food. Chem.* **117**, 647-653.

Vega-Gálvez, A., Ah-Hen, K., Chacana, M., Vergara, J., Martínez-Monzó, J. and García-Segovia, P. (2012) Effect of temperature and air velocity on drying kinetics, antioxidant capacity, total phenolic content, colour, texture and microstructure of apple (var. Granny Smith) slices. *Food Chem.* **132**, 51-59.

Yang, F., Zhang, M., Mujumdar, A.S., Zhong, Q. and Wang, Z. (2018) Enhancing drying efficiency and product quality using advanced pretreatments and analytical tools—An overview. *Dry. Technol.* **36**, 1824-1838.

Zhao, Y., Wang, W., Xie, J., Zheng, B., Miao, S., Lo, Y.M. (2017) Microwave vacuum drying of lotus seeds: Effect of a single-stage tempering treatment on drying characteristics, moisture distribution, and product quality. *Dry. Technol.* **35**, 1561-1570.

Received: July 9, 2021
Sent to Subject Editor: August 2, 2021
Accepted: December 15, 2021
Recommended by Subject Editor Diego Lomonaco