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ENGINEERING SCIENCES

The Effects of Electric Field and Ultrasound Pretreatments on the Drying Time and Physicochemical Characteristics of the Zucchini Chips

AHSEN R. ERGÜN

Abstract: The aim of this study was to investigate the effects of electrical pretreatment (40V, 60 sec) and ultrasound blanching (35kHz, 80°C, 2 min) on the drying time, texture, color, and rehydration properties of zucchini which were dried by hot air and freeze dryers to 8% moisture content (wet basis). The synergistic effect of electrical and ultrasonical applications reduced the drying time (36%) to reach the target moisture content in hot air drying and provided fracturable, chewy, and edible hard zucchini chips. The highest lightness value was found as 86.04 at the group blanched ultrasonically and freeze dried chips.The greenness was found at most (-9.31) in the combined group of electrical pretreated, ultrasound assisted blanched and freeze dried sample group. The rehydration capacity of the dried samples increased significantly with the effect of ultrasound compared to the increase with the effect of electroplasmolysis application ($P \leq 0.05$). Zucchini chips with higher quality characteristics were produced by these combined applications. The electrical method can be alternatively used for drying pretreatments in the food industry with the advantage of decreasing the processing time and improving the textural and sensorial properties compared to the method of hot drying.

Key words: Drying time, electroplasmolysis, freeze drying, ultrasound blanching, zucchini.

INTRODUCTION

Zucchini (*Cucurbita pepo, L.*) is defined as a small summer marrow or green squash, with a shape such as a ridged cucumber (Neves et al. 2019), and can easily adapt to all temperate regions (Verdejo-Lucas & Talavera 2019). This plant is especially known in the Mediterranean area, and this type is classified as one of the three subspecies of subsp. Pepo includes cococelle, courgette, summer squash, pumpkin, vegetable marrow, and zucchini (Pomares-Viciana 2018). It is usually available fresh, in the markets, being consumed raw with its skin in salads or served cooked in soups and other recipes. Zucchini is rich in water content and low solutes (sugars, fibers, and polysaccharides) (Occhino et al. 2011), and it is preferred for a healthy diet with antioxidant properties (Martínez-Valdivieso et al. 2015). Zucchini is highly sensitive to cold storage (Palma et al. 2019), and its tissue is typically firm in the ripened fruit but tends to soften during storage and particularly when it is cooked for dish preparation; therefore this process limits its usage for processed products (Occhino et al. 2011). Accordingly, as it was mentioned previously, processed zucchini (e.g. frozen, dried) needs pretreatments such as blanching for long shelf life since enzymes, especially peroxidase which catalyzes the oxidation reactions, can cause quality changes during storage (Neves et al. 2012). Jia et al. (2019), underlined the popularity of fruit and vegetable chips produced using different drying techniques that removed moisture and made the fruit crispier. Air drying is a conventional method generally used for producing these attractive slices. Vallespir et al. (2019), discussed using different food pre-treatment methodologies to enhance the convective drying of fruits and vegetables; however, these methods are time and energy demanding processes that also cause some color and nutritive losses (Siebert et al. 2019). Freeze drying preserves quality better than other methods (Marques et al. 2006), because of the phenomenon which suggests that rehydration occurs during sublimation of the previously frozen tissues (Tylewicz et al. 2016). Lyophilization can be defined as a kind of drying in which the solvent, (usually water), and/or the suspension medium is crystallized at a low temperature and thereafter sublimates from the solid phase to the vapor phase (Ciurzyńska & Lenart 2011). Therefore, this process restrains the shrinkage of the dried product, solute depredation, browning or surface crusting, and poor rehydration capacity seen in conventional drying (Genin & Rene 1996). In the literature, there were several researches about the production of fruit and vegetable chips using this method such as freeze dried strawberry (Agnieszka & Andrjez 2010, Ciurzyńska & Lenart 2011, Zhang et al. 2020), sea cucumber (Duan et al. 2010), apple discs (Moreira et al. 2009, Menlik et al. 2010), carrot (Voda et al. 2012), tropical fruits (Marques et al. 2006), mushroom (Hernando et al. 2008) microwave freze dried onion slices (Abbasi & Azari 2009), and the combined microwave-vacuum and freeze drying of carrot and apple chips (Cui et al. 2008). In recent studies, ultrasound assisted the drying process as suggested by Bozkir et al. (2019) for persimmon, garlic, and banana (Azoubel et al. 2010). Ultrasonic waves can provoke vapor bubbles to collapse rapidly or creates voids in liquids. This helps to produce cavitation (Duan et al. 2008) that has been used to improve the drying rate. It has been determined by several researchers that ultrasonic pretreatment could be used to lower the water content or to vary the fruit tissue by removing strongly bounded water and accelerating drying (Fernandes & Rodrigues 2008, Gamboa-Santos 2013). Besides, this method enhances the drying by preserving the heat-sensitive compounds at moderate temperatures (Carcel et al. 2007, Gallego-Juarez 1999). Fernandes et al. (2008) quoted the positive effect of ultrasound in controlling crystallization during the freeze drying.

Electrical treatments such as electroplasmolysis also had favorable effects which promote moisture removal by cell disintegration before the drying of mushroom, (Çakmak et al. 2016), garlic, and persimmon (Bozkir et al. 2019). A pulsed electric field (PEF) which reduced the conductive drying time was studied by several researchers in apples for freeze drying (Tylewicz et al. 2016, Lammerskitten et al. 2019) and also studied by Gachovska et al. (2009) in carrots before drying. Additionally, some researchers applied PEF before the convective drying of onion slices and air-dried apricots (Ostermeier et al. 2018, Huang et al. 2019). Additionally, Wiktor et al. (2015) described the synergistic effect of ultrasound and PEF in detail by pointed out the positive effect of US on the efficiency of PEF treatment by helping the removal of gasses from the system subjected to treatment. Also when US was applied after PEF, electroporated solid-like material seemed to be more sensitive for cavitation. Both of them caused poration in the plant cells (sono/electro) and helped to improve the drying process (Wiktor et al. 2015).

With all this in mind, this study aimed to show the effect of both ultrasound and electroplasmolysis and the synergistic effect of these applications as a pretreatment during the production of zucchini chips. The freeze dried chips were compared with the hot air dried samples for drying time, physical (moisture content and water activity), rehydration, textural (breaking force, hardness, and chewiness), color (L*, a*, b*, and ΔE), and sensorial properties. Additionally, the energy consumptions of the processes were calculated and compared.

MATERIALS AND METHODS

Raw materials

The zucchini was purchased from a local market (Turkey) and refrigerated at 4°C until needed. Samples were then sliced using a slicer (Berkel, Germany), in a thickness of 0.3cm and a diameter of 4.5cm. The chemicals (hexane guaiacol, hydrogen peroxide, and sodium phosphate) were analytically graded and obtained from Merck (Darmstad, Germany).

The raw materials were washed and peeled then divided into two groups as the first group being the electroplasmolysis treatment group (EP) and the second group which was processed without EP treatment. Then each group was divided into two groups one for ultrasound blanching (US) and the other for traditional blanching (TB). After that, all four groups were separately dried with hot air (HAD) and freeze dried (FD).

So the 8 sample groups (EP+TB+HAD (electroplasmolysis+traditional blanching+hot air drying), EP+US+HAD (electroplasmolysis+ultrasound blanching+hot air drying), EP+TB+FD (electroplasmolysis+traditionalblanching+freezedrying),EP+US+FD(electroplasmolysis+ultrasound blanching+freeze drying), US+HAD (ultrasound blanching+hot air drying), US+FD (ultrasound blanching+freeze drying), TB+HAD (traditional blanching+hot air drying), and TB+FD (traditional blanching+freeze drying)) were processed as shown in Fig. 1.

TB+HAD was selected as the control group which was not treated with ultrasonication and electroplasmolysis, processed with traditional methods.

Electroplasmolysis application

The electroplasmolysis (EP) was applied using a drum type electroplasmolyzator (2011/10506Y, utility model, Turkey) designed with the cooperation of Çermak Machine (Manisa-Turkey). This equipment has two drums with stainless steel pins. An alternative electric current was given from a voltage control unit, and the samples were fed between the pins (Figure 2). The distance was 7 cm between the cylinders, 5 cm between the pins, and the rotation rate of the cylinders was 25 s per 1 cycle. The EP was applied before slicing. The voltage gradient and time (40, 50, 60, 70, and 80V for 30, 60, and 90 sec.) were determined by pretreatments. The optimum voltage gradient for zucchini was selected as 40V/60sec. The voltage was not effective for the cell poration under 40V/cm, whereas the structure and color loss were seen in the surface of the samples over 40V/cm.

Ultrasound blanching

An ultrasonic bath (Sonorex Super Ultrasonic Bath-RK-10, Berlin, Germany) was used for the ultrasound treatment. A sample of 25 g was weighed and placed directly into the ultrasonic bath having a capacity of 1 liter of water and samples were completely immersed and sonicated at 80°C for 2 min at 35 kHz. The time was decided via the inactivation of the peroxidase enzyme. The temperature of the samples measured with K-type thermocouples from the center of the slices and found only a temperature rise of 2.0 ± 0.1 °C. The energy consumption was 0.046 kWh during sonication.

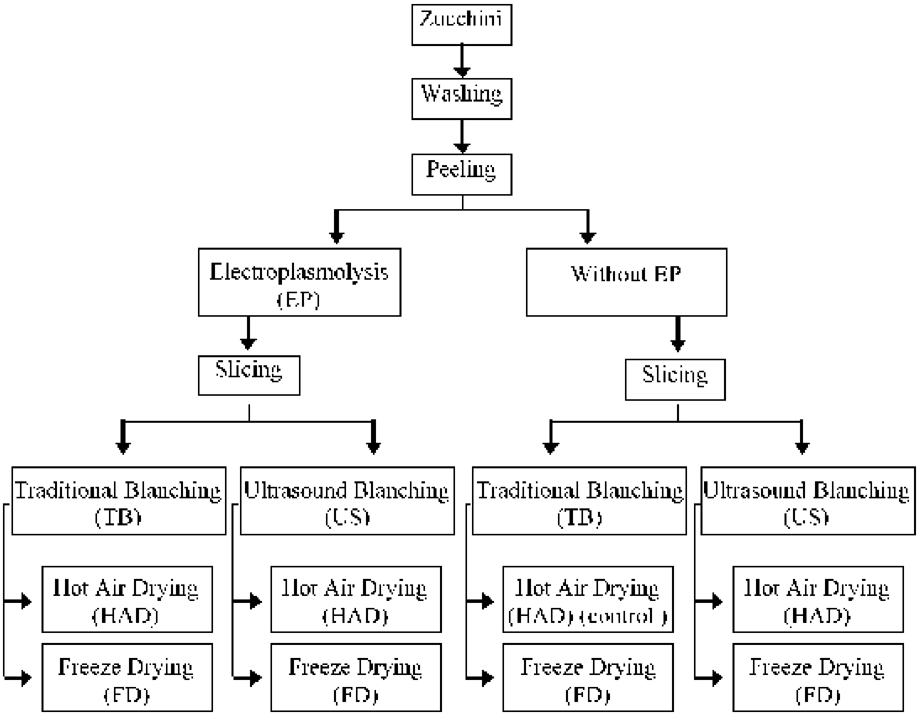

Figure 1. Processing groups zucchini chips.

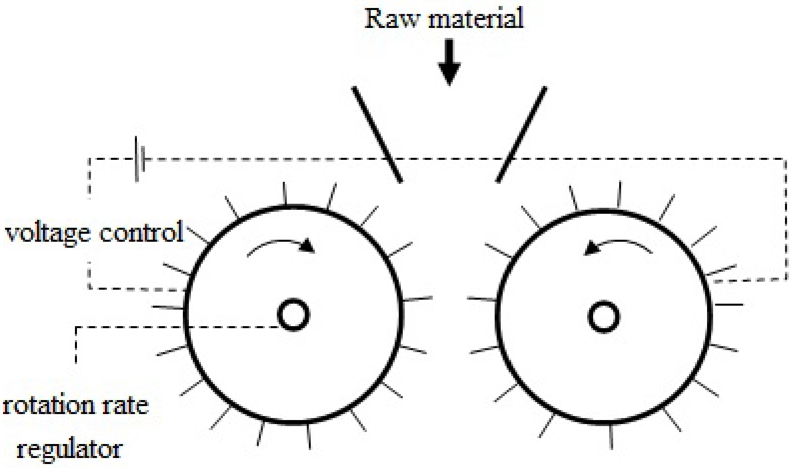

Figure 2. Schematic diagram of electroplasmolysis.

Traditional blanching

A water bath (Nuve ST30, Turkey) was performed at 80°C for 3 minutes which was enough the inactivation of the peroxidase enzyme. The energy input during traditional blanching was 0.105 kWh.

Drying process

Drying experiments for the hot air drying method were conducted using a laboratory-scale hot air drier (Armfield Ltd., Model UOP8 Hampshire, England) operating at an air velocity of 1.5 m/s. A temperature of 70 °C was selected (Bagheri & Dinani 2019). The mass of the samples was recorded every 15 minutes during drying. The sieve load was 1.68±0.05 kg/m^2. The initial moisture contents of the fresh zucchini slices were determined as 95.0% using infrared moisture equipment (Shimadzu MOC-63U, Japan) (AOAC 1990). The aimed moisture content was 8% in all samples to evaluate the effect of the drying methods on the physical attributes. For freeze dying the experiments were carried out in a pilot-scale freeze dryer (Armfield, FT 33 Vacuum Freeze Drier, England), the samples were frozen at -40 °C in an air blast freezer for 2h, then freeze-dried under vacuum (13.33 Pa absolute pressure) and at -48°C condenser temperature. The temperature of the heating plate was set to +10 °C which accelerated the sublimation process, not leading to melting of the product under working conditions and kept as constant during the drying process. The sieve load was 1.90±0.05 kg/m^2

Methods of analysis

Peroxidase activity measurement for determining the blanching time was conducted spectrophotometrically with a UV 1601 PC UV-visible spectrometer (Shimadzu Corporation, Japan) at 470nm using guaiacol as the substrate and H_2O_2 as the hydrogen donor. 10 ml of 1% guaiacol, 10 ml of 0.3% hydrogen peroxide, and 100 ml of 0.05M sodium phosphate buffer with 6.5 pH value were the substrate mixture (Güneş & Bayındırlı 1993). The *moisture contents* were measured using infrared moisture measuring equipment (Shimadzu MOC-63U, Japan). *Water activity* was measured using water activity equipment (TestoAG 400, Germany). The *rehydration capacity* was performed by dipping weighted dehydrated zucchini into hot water at 80°C for 15 min. The rehydrated samples were filtered over a screen for 2 min and slightly blotted with absorbent paper 3 times and weighted again (Cui et al. 2008). Rehydration capacity was calculated with equation (1) where W_d represented the weight of dehydrated samples and W_r represented the weight after rehydration.

$$\text{Rehydration capacity} = W_r / W_d \tag{1}$$

The color (L*, a*, and b*) values of the samples were measured using a Minolta color meter (MINOLTA, CM-3600d, Japan). The device was calibrated according to standard white line (Y = 93.9, x = 0.313, y = 0.321), L * (light), a * (red-green), and b * (blue-yellow). The source of light type was D65 (6500 K). The total color differences (ΔE) were calculated using the following equation (2) where the control group (TB+HAD) was used as the reference in the calculations (Dueik et al. 2010).

$$\Delta E = \sqrt{}(L^* - L^*_{ref})^2 + (a^* - a^*_{ref})^2 + (b^* - b^*_{ref})^2 \tag{2}$$

The *textural properties* were measured with a TA-XT plus texture analyzer (Stable Micro System Co. Ltd., Surrey, UK). 0.25 mm diameter spherical stainless-steel test probe was used. The hardness of the product was determined while the sample (5 different slices from each group in 3 replicates) was placed over the end of a hollow cylinder against the probe. The test parameters were: 0.80 mm/s pre-speed, 0.80 mm/s test-speed, and 4 mm/s post-test speed, and the test distance was set as 3 mm.

The analysis of variance (ANOVA) software SPSS 18 (SPSS Inc., Chicago, IL, USA) was used for comparing the results statistically with the help of the Duncan test that showed the differences between the treatments at a level of significance *P≤0.05*. The tests were carried out three times. Finally, the average value of the 3 measurements were taken as the test result.

Sensory properties were tested with a hedonic chart from 1 to 9 (9 = like extremely, 8 = like very much, 7 =like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3

= dislike moderately, 2 = dislike very much, 1 = dislike extremely) indicating increasing general appeal level in the 0.05 significance scale. All samples were given at room temperature coded in three-digit numbers randomly. The average value of color, texture, odor, taste, and overall acceptance scores was evaluated by the 9 panelists (Altuğ & Elmacı 2005).

The *energy consumption* of each process was measured using a digital energy meter. The energy consumption was calculated by the method used by Jia et al. (2019), with Eq.3.

$$Pt = P \times t. \qquad (3)$$

where: Pt-power consumption, P-electronic output power (kW), t-drying time (h).

The calculation of power consumption for the sample groups was made by the cumulatif summation of power in each treatment.

RESULTS AND DISCUSSION

Evaluation of drying time

Moisture contents versus time during the hot air drying were shown in Figure 3. The moisture contents of the groups treated by electroplasmolysis and ultrasound applications were lower than the control group (TB+HAD). The samples in the TB+HAD group took the longest time (11h) to reach the 8% moisture content. The ultrasound pretreated hot air dried samples (EP+US+HAD) had 8.62% moisture after 4h of drying. Drying took place in the falling rate period as shown in Figure 3. EP was found to be more effective on the drying time than the US in the early drying period of the drying, but after 75 minutes, the moisture content of the US+HAD group was lower than EP+TB+HAD. The EP+US+HAD samples dried faster than the other groups with a synergistic effect. The EP+US+FD group reached 8% moisture content after 6h, whereas TB+FD samples reached at the end of 10h, but the EP+TB+FD and US+FD group showed a similar drying time as 8h. Ultrasound blanching improved vapourization compared to traditional blanching.

Bagheri & Dinani (2019) confirmed the results by finding the reduced drying rate for zucchini slices in the ultrasound-assisted convective drying process. The drying time after

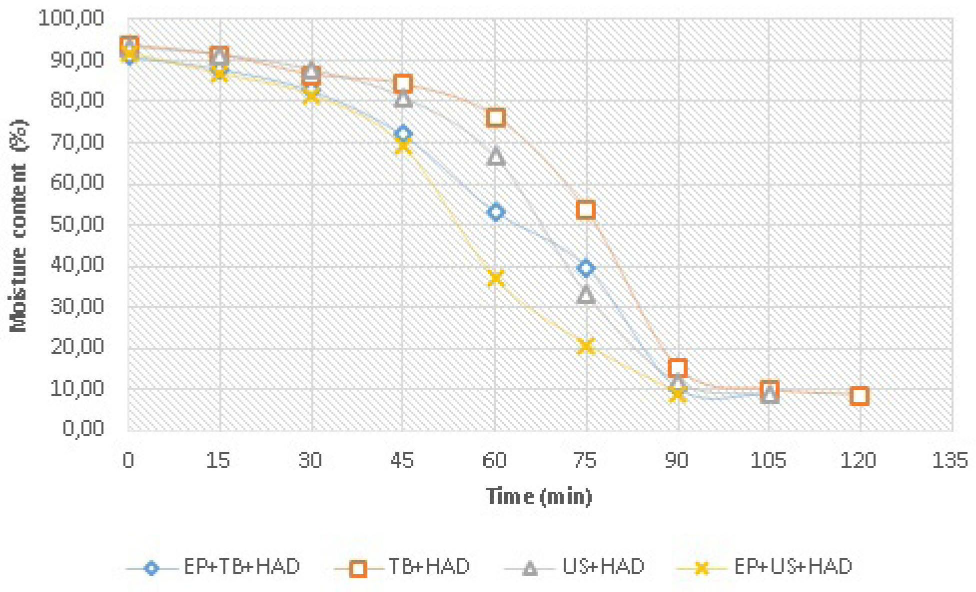

Figure 3. Drying curves of zucchini chips.

the ultrasound application was decreased by the effect of the cavitation bubbles near to the surface that formed microjets in the direction of the surface (Knorr et al. 2004). The ultrasound-assisted osmotic dehydration before the hot air drying decreased the drying time by 135 min when compared to the control group by Bozkir et al. (2019). The electrical treatment also affected the plant cells and made the transfer of water from plant cells easier. This was discussed in some studies; for example, one study examined PEF and discovered a significant reduction in the drying time of onions (Ostermeier et al. 2018). Furthermore, all PEF treated samples showed a higher decrease in the moisture ratio than the untreated samples dried at the same temperature. They found a 6.4% decrease in the drying time of onions after the PEF treatment at 75°C (Ostermeier et al. 2018). The drying rates of PEF treated apricot samples increased after PEF treatment (Huang et al. 2019). Additionally, the PEF pretreatment enhanced the drying rate of carrots (Gachovska et al. 2009). Similarly, Wiktor & Witrowa-Rajchert (2019) found that the combined pretreatment of PEF and ultrasound reduced drying time by 27–49% in carrots. In another study, the drying periods for the control sample, the samples pretreated until the moisture content was reduced below 8% using ultrahigh-pressure (UHP), ultrasound (US), and their combination (UHP-US) were 20h, 16h, 18h, and 14h, respectively (Zhang et al. 2020). Similarly, Jambrak et al. (2007), found that ultrasound was effective on the reduction of the drying time for some vegetables compared to the untreated ones. It was observed that the drying rate increased for apple slices treated with the ultrasound assisted air drying system (Santacatalina et al. 2014). The results of these studies were in line with those found in this research. Similarly, PEF intensified the freeze-drying kinetics and reduced the processing time by 57% compared to the untreated apple slices, and also increased the effective water diffusion coefficient by 44% (Lammerskitten et al. 2019).

Evaluation of moisture content, water activity, and rehydration capacity

The results of the measurements for moisture content were shown in Table I. There were no significant differences between the moisture contents as expected because the intended moisture was to be below 10% for all the samples (P>0.05). Similarly, the water activities were the same for all of the samples (P>0.05), while the rehydration capacities changed

Table I. **Some quality characteristics of zucchini chips**

Samples	Moisture content (%)	Rehydration rate (%)	Water activity	L*	a*	b*	ΔE
TB+HAD	8.59^{a}±0.05	75.26 ^{a}±0.01	0.35 ^{a}±0.01	59.51 ^{a}±0.01	-4.51 ^{a}±0.01	25.70 ^{a}±0.01	
TB+FD	8.79 ^{a}±0.50	82.82 ^{e}±0.24	0.38 ^{a}±0.05	77.19 ^{f}±0.02	-6.12 ^{g}±0.06	31.82 ^{f}±0.06	18.00^{f}±0.02
US+HAD	8.62 ^{a}±0.55	80.51^{b}±0.05	0.34 ^{a}±0.01	64.18 ^{b}±0.01	-4.62 ^{c}±0.02	37.95 ^{c}±0.50	4.76 ^{b}±0.05
US+FD	8.42 ^{a}±0.40	85.14 ^{f}±0.50	0.32^{a}±0.03	86.04 ^{g}±0.03	-5.96 ^{h}±0.01	37.02 ^{g}±0.01	28.68 ^{g}±0.01
EP+TB+HAD	8.67 ^{a}±0.50	66.96 ^{a}±0.10	0.36 ^{a}±0.03	61.17 ^{c}±0.04	-0.38 ^{d}±0.03	38.01 ^{d}±0.40	4.55 ^{c}±0.03
EP+TB+FD	8.11 ±0.33	79.69 ^{c}±0.05	0.36 ^{a}±0.08	81.48 ^{d}±0.04	-6.85 ^{e}±0.04	37.79 ^{c}±0.20	22.74^{d}±0.10
EP+US+HAD	8.90 ^{a}±0.48	66.40 ^{b}±0.44	0.34 ^{a}± 0.02	64.28 ^{b}±0.02	-4.10 ^{b}±0.02	38.85 ^{b}±0.02	5.12 ^{a}±0.01
EP+US+FD	8.31 ^{a}±0.25	74.66 ^{d}±0.04	0.35 ^{a}±0.01	74.97 ^{e}±0.01	-9.31 ^{f}±0.05	45.34 ^{e}±0.01	18.34 ^{e}±0.00

Different letters (^{a} to ^{h}) within columns represent significant difference at the level of p<0.05.

significantly by the effect of the process ($P \leq 0.05$). EP decreased the rehydration capacity when compared to the groups of EP+TB+FD (79.69±0.05), and TB+FD (85.82±0.24). The same results were obtained between the groups of TB+HAD and EP+TB+HAD. The freeze drying process improved the rehydration properties when compared to air drying. Rehydration changed significantly with the exception to the sample groups of EP+US+HAD and US+HAD ($P \leq 0.05$). Electroplasmolysis did not affect the samples before hot air drying, but samples were negatively affected by EP when freeze drying was used. This showed that EP caused cell disruption after drying since the water recovery was lower because of the destroyed structure. Similar to our results, it was found that the rehydration rates of carrots treated by PEF were lower than that of blanched carrots (Gachovska et al. 2009). As stated before there was a conflict in this estimation as some researchers found decreases rather than improvements in the rehydration capacities after PEF (Tylewicz et al. 2016). The freeze-dried fruits subjected to PEF pretreatment absorbed more water than the untreated samples. There were no changes in hygroscopicity and loss of the soluble solids during rehydration (Lammerskitten et al. 2019). The US pretreatment increased the rehydration capacity which could be explained by the sponge and cavitation effect of ultrasonic waves. Previous studies also found that the rehydration behavior of plant food could also be enhanced with the use of ultrasound. For example, the highest rehydration capacity was found after ultrasound pretreatment in the drying of carrots (Wiktor & Witrowa-Rajchert 2019). In another study by Bozkir et al. (2019), ultrasound-assisted osmotic dehydration before hot air drying increased the rehydration rate. Torringa et al. (2001), determined that rehydration properties of freeze dried mushroom chips were the best among the microwave, hot air dried, and osmotically pretreated microwave dried ones. The rehydration ratio was found higher in the freeze dried sample which facilitated rehydration relatively better than other options. Similar to our study, the rehydration properties (weight gain, %) of the freeze-dried (FD) samples were the best (Jambrak et al. 2007). In another study, rehydration capacity was found as 5.45±0.107% in the FD samples, the synergistic effect of mid-infrared drying (MIRD-10 min) and FD application changed this value to 4.95±0.102% (Wang et al. 2015). Freeze-dried samples showed a porous structure that allowed the rehydration to take place at the extracellular level. This situation showed that freeze-dried mushrooms absorbed water more and faster than the samples dried convectively (Hernando et al. 2008). In line with this study, the rehydration ratio of freeze dried sea cucumbers increased after FD compared to the air and microwave drying (Duan et al. 2010).

Changes in the color value

The total color changes of the samples were shown in Table I. The highest lightness value was found for the US+FD group but the lowest in the control group (TB+HAD). Electroplasmolysis was found effective on the lightness of both samples which were traditionally blanched and then dried with HAD and FD. The freeze drying process protected the brightness better than conventional dryers. Also greenness ($-a^*$) was important for the consumers as a specific skin color for this vegetable was found the highest after the EP+US+FD group. EP+TB+FD followed this group with an $-a^*$ value of -6.85±0.04. Additionally, the greenness varied significantly among all the groups ($P \leq 0.05$). EP increased the permeability of plant cells by helping the transfer of pigments to the surface. Specially EP combined with the US before FD affected a^* significantly ($P \leq 0.05$). In contrast to our study, no significant differences were found between the redness (a*) value after the PEF treatment to fresh apricots, whereas, the hue angle (h) was significantly affected after PEF at 0.625 kV/cm for 30 s. (Huang et al. 2019). This difference was associated with the material used and cell membrane permeabilization (Wiktor et al. 2015, Huang et al. 2019). Besides, discoloration was observed in white asparagus after PEF (Janositz et al. 2011). Similarly, the lightness was higher in the freeeze drying group compared to the microwave-assisted freeze drying after blanching (Wang et al. 2010).

Ultrasound also made the color values better. Based on the results given in Table I, b* (yellowness) values significantly differed between the groups (P≤0.05). EP+US+FD had the highest b* value; this could be explained by the lack of Maillard reactions (Abbasi & Azari 2009). Total color difference (ΔE) was calculated by taking the group of TB+HAD as the control group and observing a significant change due to the changes in lightness, greenness and yellowness of zucchini chips; was found as the highest in the US+FD group (P≤0.05). In a previous study, using strawberry chips, after US the L* and b* values decreased, but redness increased (Zhang et al. 2020). The dried zucchini slices pretreated by 15 min ultrasonic application had the lowest ΔE value (29.32±0.37) (Bagheri & Dinani 2019). The color of pineapple, Barbados cherry, guava, papaya, and mango was protected with freeze-drying (Marques et al. 2006). In another study, hot air dried cabbage samples with the highest a*, b*, and ΔE values showed color damages. FD led to the best drying quality in terms of color, followed by microwave vacuum drying and vacuum drying (Xu et al. 2020). In parallel with this discovery, persimmon fruit was studied, three different drying technologies (hot air, hot air-microwave, and vacuum freeze drying) were used and compared, and it was concluded that lower drying temperature and lack of oxygen minimized the degradation reactions and enzymatic changes (Jia et al. 2019). It was found that freeze dried chips showed the highest brightness followed by hot air and hot air-microwave drying (Jia et al. 2019).

Changes in the textural properties

The breaking force showed a decreasing effect in the following order: the raw zucchini> EP+US+HAD>TB+HAD>EP+TB+FD>EP+US+FD>US+FD>EP+TB+HAD>US+HAD>TB+FD (Table II). The least force was needed for the TB+FD samples, therefore it was concluded that FD made the chips crispier and less hard. Samples pretreated with EP needed more force than the ones without EP, which destroyed the cells so water was removed faster during drying. However, EP increased the solute impregnation on the surface and the hardness indirectly compared to freeze drying which protected the structure better by sublimation. Fracturability changed reversely with hardness, and it was found highest in the TB+FD group. Cohesiveness decreased after US+HAD. The chewiness improved when electrical pretreatment was made with TB and hot air drying. Based on the comparison with the groups of TB+HAD and US+HAD, traditional blanching could be preferred rather than ultrasound to increase the chewiness of chips. The resiliences of the samples were detected as being similar between the groups which were freeze dried, ultrasonically and conventionally blanched. It was determined that, EP combined with the US, improved the resilience property of the sample.

For dehydration methods, the texture values demonstrated that the decrease in moisture was in parallel with the increase in maximum force (Hernando et al. 2008). According to Cuccurullo et al. (2017), the initial moisture content was found as 91.8% for zucchini and a decrease

Table II. Textural properties of zucchini chips.

Sample Group	Breaking force (N)	Hardness (g-force)	Fracturability (g-force)	Springiness (m)	Cohesiveness (N cm)	Gumminess (N)	Chewiness (J)	Resilience (N)
Raw zucchini	19492.30 ^{a}±323.320	26525.647^{a}±250.140	1.07 ^{a} ±0.14	0.67 ^{g} ±0.01	0.79 ^{a}±0.20	21066.51^{a}±250	13607.096 ^{a} ±214.00	0.65 ^{a} ±0.01
TB+HAD	4656.46 ^{b} ± 330.160	5.49 ^{b} ±4.55	3.96 ^{b}±0.11	0.83^{b} ±0.02	0.31 ^{b}±0.10	12.58 ^{b}±5.66	10.33^{b} ±1.14	0.14 ^{b} ±0.02
TB+FD	2687.37 ^{h} ±232.240	2.60^{h} ±2.21	10.19 ^{h}±2.10	0.85^{b} ±0.03	0.64 ^{g}±0.50	1.2 ^{h}±0.10	12.59 ^{h} ±5.16	0.20 ^{g}±0.01
US+HAD	2896.79 ^{d} ±220.120	4.63^{d} ±1.25	10.09 ^{d} ±3.10	0.72 ^{c}±0.50	0.52^{c} ±0.50	12.21^{d} ±1,24	8.94 ^{d} ±3.18	0.10 ^{d} ±0.04
US+FD	2745.33 ^{g}±189.140	2.38 ^{c}±1.50	9.09^{i} ±1.10	0.77 ^{c}±0.01	0.52^{c} ±0.24	1.46 ^{i}±2.12	1.13 ^{i} ±0.10	0.21 ^{g}±0.01
EP+TB+HAD	2800.70 ^{e} ±165.150	6. 29^{e}±3.10	5.17^{e}±2.10	0.82 ^{b} ±0.40	0.35^{b} ±0.12	2.04 ^{e} ±2.10	2.95 ^{e} ±1.25	0.13 ^{e}±0.06
EP+TB+FD	4331.05^{f} ±140.150	3.18 ^{f}±1.12	3.68 ^{f}±1.21	0.83 ^{b} ±0.10	0.48^{e} ±0.10	3.01^{f} ±1.11	20.50 ^{f} ±4.66	0.18 ^{f}±0.01
EP+US+HAD	5951.75 ^{c} ±136.240	7.20 ^{c} ±4.12	4.48 ^{c} ±2.12	0.86 ^{b} ±0.50	0.50^{c} ±0.10	1.66 ^{c}±0.05	1.44^{c} ±0.25	0.27 ^{c} ±0.07
EP+US+FD	3965.00 ^{g}±140.154	2.80^{g} ±1.14	8.48^{f} ±2,50	0.79^{c}±0.20	0.58^{f}±0.10	3.13 ^{g}±0.60	2.49 ^{g} ±1.00	0.16^{f}±0.08

***Different letters (^{a} to ^{h}) within columns represent significant difference at the level of $p<0.05$**
N: Newton; g-force:gram force; m: metre; J: joule; N cm: Newton centimeter.

was detected on the breaking force that shows softening. This parameter was correlated with the first bite of the internal structure of the material (Rahman & Al-Farsi 2005). Paciulli et al. (2015), maintained that after blanching, a light change occurred in the structure of the zucchini due to its epidermal cells, and the intercellular spaces became visible. Freeze dried products were detected to have less cellular tissue shrinkage and collapse than hot air dried products which caused the HAD samples to become harder (Xu et al. 2020). In line with this opinion, the shrinkage and collapse took place during hot air drying, resulting in a much tougher texture (Cui et al. 2008). In the hot air drying the liquid diffused from the inside to the surface carrying solutes within the liquid as the surface moisture drifted the solid concentration and the skin became harder (Jia et al. 2019). They found the lowest chewability value in the hot air dried persimmon chips. For the sea cucumber samples hardness decreased after FD compared to air and microwave drying (Duan et al. 2010). The hardness of strawberry chips was increased after US process (Zhang et al. 2020). Results showed that water loss was only detected in the samples of strawberries dehydrated with trehalose due to the reversible electroporation after the 100 V/cm treatment, while the irreversible electroporation was effective for all samples. Tylewicz et al. (2019), stated that tissue firmness reduced strongly after the application of PEF changes with the applied voltage. The firmness values of the samples treated to a combination of osmotic dehydration with the 100 V/cm PEF treatment were significantly reduced (Tylewicz et al. 2019). In another study, carrots became firmer after pretreatment with PEF compared to blanched ones (Gachovska al. 2009). It should be taken into account that the final appearance and texture quality after dehydration of freeze-dried courgettes were affected by the raw materials' maturity (Genin & Rene 1996). The final microstructure of the frozen products was related to the rate of freezing; while slow freezing formed crystals as the water inside the cells diffused to outside by damaging the structure; in quick-freezing, water movement was limited within the material, causing water to freeze inside the cells and the formation of crystals inside the structure of the cell walls (Vallespir et al. 2019). Moreover blanching increased the hardness of the potatoes before FD (Wang et al. 2010).

Changes in sensorial properties

The radar chart of the sensory evaluation was presented in Fig. 4. The result showed that zucchini chips processed by MEF and US treatments had high scores in texture and color but the panelist gave high scores to TB+FD for the texture. EP+US+FD group was preferred via the taste. Electrical application and ultrasonic blanching affected the odor of the samples. Ultrasonic blanching as mentioned before in the textural properties made the chips crispier so this made it attractive and preferable for the panelists. Jia et al. (2019), found that persimmon chips processed by freeze-drying and the combined hot-air microwave drying technique had better quality than hot air drying. They stated that, in sensory analysis, freeze-dried persimmon chips had the brightest color, while the hot-air dried samples had poor overall color perception.

Evaluation of energy consumption

In the drying process, the most important target was to use a low amount of energy to remove the most moisture for long-term storage (Özkan et al. 2007). Thus, the power consumption of different drying techniques was very important.

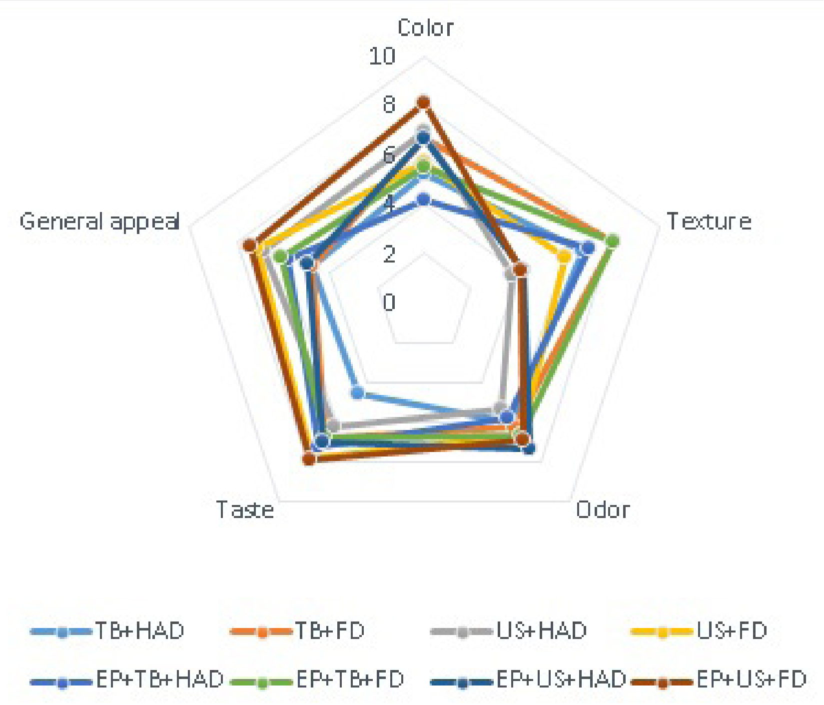

Figure 4. Radar chart of sensory evaluation of zucchini chips processed by different drying technique.

The energy consumptions of all the groups were calculated and given in Table III. The energy saving was found significant after the ultrasonic treatment compared to traditional blanching (P≤0.05). The results showed that the power consumption of processing zucchini chips with freeze dryer was significantly lower than the hot air drying (P≤0.05). This was because of the long process time of the hot air dryer. Electrical treatment consumed more energy when compared to the sample groups of with and without EP as expected. This was worth mentioning that the drying method was very effective to maximize energy saving with the pretreatments. Similar results were found in previous researches. Ultrasound was pointed out with the lower energy consumption (Su et al. 2018). Differently, in another study, the power consumption of processing freeze-dried persimmon chips was about 7–9 times higher than that of combined hot-air-microwave drying and single hot-air drying. It was explained by the long drying time needed for freeze-drying, which was about five times longer than the hot-air and the combined hot-air-microwave processes (Jia et al. 2019).

CONCLUSIONS

The current study demonstrated that zucchini slices dried faster after electrical and ultrasonic pretreatments since these applications

Table III. Energy consumption for processing groups.

Sample	Energy consumption (kWh)
TB+HAD	6.595^{a}±0.10
TB+FD	6.005^{b}±0.10
US+HAD	6.536^{c}±0.05
US+FD	5.566^{d}±0.10
EP+TB+HAD	6.830^{e}±0.18
EP+TB+FD	5.806^{f}±0.16
EP+US+HAD	6.776^{g}±0.15
EP+US+FD	5.864^{h}±0.12

***Different letters (^{a} to ^{h}) within columns represent significant difference at the level of p<0.05. kWh: Kilowatthours.**

encouraged the removal of water from the disrupted cells and the chips became crispier. The freeze dryer gave the best rehydration characteristics and color values. The synergistic effects of EP+US increased the greenness and protected color against the browning reactions. When the blanching techniques were compared within the EP group, the US method was significantly beneficial on the rehydration rates, lightness, and hardness. This study could initiate further studies about optimizing the conditions needed for these integrated applications to progress the final physical and chemical characteristics of the fruit and vegetables. New researches are needed for using freeze dryers in industrial production and to focus on energy and capital investments.

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AHSEN R. ERGÜN
https://orcid.org/0000-0003-0943-1950

Ege University, Faculty of Engineering, Department of
Food Engineering, 35100, Bornova, Izmir, Turkey

E-mail: ahsenrayman@hotmail.com