GRASAS Y ACEITES 73 (1)
January-March 2022, e446
ISSN-L: 0017-3495
https://doi.org/10.3989/gya.1126202

The effects of electrical and ultrasonic pretreatments on the moisture, oil content, color, texture, sensory properties and energy consumption of microwave-fried zucchini slices

A. Rayman Ergün

Ege University, Engineering Faculty, Food Engineering Department, Bornova, 35100, İzmir, Turkey
Correspondence: ahsenrayman@hotmail.com

Submitted: 16 September 2020; Accepted: 06 November 2020; Published online: 30 March 2022

SUMMARY: In this study, the effects of a moderate electrical field application and two different blanching methods (conventional and ultrasound) on the frying (deep-frying in oil at 180 °C for 6 minutes and compared to the microwave (400W)) of zucchini slices were investigated. Microwave-fried samples presented a lower moisture content than deep fried ones. The moderate electrical field significantly reduced the oil content before the microwave frying. Greenness (–a*), which is important for the zucchini samples, was found at its best (-3.25) in the combination group of moderate electrical field pre-treated, ultrasound blanched, and microwave fried. Gumminess, cohesiveness, and fracturability of the zucchini slices decreased while chewiness, springiness, and resilience increased after microwave frying. The scores of the sensory test were higher for the ultrasonic blanching and microwave fried sample groups. Besides, these electrical methods were found more advantageous in terms of energy consumption.

KEYWORDS: *Frying; Microwave; Moderate electrical field; Texture; Zucchini.*

RESUMEN: ***Efecto de pretratamientos eléctricos y ultrasónicos sobre la humedad, el contenido de aceite, color, textura, propiedades sensoriales y consumo de energía de rodajas de calabacín frito en microondas.*** En este estudio se investigaron los efectos de una aplicación moderada en el campo eléctrico y dos métodos diferentes de escaldado (convencional y ultrasonido) en la fritura (fritura en aceite a 180 °C durante 6 minutos y comparada con el microondas (400W)) de virutas de calabacín. Las muestras fritas en microondas presentaron un menor contenido de humedad que las de fritura clásica. El campo eléctrico moderado redujo significativamente el contenido de aceite antes de la fritura en microondas. El color verde (–a*) que es importante para las muestras de calabacín se encontró como máximo (-3.25) en el grupo combinado de campo eléctrico moderado pretratado, ultrasonido blanqueado, y frito con microondas. La gomosidad, la cohesividad y la fragilidad de las rodajas de calabacín disminuyeron, mientras que la masticación, elasticidad y resiliencia aumentaron después de freír con microondas. Las valoraciones sensoriales fueron más altas en los grupos de muestras de blanqueo ultrasónico y frito con microondas. Además, estos métodos eléctricos fueron más ventajosos desde el punto de vista del consumo de energía.

PALABRAS CLAVE: *Calabacín; Campo eléctrico moderado; Freir; Microondas; Textura.*

Citation/Cómo citar este artículo: Rayman-Ergün A. 2022. The effects of electrical and ultrasonic pretreatments on the moisture, oil content, color, texture, sensory properties and energy consumption of microwave-fried zucchini slices. *Grasas Aceites* **73** (1), e446. https://doi.org/10.3989/gya.1126202

1. INTRODUCTION

Frying technology has a wide range of application in the food industry, such as the production of french fries, vegetable chips, especially potato, meat products, including meatballs, chicken products like fingers or nuggets, mozzarella and onion rings, some seafood products such as fish fillets and it is also applied to bakery products. These products used to be consumed a lot due to their attractive textural properties, but conscientious consumers reduced their daily intake because these types of products are rich in oil (Barutçu *et al.,* 2009; Shaker, 2015; Su *et al.,* 2016) and have a high risk of acrylamide formation (Jung *et al.,* 2003; Gökmen *et al.,* 2006; Tuta *et al.,* 2010). For these reasons, the studies were focused on the novel methods to decrease the oil absorption or processing time by frying under vacuum (Fan *et al*., 2005; Moreira *et al*. 2009; Troncoso *et al*. 2009; Dueik *et al.,* 2010) or frying with microwave (Öztop *et al.,* 2007; Su *et al.,* 2016; Aydınkaptan and Mazı, 2017) and or pulsed electric field (PEF) pre-treatments (Liu *et al.* 2007; Jonasitz *et al.,* 2011; Fauster *et al.,* 2018).

Electric field application was advantageous to fried potato production in terms of structure and oil intake (Jonasitz *et al.,* 2011). Liu *et al.* (2017) investigated the pre-treatment of the pulsed electric field (PEF) on frying and reported a membrane permeabilization effect on the vegetables and enhancing effect on the preferable textural properties, along with a beneficial impact on enhanced mass transfer (Ignat *et al.,* 2015). Electric field procures cell wall permeability, the softening of tissues, and pore formation (Ngadi *et al.,* 2003; Lebovka *et al.,* 2004; Rayman *et al.,* 2011). It helps to transfer water to the surface, so the drying becomes faster in vegetable slices (Çakmak *et al.,* 2016) or moves the nutritive components during processing (Bazhal and Vorobiev, 2000). Moderate electric field (MEF) is an electroporation technique. Electroporation occurs through the formation of pores and, which increases the permeability of biological membranes; therefore, the natural osmotic balance inside and outside the plant cells is disturbed. That affects the electrical, thermal, diffusion and, rheological properties of plant tissues and increases internal diffusion processes and moisture removal from cell vacuoles (Ngadi *et al.,* 2003; Rayman *et al.,* 2011).

In recent studies, microwave frying was often used alternatively to deep frying, as Gharachorloo *et al.* (2010) mentioned. In general, previous research determined that the microwave process has the advantages of increasing the moisture evaporation rate and uniform heating, decreasing the oil content, improving crispness and protecting the color of fried foods (Sham *et al.,* 2001; Su *et al.*, 2016; Al Faruq *et al.,* 2019; Sun *et al.,* 2019). Removal of water requires less time than traditional frying because the internal heat generation occurs after microwave energy, causing water to boil within the food (Barutçu *et al.,* 2009).

Ultrasound also produces the same results by cavitation and sponge effects; moisture removal improves during dehydration (Rodrigues *et al.,* 2008). Al Faruq *et al.* (2019), who studied ultrasound and microwave combined with the frying of apple slices, found a significant reduction in the oil uptake after ultrasound treatment compared to microwave frying. Improvements in crispiness and color were also detected. Similar results were found by Su *et al.* (2018) for potato chips. They found that ultrasound reduced the oil uptake and improved the color after ultrasound-assisted microwave frying. In another research, the ultrasound and microwave -assisted vacuum frying of mushroom chips were studied, which accelerated the frying rate; oil uptake was reduced, and texture and color properties were improved using this method (Devi *et al.,* 2018). Similarly, Huang *et al*. (2018) applied microwave and ultrasound in the frying process of pumpkin chips, and reported a synergistic effect in promoting the quality parameters. In addition to these studies, Sunsano *et al.* (2018) researched the acrylamide reduction during the microwave frying of French fries. They determined that the acrylamide content was less than 100 µg/kg on a weight basis (wb) after microwave frying.

Blanching before frying also improves the process. Blanching affects plant material cells and increases moisture removal at the beginning stage of the frying process, thus maintaining color and inactivating enzymes. Blanching also removes air from the sample, which facilitates heat transfer afterward. Ignat *et al.* (2015) reported the blanching treatment as a critical stage in the frying process. Troncoso *et al.* (2009) specified the effect of blanching on protecting the color and texture by preventing oil absorption. Fan *et al*. (2005) blanched the carrots prior to frying to protect their color. Similarly, pumpkin slices were blanched before ultrasound-assisted microwave vacuum frying (Huang *et al.,* 2018). It was also reported by Belkova *et al*. (2018) that pretreatment such as blanching reduces acrylamide. Apple slices were also blanched before microwave frying (Al Faruq *et al.,* 2019). The importance of a blanching pre-treatment in zucchini was well described by Neves *et al.* (2019). They mentioned the effectiveness of blanching on microbial reduction and improving product quality such as zucchini squash.

Zucchini (*Cucurbita pepo L.)* is a green squash (Neves *et al.,* 2019), low in calories (Iswaldi *et al.,* 2013), but rich in vitamins and minerals (Bagheri *et al.,* 2019), consumed generally in the fried form in summer. This squash can be found in many shapes and different skin colors (Iswaldi *et al.,* 2013). This vegetable was generally processed for freezing and drying (Paciulli *et al.,* 2015; Cuccurullo *et al.,* 2017), and limited studies researched zucchini frying (Abtahi *et al.,* 2016). There is no study about the ultrasound blanching effect on frying to the knowledge of the authors. Moreover, there is a lack of studies about investigating the pre-treating effect of electrical methods combined with blanching and the impact on the quality of fried products.

Therefore, the purpose of this study was to evaluate the quality characteristics (color, texture, oil, and moisture contents) of microwave-fried zucchini slices after electrical pre-treatment (MEF) and two different blanching methods (ultrasound and traditional) by comparison to the deep-frying method using sun flower oil at 180 °C for 6 minutes.

2. MATERIALS AND METHODS

2.1. Materials

Zucchini (*Cucurbita pepo L.*) was obtained from a local market (İzmir, Turkey). Samples were sliced with a slicer (Berkel, Germany), at a thickness of 0.3 cm and a diameter of 4.5 cm. Sunflower oil (Yudum Sun flower oil, Istanbul, Turkey) was used for frying. Chemicals (hexane, guaiacol, hydrogen peroxide, and sodium phosphate) were of analytical grade and obtained from Merck (Darmstad, Germany).

The raw materials were washed and peeled, divided into two groups as electrical treatment group (MEF) and the control. Each group was divided into two more groups for blanching as ultrasound blanching (US) and traditional blanching (TB). After that,

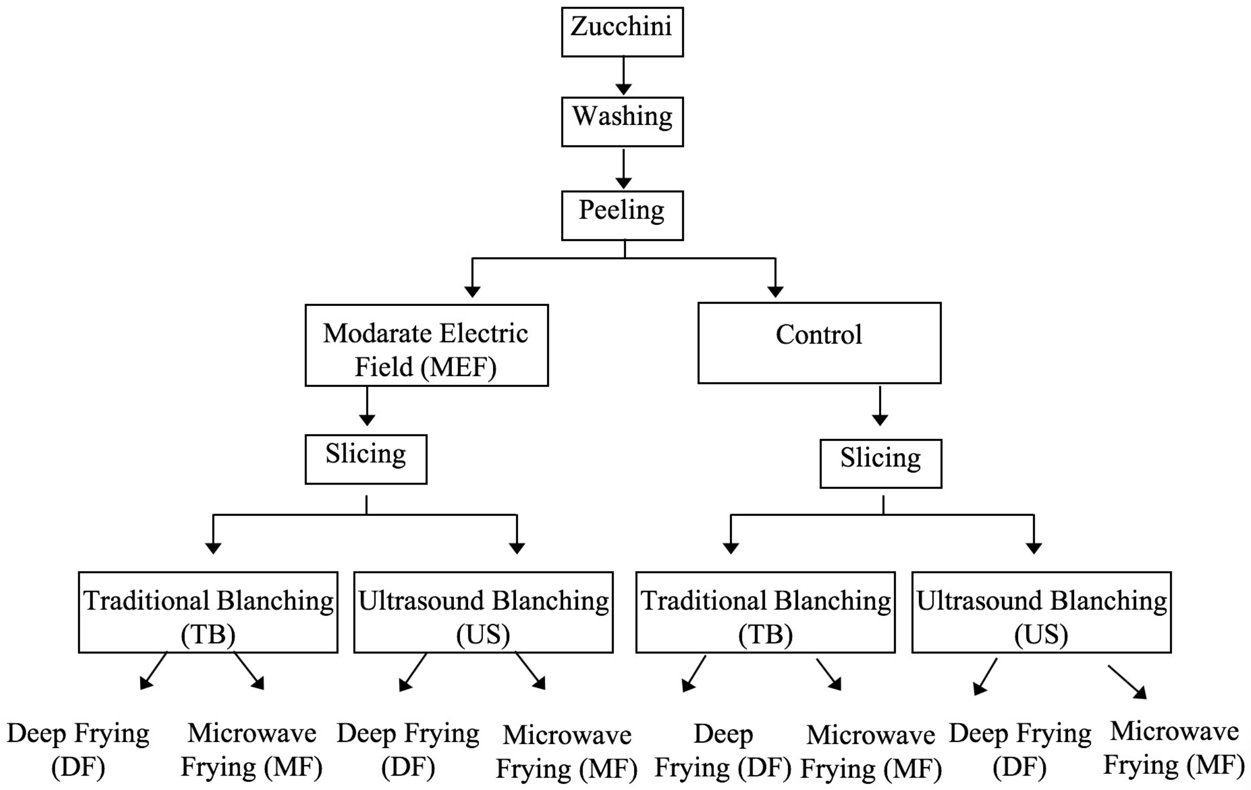

FIGURE 1. Flow chart of fried zucchini slices.

all four groups were separately fried by microwave (MF) and deep-frying (DF). The 8 sample groups (MEF+TB+MF), (MEF+US+MF), (MEF+TB+DF), (MEF+US+DF), (US+DF), (US+MF), (TB+MF), and (TB+DF) were processed as shown in Figure 1.

2.2. Moderate Electric Field (MEF)

MEF was applied by using a drum-type electroplasmolyzator designed by a research group in the Ege University, Food Engineering Department, with the cooperation of a Cermak Machine (Manisa, Tukey) from a previous research study (Baysal *et al.,* 2007). This equipment has two drums with stainless steel pins. A device was used to provide electric current to the system and a feed unit made contact between the pins and samples. The distance between the pins of the drum-type electroplasmolyzator was adjusted to 1.8 cm. MEF was applied before slicing. Electric current was provided to the system at between 0-400V.

The voltage gradients, and times (40, 50, 60, 70, 80V for 30, 60 and 90 s) were determined by pre-treatments. The process conditions were determined by pre-treatments for zucchini as 40V/60 s voltage gradient. The voltage was not effective for the cell poration under 40V/cm, although the structure, and color lost were seen on the surface of the samples when treated at over 40 V. 60 seconds were chosen because frying time over 60 s harmed the structure, whereas 30 s was found to be insufficient.

2.3. Blanching methods

Samples were blanched in an ultrasonic bath (35 kHz, Everest ultrasonic, Turkey) at 80 °C for 2 min. A conventional method was also carried out in the water bath (Nuve ST30, Turkey) (at 80 °C for 3 min) with a zucchini-to-water ratio of 1:8 (w/w). These parameters were selected with pre-treatments for enzyme (peroxidase) inactivation. After blanching, the slices were cooled under running tap water. Then the surface water was dried with absorbent paper.

2.4. Frying methods

Microwave frying was performed in a household microwave oven (GW72N Samsung Electronics), which works in the range of 100 to 900 W. The oil was heated to the frying temperature of 180±1 °C by using three different microwave power levels of 300, 400, 600 W used in the pre-treatments to select the effective power. For each frying experiment, 250 mL of fresh oil were placed in a Pyrex beaker when the temperature reached 180 °C. Ten zucchini slices (25 g±1.0 g) were immersed in the oil (sample-oil ratio of 1:10 w/v) to conduct a frying run at a specified time and power. The temperature was controlled by fiber optic sensors (Neoptix Qualitrol Campany, USA). All runs were conducted with fresh oil. The lowest power level (300 W) provided low temperatures and took longer times, increasing the oil intake. Therefore, 300 W was also eliminated. In the case of the highest power (600 W), the temperature increased suddenly, and this was eliminated also to provide an effective process. For this reason, samples were fried at 400 W. After selecting this power level, different times were treated, such as 4, 6, 7 minutes at 400 W to select the sufficient time. The samples fried for 7 minutes began to brown. This situation was undesirable. Samples fried for 4 minutes at 400 W did not fry enough, and the peroxidase enzyme was not inactivated. Therefore, the frying time was selected as 6 minutes at 400 W and the enzyme was inactivated.

Deep frying was carried out under the same conditions as microwave frying at 180 °C for 6 min, which inactivated the peroxidase enzyme, with a 3-L capacity Sinbo model fryer (SDF 3827, France) equipped with temperature adjustment in the range of 90 to 190 °C. The sample-oil ratio was 1:10, (w/v) the same as the microwave method. Before a new run, the basket cooling period was observed closely, and fresh oil was used for each sample. After reaching the intended frying temperature, samples were placed in the basket, and the same procedure was followed.

The excess oil on the surface of the samples was removed with dry tissue paper for 20 s after both frying techniques. The frying process was performed in 2 replicates and, analyses were replicated 3 times.

2.5. Analytical methods

Peroxidase activity for determining the blanching time was conducted qualitatively by adding 1 mL guaiacol as the substrate and 1 mL H_2O_2 (0.5%) as the hydrogen donor to the mixture of 5 mL demineralized water and 5 g sample. The test was evaluated as positive when a reddish-brown color was observed and negative if there was no color. A negative test indicated the inactivation of the enzyme (Cemeroğlu, 2010).

The samples were analyzed for moisture contents with infrared moisture equipment (MOC63u, Shimadzu Inc. Japan) (Anon, 1990). Three samples were taken at random, and a shredded 1.5 g sample was tested in triplicate.

The total oil content was determined by solvent extraction using the Soxhlet method with hexane for 6 hours with the samples dried and ground into small particles (Ignat *et al.,* 2015).

Color values (L*, a*, b*) were measured with a Minolta chromameter (CR-400 Konica Minolta Inc, Japan). The total color difference (ΔE) was calculated (Eq. 1) by taking the TB+DF as a reference. Three different samples were scanned at three different positions, and the average values of three replicate measurements were reported.

$$\Delta E=\sqrt{(L^*-L^*_{ref})^2+(a^*-a^*_{ref})^2+(b^*-b^*_{ref})^2} \quad \text{(Eq.1)}$$

Textural properties were measured with a TA-XT plus texture analyzer (Stable Micro System Co. Ltd., Surrey, UK). A spherical stainless-steel test probe (P/25) of 25 mm in diameter in compression test mode was used to determine the hardness of the product by placing the one slice of the sample over the end of a hollow cylinder against the probe (Su *et al.,* 2016). The test parameters were: 0.80 mm/s pre-speed, followed by 0.80 mm/s test-speed and 4 mm/s post-test speed. The test distance was set at 3 mm by preliminary tests. Breaking force (N), Hardness (g-force), Fracturability (g-force), Springiness (m), Cohesiveness (N cm), Gumminess (N), Chewiness (J), and Resilience (N) were measured. Three slices were tested in triplicate for each group. The parameters were defined as the peak force observed at the maximum compression.

The sensory analysis was performed in line with international standards (Norma UNE, 2020) The tests were developed in a standard room equipped with 10 individual tasting areas. The sensory test was performed with 20 untrained panelists. All samples were given at room temperature and coded with three-digit random numbers. Water and bread pieces were served to panelists for oral rinsing. An acceptance test was used by applying a hedonic scale structured in 9 points, 1 being "I dislike extremely" and 9 being "I like extremely", indicating an increasing general appeal level in the 0.05 significance scale. Characteristics such as color, texture, flavor, and general appearance were evaluated (Altuğ and Elmaci, 2005; Tejada *et al.,* 2020).

The energy consumption of each process was measured using a digital energy meter. The energy meter recorded the energy during each treatment process (Su *et al.,* 2018). The calculation of power consumption for the sample groups was made by the cumulative sum of power for each treatment.

Results of the analyses were statistically analyzed by one-way analysis of variance (ANOVA) software SPSS 18 (SPSS Inc., Chicago, IL, U.S.A.) with the Duncan test to evaluate differences between treatments at a level of significance of $p < 0.05$.

3. RESULTS AND DISCUSSION

The zucchini slices were fried with the selected parameters (power level and time), which provided the peroxidase enzyme inactivation and the samples were analyzed for comparing quality properties.

3.1. Influence of moisture and oil contents after the frying process

The quality properties of the fried zucchini slices are given in Table 1. Moisture contents significantly differed at the end of the applications ($p < 0.05$). The results showed that ultrasound blanching reduced the moisture content considerably for the same frying time as the traditonal method ($p < 0.05$). This is an advantageous result considering that the time for US blanching was 1 min less than the traditional method. The combination group of MEF+US+MF had the least moisture content at 26.67%. The zucchini slices, blanched in the traditional method, had a 93.65% moisture content before frying, whereas the moisture content found in the samples blanched with ultrasound was 93.09%. These values were 91.12 and 91.82% for the MEF+US and MEF+TB, respectively (Table 1). The electrical treatment destroyed the cell and made the water transfer easier. The microscopic channels were increased by ultrasound, and this accelerated the water pathway. The synergistic effect of these two applications helped to reduce the moisture in both the deep oil and microwave frying. Similarly, Bagheri and Tinani (2019) maintained that ultrasonic pre-treatment for 20 and 30 min before drying zucchini slices resulted in the

TABLE 1. Moisture, oil and color contents in zucchini slices.

Sample	Moisture (%)	Oil (%)	L*	a*	b*	ΔE
TB	93.65±0.20[a]					
US	93.09±0.10[b]					
MEF+TB	91.82±0.05[c]					
MEF+US	91.12±0.10[d]					
MEF+TB+MF	31.49±0.10[f]	25.92±0.60[e]	64.14±0.02[g]	-2.20±0.00[d]	35.80±002[b]	7.60±0.04[e]
MEF+US+MF	26.67±0.20[k]	38.10±0.35[b]	60.71±0.03[h]	-3.25±0.00[h]	33.55±0.05[c]	5.94±0.01[f]
MEF+TB+DF	62.37±1.00[g]	19.02±0.30[f]	72.84±0.01[b]	-2.42±0.03[e]	38.49±0.50[a]	14.50±0.00[a]
MEF+US+DF	59.10±0.55[h]	27.81±0.55[d]	71.27±0.00[c]	-3.15±0.01[g]	37.29±0.01[a]	13.58±0.06[b]
TB+MF	44.98±0.58[i]	30.00±0.60[c]	70.68±0.01[e]	-2.51±0.02[f]	32.42±0.01[c]	3.36±0.00[g]
TB+DF	72.70±0.60[e]	9.09±0.25[h]	70.78±0.05[d]	-0.14±0.01[a]	29.10±0.03[d]	
US+MF	35.24±0.40[j]	40.62±0.45[a]	66.73±0.05[f]	-1.58±0.00[c]	39.37±0.04[a]	8.23±0.01[d]
US+DF	63.74±0.02[f]	16.81±0.50[g]	74.65±0.04[a]	-0.33±0.04[b]	32.26±0.10[c]	10.39±0.04[c]

[a]Mean value ± standard deviation, and the number of samples analyzed (n= 3).
[b]a,b,c,.. Different letters within columns are significantly different according to Duncan´s test (p<0.05).
[c]Abbreviations: (MEF+TB+MF)=moderate electric field+traditonal blanching+microwave frying; (MEF+US+MF)=moderate electric field+ultrasound blanching+microwave frying; (MEF+TB+DF)= moderate electric field+traditonal blanching+deep-oil frying;(MEF+US+DF)=moderate electric field+ultasound blanching+deep-oil frying ;(TB+MF)=traditonal blanching+microwave frying and (TB+DF)=traditonal blanching+deep-oil frying; (US+MF)=ultasound blanching+microwave frying; (US+DF)=ultasound blanching+deep-oil frying. L*: Lightness, +a*/-a*: Redness/Greenness; +b*/-b*: Yellowness/Blueness; ΔE: Total Color Difference

cavitation phenomenon, causing the breakdown of cells, with microscopic channels becoming more prolonged and more profound. The water evaporated efficiently by the formation of microscopic channels due to an increase in water diffusivity.

In the US treated deep oil frying process, the moisture was 63.74%, although this value was reduced to 35.24% when the same sample was fried with the microwave technique. Su *et al.* (2018) studied with microwave vacuum frying of potato chips and explained the effect of microwave by finding a marked increase in the moisture evaporation kinetics and effective moisture diffusivity compared to fried samples without the microwave. They suggested that the higher microwave setting used in the process achieved a higher moisture evaporation rate and higher effective moisture diffusivity. Similarly, it was pointed out for apple chips that the moisture removal became easier after the microwaves, which penetrated the food and led to water boiling within the food, which increased the vapor pressure differential between the center and the surface of the product (Sham *et al.,* 2001). It was also found that the microwaved ones had more moisture loss than the deep oil-fried potatoes, similar to our study (Oztop *et al.,* 2007). Huang *et al.* (2018) stated that the ultrasound application lowered the moisture content significantly when comparing the microwave-assisted vacuum frying and vacuum frying samples. Hosseinzadeh and Shaheed (2015) also determined that the moisture content in zucchini slices was between 31.6-39.7% after frying at 150, 170, 190 °C. They said that the moisture loss was high, and a high amount of oil absorption was recorded. The oil uptake was in line with our study with the lower moisture contents. Moisture loss and oil absorption are the two most important mass transfer processes taking place during the frying of food (Quan *et al*., 2014). Fat uptake reduced from 7.5 to 6.8 by applying PEF at 1.0 kV/cm electric field (Fauster *et al.,* 2018), and elasticity increased, while firmness decreased.

The oil content was found at its highest in the US+MF group and lowest in the TB+DF group (Table 1). MEF significantly affected the oil content before microwave frying compared to the groups of MEF+TB+MF with TB+MF (p < 0.05). MEF pre-treatment increases the oil absorption of the sample in deep-oil frying rather than MF with both blanching methods. This situation was due to the synergistic effect of MEF and deep-oil frying. During deep-oil frying, the transfer of water and intracellular substances to the surface of the fries could be increased due to the MEF-induced electroporation. Thus, the water at the surface of the samples improves the rate of mass transfer and increases moisture removal and oil uptake. In addition, Quan *et al.* (2014) indicated that in the early stage of frying, the rate of moisture evaporation was high, which facilitated the formation of large pores at faster rates. The formation of larger pores at faster rates facilitated the fast absorption of oil into these pores. Therefore, it can be said that MEF provided a faster early stage in deep-oil frying than MW frying and the oil absorption was high in this stage in deep-oil fried samples.

Ultrasound caused more rapid moisture removal and higher oil absorption compared to the groups without ultrasound. Janositz *et al.* (2011) mentioned that PEF decreased oil uptake by the mechanisms of permeabilized cell membranes. A higher vapor pressure difference which reduces dehydration also removes substrates, reducing sugars, such as saccharides for the Maillard reaction. Ignat *et al.* (2015) confirmed this condition by using potato cubes submitted to PEF treatments and par-fried for 1 min with a 74.2% moisture content. In another study, the oil uptake of fried apple slices was reduced after ultrasonic application in microwave frying (Al Faruq *et al.,* 2019).

It was found that the deep-oil frying groups had less oil than the microwave frying group ($p < 0.05$). Similarly, Sunsano *et al.* (2018) stated that the oil uptake was more significant in potatoes with microwave frying than deep frying. The increase in temperature and the internal pressure were faster in microwave frying than in conventional frying due to the volumetric heating in the presence of microwaves. Therefore, the moisture escape became easier. The creation of structural channels through the sample tissue during MW frying favored the oil uptake significantly compared to deep-oil frying (Sansano *et al.,* 2018). Similar to our study, previous researchers suggested that a large amount of oil is absorbed when the moisture loss is high. This condition was explained by Quan *et al.* (2014) in the dry areas of chips which were previously occupied by water and become dryer and less hydrophilic. These made an easier interaction between the oil and pores and even the non-porous areas of the chips. However, in contrast to this, Aydınkaptan and Mazı (2017), determined that microwave- fried French fries had a lower oil content and moisture content than those fried conventionally. They explained a slight decrease in the oil content of all samples an increasing level of oil degradation. In line with this, Devi *et al.* (2018) determined that microwave-fried samples had lower oil values than deep-oil fried ones. The authors argued that the diffusion of oil into the product was limited by a high evaporation rate of water during microwave frying; thus, the oil content was lower in MW.

3.2. Changes in color properties

The color values L*, a*, and b* of the samples were measured and then the total color differences (ΔE) were calculated for each group and are presented in Table 1. There was a significant difference between the ΔE values ($p < 0.05$). The highest L* (lightness) was found in the US+DF group and the lowest in the MEF+US+MF group. Traditional methods showed higher L* values. There were no significant differences among the L* values of the TB+DF and TB+MF groups ($p > 0.05$). The L* value decreased after TB+MF when electrically pre-treated, and the same effect was found in the US+MF group. This may be because the higher oil content showed less light in the samples. MEF application with the poration effect caused more oil absorption and a lower lightness value. Also, the accumulation of moisture could lead the sample to be less bright. In addition, traditional blanching protected the brightness better than US when comparing the groups (MEF+TB+MF), (MEF+US+MF), (MEF+TB+DF), and (MEF+US+DF). This could be due to the cavitation effect of US, and the brightness was affected by the treatment.

There are different remarks about lightness in the literature. For example, it was mentioned that when brightness is reduced, the product obtains the desired golden color. Additionally, the reason for lowering the brightness or darkness of fried zucchini was explained by the nonenzymatic browning reactions due to increased frying temperatures (Hosseinzadeh and Shaheed, 2015). In contrast to this, as previously stated, a higher L* value is needed to give better consumer acceptance. The L* values for the fried samples decreased with increasing frying temperature, and it was significantly ($p < 0.05$) highest in the ultrasound-assisted microwave frying group at the same frying temperature (Devi *et al.,* 2018). In another study, the lightness parameter (L*) decreased to a lesser extent in microwave frying than in conventional frying. The color values for microwave fried French fries were lighter and more yellow at higher temperatures compared to the conventional fries. During the microwave frying of potatoes, the L* value for microwave fried was found higher than that for conventional fried under the same conditions (Parikh and Takhar, 2016). Huang *et al.,* (2018) published that ultrasound produces a slight increase in microwave frying lightness.

The -a* value, which shows the green color, was found mostly higher in MEF+US+MF but lower in the group TB+DF; therefore, the process US and MF protects the specific color of zucchini slices. The green color was found higher in the MF-treated samples when US+MF was compared to the US+DF groups ($p < 0.05$). This was because of the microwave heating effect that began from the inside. In line with this opinion in previous research, it was found that the moisture ratio in the frying process was associated with browning. Reduction in the moisture content in potato chips during microwave-assisted frying preserved the color better. But low temperature did not significantly affect the a* value in the microwave-assisted vacuum frying of fried potato chips (Su *et al.,* 2016). The microwave used in the frying process is a kind of assisted dehydration technology which is based on the thermal effect of microwaves. In another study, they stated that the microwave energy travels through the material and is absorbed more in the wet region than in the dry region of the product (Sun *et al.,* 2019). At 193 **°C,** the MF French fries had significantly larger a* values for all frying times than deep-oil frying (60, 90, and 120 s) (Parikh and Takhar, 2016). However, Ignat *et al.* (2015) found the a* values to be lower for the blanched potato than in the low PEF at 9000 pulses at 75kV/cm treatment.

There were no significant differences between the b* values of MEF+TB+DF and MEF+US+DF and US+MF groups ($p > 0.05$). In addition, the b* values did not significantly differ between the groups of MEF+US+MF, US+DF, and TB+MF ($p > 0.05$). The effect of TB and US was the same on the yellowness, but MF was significantly and positively affected. When b* values were high for fried products, this showed a more yellow product, which was preferred (Krokida *et al.,* 2001). In another study, ultrasound decreased the non-enzymatic browning in the vacuum frying of mushroom chips. They also determined a significant increase in the b* value after ultrasound (Devi *et al.,* 2018).

Total color differences significantly differed between the groups due to the L* and a* values ($p < 0.05$). The chemical browning reactions in food, oil absorbed by food, time and temperature of the frying process, etc. affect the color of fried products (Aydinkaptan and Mazi, 2017).

3.3. Changes in the textural characteristics

During frying, due to the removal of water from the slices, some textural changes occurred. Textural properties such as hardness (g-force), fracturability (g-force), cohesiveness (N cm) and chewiness (J) are shown in Table 2. The breaking forces were also evaluated, and significant differences were found between the forces ($p < 0.05$). As mentioned previously (Fan *et al.,* 2005), when the breaking force was found to be lower, the crispiness value was higher. After the MEF application, the breaking force was significantly lower than the other groups ($p < 0.05$).

In parallel with this study, Ignat *et al.* (2015) noted that the PEF treatment for the potato crisps needed a lower force for breaking, which was accomplished by making the plant tissue firmer through the effect of electroporation. Su *et al.* (2017) suggested that breaking force and crispiness were inversely proportional. They found the moisture content in the potato chips fried in microwave-assisted vacuum frying directly proportional to breaking force and reversely proportional to crispiness.

Microwave frying increased the breaking force rather more than deep oil. Deep-oil frying gave a softer textural property to the samples than the microwave method. The structure could be improved using the application of MEF before microwave and deep-oil frying. Similar to our study, ultrasound-assisted microwave frying showed a higher moisture removal rate, which may have led to the formation of a crust and mad the product crispier (Devi *et al.*, 2018). The breaking force decreased with increased frying time and microwave power due to reduced water content and increased oil content (Al Faruq *et al.,* 2019).

The US significantly decreased the hardness compared to traditional blanching ($p < 0.05$). The ultrasound, together with the effect of sponge and

Table 2. Textural properties of zucchini slices

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±20.22[a]	26525.647±85.17[a]	9.071±2.33[c]	0.67±0.09[b]	0.79±0.01[a]	21066.51±18.10[a]	13607.096±15.10[a]	0.65±0.02[a]
MEF+TB+MF	19.33±26.45[h]	7.37±10.12[e]	0.98±1.22[i]	0.54±0.01[c]	0.60±0.01[c]	0.71±10.45[g]	6.37±2.50[b]	0.16±0.02[d]
MEF+US+MF	99.85±30.50[d]	19.43±10.20[b]	5.48±3.11[e]	0.90±0.02[a]	0.75±0.00[a]	0.61±0.90[g]	4.98±1.21[c]	0.12±0.01[e]
MEF+TB+DF	16.14±9.27[i]	16.44±6.66[c]	11.96±4.16[b]	0.51±0.02[c]	0.55±0.01[c]	9.19±3.88[c]	4.68±1.49[c]	0.11±0.01[f]
MEF+US+DF	68.98±15.08[e]	1.79±3.55[g]	3.68±1.45[g]	0.13±0.04[e]	0.53±0.02[c]	3.71±1.40[d]	2.62±2.55[d]	0.17±0.00[d]
TB+MF	22.54±12.52[g]	7.47±1.45[d]	6.28±1.17[d]	0.02±0.02[f]	0.43±0.01[d]	3.23±0.80[e]	0.09±1.42[h]	0.20±0.01[c]
TB+DF	1249.16±40.41[b]	1.09±2.31[h]	18.54±0.50[a]	0.49±0.01[c]	0.56±0.06[c]	11.65±2.48[b]	0.30±0.77[f]	0.21±0.03[c]
US+MF	60.78±10.12[f]	3.78±2.00[f]	1.59±0.60[h]	0.57±0.02[c]	0.65±0.02[b]	0.67±1.65[h]	1.43±0.01[e]	0.26±0.01[b]
US+DF	278.62±50.52[c]	0.69±1.52[i]	3.88±1.93[f]	0.30±0.06[d]	0.62±0.02[c]	2.48±0.45[f]	0.16±1.90[g]	0.23±0.03[c]

[a]Mean value ± standard deviation, and the number of samples analyzed (n= 3).
[b]a,b,c,.. Different letters within columns are significantly different according to Duncan´s test (p<0.05).
[c]Abbreviations: (MEF+TB+MF)=moderate electric field+traditonal blanching+microwave frying; (MEF+US+MF)=moderate electric field+ultrasound blanching+microwave frying; (MEF+TB+DF)=moderate electric field+traditonal blanching+deep-oil frying;(MEF+US+-DF)=moderate electric field+ultasound blanching+deep-oil frying ;(TB+MF)=traditonal blanching+microwave frying and (TB+DF)=traditonal blanching+deep-oil frying; (US+MF)=ultasound blanching+microwave frying; (US+DF)=ultasound blanching+deep-oil frying. N: Newton; g-force: gram force; m: metre; J: joule; N cm: Newton centimeter.

cavitation, provided more crispiness compared to conventional blanching. Hhowever, when compared to MEF, it was less effective. The deep-oil fried samples had a softer structure than the microwave fried ones. More fracturability was found in the MEF+TB+DF and TB+DF groups. This was due to the effect of the frying process which reduced the breaking force of the zucchini slices through the removal of water. Due to the removal of water from the structure, the fried slices gained brittleness and hardness. In other words, the breaking force decreased significantly (Karacabey *et al.,* 2016). Sansano *et al.* (2018) confirmed these results by stating that microwave-fried samples were harder than conventional ones, mainly because of the significant water loss in microwave frying.

Cohesiveness, which was not desired in high levels, was found to be lower in the TB+MF samples, and also gumminess was low in the MEF+US+DF samples. Traditinonal blanching and frying increased gumminess. The moisture content of the US blanched groups was lower than the other in line with the gumminess. Chewiness was found highest in the group of MEF+TB+MF as 6.376. Resilience, which indicates flexibility, was found highest after the applications of US+MF.

The oil content and moisture were also effective on the textural properties of the fried samples. Microwave frying reduced the time compared with conventional frying (Sahin *et al*., 2007). They also mentioned that the moisture content decreased while color developed during both conventional and microwave frying. This situation was due to the decrease

Table 3. Energy consumption for processing groups.

Sample	Energy consumption (kWh)
MEF+TB+MF	0.42±0.01[c]
MEF+US+MF	0.36±0.01[d]
MEF+TB+DF	0.56±0.02[a]
MEF+US+DF	0.50±0.05[b]
TB+MF	0.18±0.08[g]
TB+DF	0.32±0.06[e]
US+MF	0.12±0.04[h]
US+DF	0.26±0.02[f]

[a]Mean value ± standard deviation, and the number of samples analyzed (n= 3)
[b]a,b,c,.. Different letters within columns are significantly different according to Duncan´s test (p<0.05).
[c]Abbreviations:(MEF+TB+MF)=moderate electric field+traditonal blanching+microwave frying; (MEF+US+MF)=moderate electric field+ultrasound blanching+microwave frying; (MEF+TB+DF)= moderate electric field+traditonal blanching+deep-oil frying;(MEF+US+DF)=moderate electric field+ultasound blanching+deep-oil frying; (TB+MF)=traditonal blanching+microwave frying and (TB+DF)=traditonal blanching+deep-oil frying; (US+MF)=ultasound blanching+microwave frying; (US+DF)=ultasound blanching+deep-oil frying. (kWh): Kilowatthours.

Table 4. Average scores of panelists for hedenoic test

Sample	Color	Texture	Odor	Flavor	General appearance
MEF+TB+MF	5.50±0.05[d]	5.11±0.02[f]	6.00±0.15[d]	6.89±0.14[c]	7.70±0.25[a]
MEF+US+MF	7.67±1.01[a]	8.10±0.09[b]	5.33±0.42[f]	6.20±0.48[e]	6.89±0.78[b]
MEF+US+DF	6.00±0.08[b]	8.70±0.15[a]	5.33±0.48[f]	6.20±0.36[e]	6.89±1.12[b]
MEF+TB+DF	5.55±0.04[d]	7.80±0.13[c]	6.67±0.69[c]	7.78±0.98[a]	6.88±0.14[b]
US+DF	5.60±0.06[d]	6.00±0.74[d]	5.78±0.52[e]	7.22±0.65[b]	5.77±0.65[d]
US+MF	5.40±0.05[d]	8.11±0.90[b]	6.67±0.66[c]	6.10±0.25[f]	5.89±0.24[d]
TB+MF	5.90±0.07[c]	5.67±1.05[e]	7.30±1.00[a]	6.11±0.36[f]	3.11±0.98[e]
TB+DF	4.40±0.06[e]	3.67±0.82[g]	6.88±0.85[b]	6.44±0.76[d]	6.67±0.45[c]

[a]Mean value ± standard deviation, test was carried with 20 panelists in 2 sessions.
[b]a,b,c,.. Different letters within columns are significantly different according to Duncan´s test (p<0.05)
[c]Abbreviations: (MEF+TB+MF) = moderate electric field+traditonal blanching+microwave frying; (MEF+US+MF) = moderate electric field+ultrasound blanching+microwave frying; (MEF+TB+DF) = moderate electric field+traditonal blanching+deep-oil frying; (MEF+US+DF) = moderate electric field+ultasound blanching+deep-oil frying; (TB+MF) = traditonal blanching+microwave frying; (TB+DF) = traditonal blanching+deep-oil frying; (US+MF) = ultasound blanching+microwave frying; (US+DF) = ultasound blanching+deep-oil frying.

in moisture content as frying time increased, which resulted in harder products, and microwave energy caused the fast water evaporation rates and created higher pore density of larger pores in the chips. Such a porous texture was expected to increase the crispness in chips. Based on the results of analysis in this study, it fell in line with the study of Quan *et al.* (2014), who found that it was possible to produce crunchier, more visually appealing fried products in a short time by the microwave-assisted frying.

3.4. Evaluation of sensory properties

The sensory quality of zucchini slices is shown in Table 4. The results showed that zucchini slices processed by MEF and US treatments had high scores for texture and color. The MEF +TB+DF groups were preferred due to the flavor and electrical applications, and ultrasonic blanching affected the samples' odor. The ultrasonic blanching mentioned before in the textural properties made the slices crispier, more attractive and preferable for the panelists. The combined effect of ultrasound and microwave showed better sensory quality. The impact of ultrasound combined with microwave on the sensorial properties such as odor and color was reported in a previous study. They informed significant differences between ultrasound-assisted microwave frying and microwave frying (Al Faruq *et al.,* 2019).

The sensory results were found to be in agreement with the color and texture measurements. The scores in the panel were higher for the color of samples, which had higher greenness values. Just the contrary, Troncoso *et al*. (2019) explained that the instrumental and sensory properties of color and texture could be irreversible. For example, panelists can prefer the sample with low lightness values. Electrically treated, traditionally blanched, and deep-fried slices were preferred by the panelists in terms of flavor, which was found to be more delicate in the texture analysis. However, the panelist gave high scores to MEF+TB+MF for general appeal.

3.5. Energy consumption

Power consumption was an important parameter to calculate the cost. In the industrial process, the most important target was to use a low amount of energy. The energy consumption of all the groups was calculated and given in Table 3. The energy saving was found significant after the ultrasonic treatment and microwave frying rather than the other techniques. The results showed that the power consumption of processing zucchini slices with the microwave was significantly lower than deep frying.

Ultrasound provided less energy consumption when compared to the sample groups of TB+DF and US+DF. The same effect was also determined in the microwave-fried samples due to the blanching methods. It is worth mentioning that the frying method effectively maximized energy saving with the same processing time.

Energy efficiency is a critical factor that restricts the development of fried fruit and vegetable slices. Consequently, the application of the combined technique may maximize energy savings and reduce expenses.

Similar results were found in previous research. Ultrasound was pointed out to require lower energy consumption. Su *et al.* (2018) reported that the combination of ultrasound could decrease the frying time and the energy consumption compared to the microwave. Fauster *et al*. (2018) suggested that PEF showed lower energy consumption than thermal pre-heating in French fry production. Similarly, Ignat *et al.* (2015) discussed the effect of an electroporation pre-treatment on processing time and energy saving. They determined that the low electric field application needed the lowest energy compared to deep-fat frying, blanching, and high-pulsed electric field application.

4. CONCLUSIONS

The single and synergistic effects of ultrasound blanching and moderate electrical pre-treatment on frying were investigated. The deep-oil and microwave frying of zucchini slices at the same temperature and during the same frying time were compared in terms of the optimal moisture and oil contents for color and textural properties. Electrical pre-treatments such as moderate electric field were found to be significantly effective on the frying of zucchini slices by making water transfer from the samples' surface easier. The electric field's synergistic effect, ultrasound and microwave treatments showed the least moisture content and the highest greenness. In addition to this, the electric field reduced oil intake before microwave frying. The breaking force of the final products was significantly affected by different frying methods and pre-treatments. Textural properties improved after microwave frying, so they were more chewy, resilient and springy but less fracturable, gummy and cohesive. Also, hard edible fried zucchini slices were produced. These alternative methods could be implemented in frying technology, considering these positive aspects with savings in energy and time.

REFERENCES

Abtahi MS, Hosseini H, Fadavi A, Mirzaei H, Rahbari M. 2016. The optimization of the deep-fat frying process of coated zucchini pieces by response surface methodology. *J. Culin. Sci. Technol*. 176-189. https://doi.org/10.1080/15428052.2015.1111181

Altug T, Elmaci Y. 2005. *Sensory Evaluation.* Meta Basimevi, Izmir, Turkey.

Al FAruq A, Zhang M, Adhikari B. 2019. A novel vacuum frying technology of apple slices combined with ultrasound and microwave. *Ultrason Sonochem.* **52**:552-529. https://doi.org/10.1016/j.ultsonch.2018.12.033

AOAC.1990. *Official Methods Of Analysis*, 15th Edn. (Ed). Association Of Official Analytical Chemists, Arlington, VA.

Aydinkaptan E, Mazia B. 2017. Monitoring the physicochemical features of sunflower oil and French fries during repeated microwave frying and deep-fat frying, *Grasas Aceites.* **68**, e202. http://dx.doi.org/10.3989/gya.1162162

Bagheri N, Dinani ST. 2019. Investigation of ultrasound-assisted convective drying process on quality characteristics and drying kinetics of zucchini slices. *Heat Mass Transf.* **55,** 2153-2163. https://doi.org/10.1007/s00231-019-02573-6

Barutcu I, Mccarthy M, Seo Y, Sahin S. 2009. Magnetic Resonance Temperature Mapping Of Microwave-Fried Chicken Fingers. *J. Food Sci.* **2,** 34-40. https://doi.org/10.1111/j.1750-3841.2009.01169.x

Baysal T, Icier F, Yildiz H, Demirdoven A. 2007. Effects of electroplasmolysis applications on yield and quality in pomegranate and cherry juice production. Ege University, Scientific Research Project-07 BIL 027, Turkey.

Bazhal M, Vorobiev E. 2000. Electrical treatment of apple cossettes for intensifying juice pressing. *J. Sci. Food Agric*. **80**, 1668–1674. https://doi.org/10.1002/1097-0010(20000901)80:11<1668::AID-JSFA692>3.0.CO;2-7.

Belkova B, Hradecky J, Hurkova K, Forstova V, Vaclavik L, Hajslova J. 2018. Impact of vacuum frying on quality of potato crisps and frying oil. *Food Chem.* **241**, 51–59. https://doi.org/10.1016/j.foodchem.2017.08.062

Çakmak Ş, Tekeoglu O, Bozkir H, Rayman A, Baysal T. 2016. Effects of electrical and sonication pretreatments on the drying rate and quality of mushrooms. *LWT- Food Sci. Technol.* **69**, 197-202. https://doi.org/10.1016/j.lwt.2016.01.032

Cemeroğlu B. 2010. *Gida Analizleri* (2nd ed). Ankara.

Cuccurullo G, Giordano L, Metallo A, Cinquanta L. 2017. Influence of mode stirrer and air renewal on controlled microwave drying of sliced zucchini, *Biosyst. Eng*. **158**, 95-101. https://doi.org/10.1016/j.biosystemseng.2017.03.012.

Devi S, Zhang M, Law. 2018. Effect of ultrasound and microwave assisted vacuum frying on mushroom (Agaricus bisporus) chips quality, *Food Biosci.* **25**, 111–117. https://doi.org/10.1016/j.fbio.2018.08.004

Dueik V, Robert P, Bouchon P. 2010. Vacuum frying reduces oil uptake and improves the quality parameters of carrot crisps, *Food Chem*. **119**, 1143–1149. https://doi.org/10.1016/j.foodchem.2009.08.027

Fan L, Zhang M, Xiao G, Sun J, Tao Q. 2005. The optimization of vacuum frying to dehydrate carrot chips. *Int. J. Food Sci. Technol.* **40,** 911–919. https://doi.org/10.1111/j.1365-2621.2005.00985.x

Fauster T, Schlossnikl D, Rath F, Ostermeier R, Teufel F, Toepfl S, Jaeger H. 2018. Impact of pulsed electric field (PEF) pretreatment on process performance of industrial French fries production, *J. Food Eng.* **235,** 16-22. https://doi.org/10.1016/j.jfoodeng.2018.04.023

Gharachorloo M, Ghavami M, Mahdiani M, Azizinezhad R. 2010. The Effects of Microwave Frying on Physicochemical Properties of Frying and Sunflower Oils, *J. Am. Oil Chem.' Soc*. **87,** 355–360. https://doi.org/10.1007/s11746-009-1508-y

Gökmen V, Palazoğlu TK, Şenyuva HZ. 2006. Relation between the acrylamide formation and time–temperature history of surface and core regions of French fries. *J. Food Eng*. **77**, 972–976. https://doi.org/10.1016/j.jfoodeng.2005.08.030

Hosseinzadeh S, Shaheed SA. 2015. The effect of osmotic dehydration on mass transfer and color changes in zucchini during the process of deep frying. *International Conference on Engineering and Applied Sciences*. https://www.civilica.com/Paper-ICEASCONF01

Huang M, Zhang M, Bhandar B. 2018. Synergistic effects of ultrasound and microwave on the pumpkin slices qualities during ultrasound-assisted microwave vacuum frying, *J. Food Process Eng*. **41,** e12835. https://doi.org/10.1111/jfpe.12835

Ignat A, Manzocco L, Brunton NP, Nicoli MC, Lyng GJ. 2015. The effect of pulsed electric field pre-treatments prior to deep-fat frying on quality aspects of potato fries, *Innov Food Sci Emerg Technol.* **9,** 65–69. https://doi.org/10.1016/j.ifset.2014.07.003

Iswaldi I, Gómez-Caravaca AM, Lozano-Sánchez J, Arráez-Román D, Segura-Carretero A, Fernández-Gutiérrez A.2013. Profiling of phenolic and other polar compounds in zucchini (Cucurbita pepo L.) byreverse-phase high-performance liquid chromatography coupled to quadrupole time-of-flight mass spectrometry. *Food Res. Int.* **50**, 77–84. https://doi.org/10.1016/j.foodres.2012.09.030

Janositz A, Noack, AK, Knorr D. 2011. Pulsed electric fields and their impact on the diffusion characteristics of potato slices, *LWT-Food Science Technol.* **44,** 1939-1945. https://doi.org/10.1016/j.lwt.2011.04.006

Jung MY, Choi DS, Ju, JW. 2003. A Novel Technique for Limitation of Acrylamide Formation in Fried and Baked Corn Chips and in French Fries. *J. Food Sci*. **68**, 1287-1290. https://doi.org/10.1111/j.1365-2621.2003.tb09641.x

Karacabey E, Özçelik ŞG, Turan MS, Baltacıoğlu C., Küçüköner E. 2016. Kızartılmış Kabak Dilimi Üretiminde Mikrodalga Destekli Ön Kurutma ve Derin Kızartma İşlem Koşullarının Optimizasyonu. *Academic Food J.* **14,** 141-150.

Krokida MK, Oreopoulou V, Maroulis ZB, Marinos-Kouris D. 2001. Colour changes during deep fat frying. *J. Food Eng.* **48***, 219–225.* doi:10.1016/s0260-8774(00)00161-8

Lebovka NI, Praporscic I, Vorobiev E. 2004. Effect of moderate thermal and pulsed electric field treatments on textural properties of carrots, potatoes and apples. *Innov. Food Sci. Emerg. Technol.* **5**, 9–16. https://doi.org/10.1016/j.ifset.2003.12.001

Liu T, Dodds E, Leong S, Eyres G, Burritt D, Oey I. 2017. Effect of pulsed electric fields on the structure and frying quality of "kumara" sweet potato tubers, *Innov. Food Sci. Emerg. Technol.* **39,** 197–208. https://doi.org/10.1016/j.ifset.2016.12.010

Moreira RG, Da Silva PF, Gomes C. 2009. The effect of a de-oiling mechanism on the production of high quality vacuum fried potato chips. *J. Food Eng.* **92,** 297–304. https://doi.org/10.1016/j.jfoodeng.2008.11.012

Ngadi M, Bazhal M, Raghavan GSV. 2003. Engineering aspects of pulsed electroplasmolysis of vegetable tissues. *Agric. Engin. Internat. Febr.* 436– 441.

Neves F, Silva CLM, Vieira MC. 2019. Combined pre-treatments effects on zucchini (*Cucurbita pepo* L.) squash microbial load reduction. *Int. J. Food Microbiol*. **305**, 108257. https://doi.org/10.1016/j.ijfoodmicro.2019.108257

Norma UNE 137005:2005 2020. https://www.une.org/encuentra-tu-norma/busca-tu-norma/norma?c=N0033212 [Google Scholr]

Oztop M, Sahin S, Sumnu G. 2007. Optimization of microwave frying of potato slices by using Taguchi technique, *J. Food Eng*. **79**, 83–91. https://doi.org/10.1016/j.jfoodeng.2006.01.031

Paciulli, M, Ganino T, Pellegrini N, Rinaldi M, Zaupa M, Fabbri A, Chiavaro E. 2015. Impact of the Industrial Freezing Process on Selected Vegetables - Part I. Structure, Texture and Antioxidant Capacity. *Food Res. Int.* **74,** 329-337. https://doi.org/10.1016/j.foodres.2014.04.019

Parikh A, Takhar S. 2016. Comparison of microwave and conventional frying on quality attributes and fat content of potatoes. *J. Food Sci*. **81,** e2743–e2755. https://doi.org/ 10.1111/1750-3841.13498

Quan X, Zhang M, Zhang W, Adhikari B. 2014. Effect of Microwave-Assisted Vacuum Frying on the Quality of Potato Chips. *Dry. Technol*. **32,** 1812–1819. https://doi.org/10.1080/07373937.2014.947428.

Rayman A, Baysal T, Demirdöven A. 2011. Optimisation of electroplasmolysis application for increased juice yield in carrot juice production. *Int. J. Food Sci. Technol*. **46,** 781-786. https://doi.org/10.1111/j.1365-2621.2011.02561.x

Rodrigues S, Oliveira FIP, Gallao MI, Fernandes FAN. 2009. Effect of ›mmersion time in osmosis and ultrasound on papaya cell structure during dehydration. *Dry. Technol.* **27,** 220–225. https://doi.org/10.1080/07373930802605883

Sahin S, Sumnu G, Oztop MH. 2007. Effect of osmotic pretreatment and microwave frying on acrylamide formation in potato *s*trips *J. Sci. Food Agric.* **87**, 2830–2836. https://doi.org/10.1002/jfsa.3034.

Sansano M., De los Reyes R, Andres A, Heredia A. 2018. Effect of Microwave Frying on Acrylamide Generation, Mass Transfer, Color, and Texture in French Fries. *Food Bıoprocess Tech*. **11,** 1934–1939. https://doi.org/10.1007/s11947-018-2144-z

Shaker MA. 2015. Comparison between traditional deep-fat frying and air-frying for production of healthy fried potato strips. *Int Food Res J.* **22,** 1557-1563.

Sham P, Scaman, Durance T. 2001. Texture of Vacuum Microwave Dehydrated Apple Chips as Affected by Calcium Pretreatment, Vacuum Level, and Apple Variety. *J. Food Sci.* **66**, 1341–1347. https://doi.org/10.1111/j.1365-2621.2001.tb15212.x.

Su Y, Zhang M, Zhang W, Adhikari B, Yang Z. 2016. Application of Novel Microwave-Assisted Vacuum Frying to Reduce the Oil Uptake and Improve the Quality of Potato Chips. *LWT – Food Sci. Technol.* **73**, 490–497. https://doi.org/10.1016/j.lwt.2016.06.047.

Su Y, Zhang M, Zhang W, Liu C, Adhikari B. 2018. Ultrasonic microwave-assisted vacuum fryingtechnique as a novel frying method for potatochips at low frying temperature. *Food Bioprod. Process*. **108,** 95–104. https://doi.org/10.1016/j.fbp.2018.02.001

Sun Y, Zhang, Fan D. 2019. Effect of ultrasonic on deterioration of oil in microwave vacuum frying and prediction of frying oil quality based on low field nuclear magnetic resonance (LF-NMR). *Ultrason Sonochem.* **51**, 77–89. https://doi.org/10.1016/j.ultsonch.2018.10.015

Tejada L, Buendía-Moreno L, Villegas A, Cayuela JM, Bueno-Gavilá E, Gómez P, Abellán A. 2020. Nutritional and sensorial characteristics of zucchini (*Cucurbita pepo* L.) as affected by freezing and the culinary treatment. . *Int. J. Food Prop*. **23**, 1825-1833. https://doi.org/ 10.1080/10942912.2020.1826512

Troncoso E, Pedreschi F, Zuniga RN. 2009. Comparative study of physical and sensory properties of pre-treated potato slices during vacuum and atmospheric frying. *LWT - Food Scı Technol.* **42,** 187–195. https://doi.org/10.1016/j.lwt.2008.05.013

Tuta S, Palazoglu TK, Gokmen V. 2010. Effect of microwave pre-thawing of frozen potato strips on acrylamide level and quality of French fries. *J. Food Eng*. **97,** 261–266. https://doi.org/10.1016/j.jfoodeng.2009.10.020.