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Original research

Effect of processing conditions on some quality characteristics of vacuum-fried onion slices (*Allium cepa* L.) at various pre-frying treatments

Simin Nobahari[a], Alireza Bassiri[b,*]

[a] *Food Science and Technology Department, Islamic Azad University, Mako, Iran*
[b] *Institute of Chemical Technologies, Iranian Research Organization of Science and Technology (IROST), Tehran, Iran*

ABSTRACT

Effects of pretreatments (blanching, air-drying, osmotic dehydration and freezing) and process parameters: frying temperature (100, 110 and 120°C) and frying time: (180, 300 and 420 s) at constant vacuum pressure of 70 mbar on some quality characteristics of vacuum fried onion chips (oil uptake, shrinkage, breaking force, and total color difference) were studied. The results showed that frying temperature and frying time at all pretreatments had a significant effect ($p \leq 0.05$) on oil uptake and shrinkage, as well as total color difference and breaking force of vacuum fried onion chips. The results demonstrated that the oil uptake, shrinkage and total color difference of the fried onion chips increased, while breaking force decreased with increasing frying temperature and time. The results showed that the different pretreatments before vacuum frying influenced significantly ($p \leq 0.05$) the quality characteristics of vacuum fried onion chips. At the same frying temperatures and frying times, the lowest oil uptakes were observed in osmotic dehydrated samples, followed by air-dried and then blanched samples. Freezing pretreated onion samples show the highest o oil uptake ($p \leq 0.05$) than other pretreatments. Freezing pretreatment resulted in minimum shrinkage, compared to other pretreatments ($p \leq 0.05$) followed by osmotic dehydrated samples. Shrinkage in air drying and blanching pre-treated samples did not differ significantly. Osmotic dehydration pretreated onion samples show less breaking force ($p \leq 0.05$) than other pretreatments followed by air-dried pretreated onion samples while blanching and freezing pretreatment resulted in minimum crispiness. At the same temperatures and frying times, the lowest levels of total color difference were observed in blanched samples, followed by osmotic dehydrated and then the air-dried samples. Freezing pretreated onion samples show the highest levels of total color difference ($p \leq 0.05$) than other pretreatments.

Keywords: Vacuum frying; Pre-frying treatments; Onion; Quality characteristics

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1. Introduction

Deep fat frying is an established process of food preparation world-wide which achieves desirable textures and flavors in a variety of foods. Taste, texture, surface color and oil uptake are important interrelated attributes of deep fat fried products (Hu et al., 2019). It is a simultaneous heat and mass transfer process during which foods lose water and absorb oil/fat while many adverse reactions take place because of high temperature treatment under atmospheric pressure before the food is fully cooked or dried (Angie et al., 2020). Vacuum frying works at lower pressure and temperature and is a promising technique for healthier fried foods with many advantages including lowering the oil absorption; keeping natural color and flavor; preserving more vitamins and minerals; and decreasing the formation of carcinogenic toxins (e.g., acrylamide and furan) (Dueik & Bouchon, 2011; Moreira, 2014). Indeed, this technology has been reported to successfully produce vacuum-fried chips of many fruits and vegetables such as potatoes, banana, carrots, apples, and kiwifruit (Belkova et al., 2018; Diamante et al., 2012a). The effects of various pretreatments such as blanching, osmotic dehydration, pre-drying and freezing on processing of fruits and vegetables and quality characteristics of products have been investigated in the past (Ayustaningwarno et al., 2017). Thermal blanching is an essential operation for many fruits and vegetables processing. It not only contributes to the

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*Corresponding author.
E-mail address: bassiri@irost.ir (A. Bassiri).

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inactivation of polyphenol oxidase (PPO), peroxidase (POD), but also increases drying rate of some products, it could reduce oil absorption by gelatinization of surface starch and forms a compact appearance with less pores and air cells and it also affects other quality attributes of products (Xiao et al., 2017). Numerous studies have been carried out for optimizing the operational parameters and design of blanching pretreatment for different vegetables and fruits such as potato chips, carrot, mango slices, garlic slices (Kidmose & Martens, 1999; Negi & Roy, 2001; Ndiaye et al., 2009; Fante & Norena, 2012; Wang et al., 2018). Limited research has been carried out on the effect of blanching pretreatment on the frying process. Fan et al. (2006) investigated the effects of blanching and other pretreatments on the physicochemical properties and fat distribution in vacuum-fried carrot chips. The results showed that Pretreatments significantly affected the moisture content, fat content, and water activity of carrot chips ($p \leq 0.05$), while there were no significant differences in the breaking force of carrot chips treated with different pretreatments ($p \leq 0.05$). Osmotic dehydration is a mild, non-thermal treatment, mainly used as a pre-processing step of preservation methods (such as drying or freezing), that refers to the immersion of a food material in a hypertonic solution (of carbohydrates, salts, and other ingredients). Osmotic dehydration is a viable process for partial removal of water from cellular materials, such as fruits and vegetables, without a phase change that reduces the physical, chemical and biological changes during drying at higher temperatures. The process results in modification of the fruit tissue which can be tailored toward compositional, textural, and sensorial quality of vacuum-fried fruit. Many researchers have investigated the influence of osmotic dehydration prior to conventional drying on the physico-chemical characteristics of products (Pavkov et al., 2021; Assis et al., 2017; Rigi et al., 2020; Rodriguez et al., 2019; Turkiewiez et at., 2020; Bae et al., 2020). There are only a few studies in the literature that investigate the effect of osmotic dehydration pretreatment on frying process. Piyalungka et al. (2019) showed that osmotic dehydration pretreatment reduced the oil absorption by 16 % (db) and enhanced approximately 70% of carotenoid retention as compared to untreated of vacuum-fried pumpkin chips. Air drying can be used as a pre-treatment before the frying operations. Air drying reduces moisture content and form a crust which produce a high resistance to oil absorption during vacuum frying. Previous studies have reported that the air-drying pretreatment significantly reduces oil absorption and improves texture in fried chips (Liberty et al., 2019; Cruz et al., 2018). Freezing products before drying or frying may also increase the rate of process and quality characteristics of end products (Diamante et al., 2012b). Shyu and Hwang (2001) found that freezing at -30°C overnight formed a porous sponge-like matrix in vacuum-fried apples. In fact, due to fast heat transfer to frozen tissue, ice crystal inside the frozen cells sublimed under vacuum condition leaving pores in the food matrix accelerated the moisture loss and sequentially decrease the final moisture content. Albertos et al. (2016) found that moisture content in vacuum-fried carrot was lower in sample with -20°C blast freezing followed by overnight freezing pre-treatment compared to not frozen sample. Common onion (*Allium cepa* L.) is one of the oldest and the most consumed vegetables in the world, appreciated for its flavor and used in salads, seasonings, soups and several other types of prepares. This species is known to contain sulphur amino acids together with many vitamins and minerals. A variety of secondary metabolites, including flavonoids, phytosterols and saponins, have also been identified (Marrelli et al., 2018). The onions are perishable commodity and cannot be stored for a long time after harvest in an ordinary condition. Processing and preservation of onion by suitable means is a major thrust area since a long time.

Onion is mainly processed into dehydrated, canned and onion pickle. Deep fat fried onion slices are a popular ingredient and condiment used for many food preparations like pizzas, ready meals, sandwiches, salads, specialty breads (Das Gupta et al., 2003). Yoshida et al. (2017) reported that average value of acrylamide in under atmospheric conditions fried onion samples at homes was 36 ng/g. Ramesh Babu (2017) studied the effects of frying temperature, frying time and pre-fry-drying time on kinetics of moisture loss, oil uptake and color development of onion slices during frying. He stated that increasing the frying temperature increases moisture loss and oil uptake. As the pre-fry drying time increased, it resulted in a decrease for moisture loss and oil uptake. Drying pretreatment reduced the oil content by 22.88 per cent. Salehi (2019) found that the frying temperature had a negative effect on the brightness of the under atmospheric pressure fried onion slices and, with increasing process temperature, the brightness parameter decreased at the same time. The results of this experiment showed that most of the color changes occur in the early stages of the process. Higher temperatures increased the yellowness and redness of the onion surface from 14.24 to 29.31 and 5.73 to 17.86, respectively. Kumar and Babu (2007) investigated the effect of frying conditions on quality of fried onion slices and found that an increase in frying temperature, decreased the frying time and increased the oil uptake ratio of onion slices. A significant decrease in sensory scores was observed when frying temperature was above 180°C. Other factors affecting the quality of fried onion slices were frying medium, slice thickness and initial moisture content. Therdthai et al. (2007) studied the effect of vacuum frying conditions on oil uptake of fried shallot slices by comparing it with the deep fat frying process under atmospheric pressure. Optimum vacuum frying conditions for shallot slices were a frying temperature of 108°C, vacuum pressure of 551 mm Hg and frying time of 13 min.

Given the lack of studies in the published literature on the effects of pre-fry treatments and processing conditions on quality of vacuum-fried onion slices the present study was designed to determine the effects of pretreatments (blanching, air-drying, osmotic dehydration and freezing) and processing condition (frying temperature and time) on some quality parameters of vacuum-fried onion chips (oil uptake, shrinkage, breaking force, and total color difference).

2. Material and Methods

2.1. *Raw material*

Fresh onions bulbs (Var-Nasik red) of uniform size, whole, healthy, free of any debris were obtained from local market. They were stored at 4°C for two weeks prior to experiments so that the storage conditions would be kept the same for all samples before vacuum frying. Soybean oil was used as the frying medium and it was also purchased from a local market.

2.2. *Samples preparation*

To start the experiments, the required numbers of onions were taken out of the Refrigerator and kept at room temperature for 2 h, until they adapt to room conditions. Then the Onions were peeled and cut into uniform circular pieces, of 3 cm diameter and 4 mm thickness. Onion slices were rinsed with water for 15s and blotted with paper towels to remove surface water (Nikzad et al., 2021). Four different pretreatments of onion slices prior to vacuum frying carried out in this study: (A) blanching was done by placing the samples in boiling brine (2% salt content) for 2min, cooling under running tap water for 3min, draining on absorbent paper until the surface was nearly dry, (B) Osmotic dehydration was performed by placing the onion slices in osmotic solution (20% salt content) at room temperature for 1h. Solution to sample ratio was kept as 10:1. The samples were washed for 30s with tap water. After a period of 1h, slices were removed quickly and blotted gently using a tissue paper to remove the surface moisture (C) Air drying pretreatment of the onion slices was carried out in a cabinet dryer with air circulation at 60°C for 60 min, (D) Freezing pretreatment was performed by placing the onion slices in a freezer at -18°C for 24 h (Fan et al., 2006).

2.3. *Vacuum frying system*

A laboratory scale vacuum frying system (schematic diagram Fig. 1) was used to carry out the experiments. The vacuum pump provides the required reduced pressure (70 mbar) for the process. The frying basket was fixed to a rod. The basket rod was held by a shaft seal attached on the center of the vessel lid. The shaft seal allowed motion of the shaft along with the basket up and down, so that the samples could be moved either into the oil while frying or above the oil after frying. A hot plate with a magnetic stirrer was used for heating and providing the desired temperature uniformity of the frying oil.

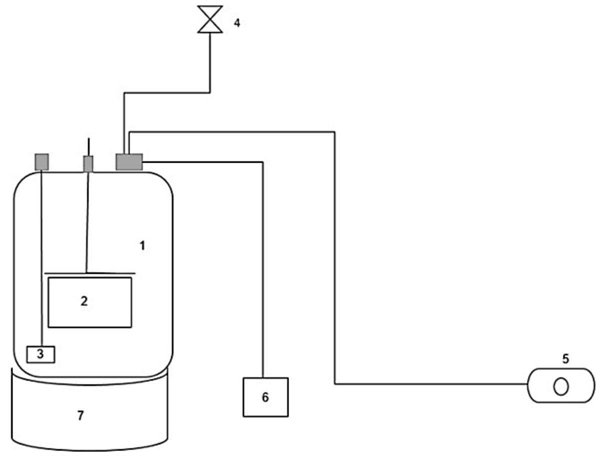

Fig. 1. Schematic view of the Lab-scale vacuum frying system (1. Vacuum frying chamber, 2. Carrier basket, 3. Thermometer, 4. Pressure relief valve, 5. Vacuum pump, 6. Pressure gauge, 7. Electrical heater).

2.4. *Vacuum frying experiments*

Once the oil reached frying temperature, 50 g onion slices were placed in the frying basket and the slices were then covered with a grid to prevent them from floating and then the vessel lid was closed and the vessel depressurized. When the pressure inside the vessel reached the desired level (70 mbar), the basket was immersed in the frying oil for different frying times. The sample holder was 2 cm below the oil surface and 2 cm above the bottom of the frying vessel. After each frying time, the basket was lifted out and left to stand for 1min and the vessel was pressurized. Vacuum fried onion chips were gently blotted with paper towels to remove oil droplets, cooled at room temperature and stored in PE bags for further analysis (Fan et al., 2006). Therefore, the oil temperatures used were 100, 110 and 120°C, and the frying times used ranged from 180 to 420 s, which were established by preliminary tests. Fig. 2 showed the flow diagram for processing of vacuum-fried onion chips.

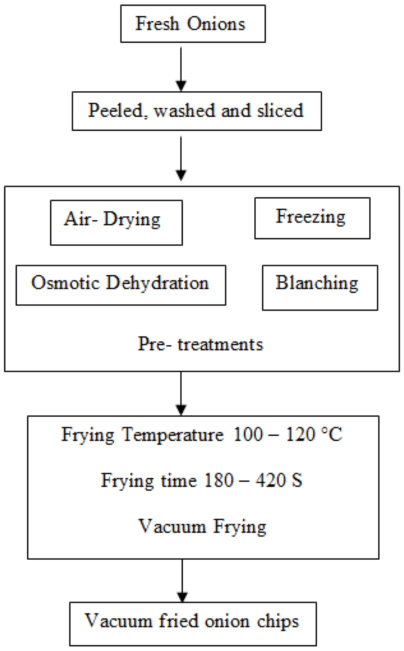

Fig. 2. Flow diagram for processing of vacuum-fried onion chips.

2.5. *Analysis of quality characteristics*

2.5.1. *Moisture content*

For moisture content analysis an oven dry method was used (AOAC, 1990). Samples (2–3 g) were dried at 103 ± 2℃ until the constant weight was obtained.

2.5.2. *Oil uptake*

Vacuum-fried onion chips were ground and oven-dried. Oil was extracted for 6 h in a Soxhlet apparatus with hexane according to the AOAC official method 972.28 (AOAC, 1990).

2.5.3. *Color indexes*

The color parameters [L* (lightness), a* (redness), b* (yellowness)] of the samples were measured using a Hunter Lab Colorimeter (Minolta CR-400, Japan). The apparatus was calibrated with white and black ceramic plates. The samples were examined at three different positions and the average values of three replicate measurements are reported. Finally, the total color difference (ΔE) between the initial color values of onion samples (L^*_0, a^*_0 and b^*_0) and vacuum fried onion slices (L^*, a^* and b^*) was determined using Eq. (1) given below (Song et al., 2007):

$$\Delta E = \frac{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}{2} \qquad (1)$$

2.5.4. *Breaking force*

The texture analyzer (Micro Systems Ltd, UK) was used for breaking force determination. The onion chip was placed over the end of a hollow cylinder. A stainless-steel ball probe moving at a speed of 5 mm/s was used to break the chip (Diamante et al., 2012a).

2.5.5. *Shrinkage*

The vacuum fried samples were defatted for 6 h with chloroform before measurement of shrinkage. The shrinkage percentage of vacuum fried onion chips was calculated using liquid displacement method (Mohsenin, 1986). In this method for decrease of liquid absorption by fried samples the toluene was used. Shrinkage of vacuum fried onion slices was calculated using Eq. (2) given below:

$$SKG\ (\%) = \left(1 - \frac{V}{V_0}\right) \times 100 \qquad (2)$$

where V_0 and V denote the initial and fried volume of the same onion slice, respectively.

2.6. *Statistical analysis*

In the present study, a factorial experiment was used in a completely randomized design to analyze the data. The mean comparison was conducted by Duncan's multiple range test at $\alpha = 5\%$ using SAS software (SAS, 2016). All the measurements made in this study were made at least in triplicate.

3. Results and Discussion

3.1. *Oil uptake*

The oil uptake is one of the most important attributes of fried foods. Growing consumer trends towards healthier and low-fat products have had a significant impact on the snack industry to produce lower oil content products that still retain desirable texture and flavor. Effects of frying temperature and frying time on oil uptake of vacuum fried onion chips with different pretreatments were shown in Tables 1-4. The oil uptake of vacuum fried onion chips at all pretreatments increased with increases in frying temperature and time. Elevated temperatures induced more expansion of tissue and pores in the food matrix. As a result, oil adhesion on the pore was higher (Sobukola et al., 2013). Similar trends were reported for potato chips (Garayo & Moreira, 2002) and vacuum fried gilthead sea bream (*Sparus aurata*) fillets (Andreas-Bello et al., 2010). Depending on the type of pre-treatment, level of oil uptake also changed significantly ($p \leq 0.05$) among the samples. The pretreatment of onion slices with osmotic dehydration and air drying resulted in significant reduction in the oil uptake compared to other pretreatments. This might suggest that these pretreatments significantly reduced the initial moisture content of samples and formation of outer crust on the surface of slices during pre-treatment (Krokida et al., 2001). Lower oil uptake in osmotically pretreated samples compared to air dried onion slices might be due to the soluble solids from osmotic solution penetrating to the food matrix (Garcia et al., 2002). Blanching has been reported as a pretreatment operation that could reduce the oil uptake by gelatinization of surface starch and expulsion of air between the cells (Xin et al., 2015), this reduction of air can reduce the porous space that can be occupied by oil during frying process, whereas, high initial moisture content and formation of ice crystals during freezing pre-treatment might be broken the cell wall of sample tissues which leads to formation of voids, porous and spongy structure during frying (Shyu et al., 2001). This spongy, porous structure of sample due freezing pre-treatment might be responsible for comparatively high oil uptake (Ren et al., 2018).

3.2. *Shrinkage*

Shrinkage is very important in characterizing the structure of processed food. Shrinkage is a normal phenomenon for products during deep-fat frying. It is defined as change in volume caused by water loss, reduction of open pores, protein denaturation and an increase in the density of fried products (Wang et al., 2010). Effects of frying temperature and frying time on shrinkage of vacuum fried onion chips with different pretreatments were shown in Tables 1-4. The shrinkage of vacuum fried onion chips at all pretreatments increased significantly ($p \leq 0.05$) with increasing frying temperature and time. The increase of frying temperature and time increase the volume of water removed, since the more the water removed the more contraction stresses and in the same proportion more shrinkage are originated in the material. It has been reported in fried sweet potatoes that shrinkage is more pronounced with increased frying time and higher frying temperatures. Fathi et al. (2011) found that shrinkage of dried kiwifruit increased as the drying time and temperature increased. The results show that pretreatments before frying significantly ($p \leq 0.05$) influenced the shrinkage of vacuum fried onion chips. Freezing pretreatment resulted in minimum shrinkage, compared to other pretreatments ($p \leq 0.05$). However, evaporation of moisture formed voids in freezing pre-treated samples which might be filled with air after frying and resulted in less shrinkage or collapse. Osmotic dehydration pretreated onion samples show less shrinkage ($p \leq 0.05$) than blanching and air-drying pretreatments. The volume occupied by osmotic agent impregnated in the tissue due to osmotic dehydration treatment avoided the structural collapse and hence further shrinkage (Garcia et al., 2016). Shyu et al. (2001) showed that osmotic dehydration in fructose solution produced chips with uniform porosity and reduced surface shrinkage of apple chips resulting in a smoother surface. Fan et al. (2006) demonstrated that osmotic dehydration and freezing treatments prior to vacuum frying improved the porosity of carrot chips and reduced the surface shrinkage. Shrinkage in air drying and blanching pretreated samples did not differ significantly ($p \leq 0.05$). Formation of outer crust on the surface and change in microstructural properties during air drying pretreatment might be responsible for high shrinkage. Taiwo and Baik (2007) also observed similar changes in shrinkage of sweet potato chips due to air drying pretreatments.

Table 1. Effects of frying temperature and time with blanching as pretreatment on the oil uptake, shrinkage, breaking force and total color difference (ΔE) of vacuum fried onion chips.

Time (s)	Oil uptake (%)			Shrinkage (%)			Breaking force (N)			ΔE		
	100°C	110°C	120°C	100°C	110°C	120°C	100°C	110°C	120°C	100°C	110°C	120°C
180	28.9^{Aa}	29.3^{Ab}	32.7^{Ac}	67.1^{Aa}	68.1^{Ab}	69.8^{Ac}	3.4^{Aa}	3.1^{Ab}	2.8^{Ac}	61.3^{Aa}	63.5^{Ab}	65.0^{Ac}
300	31.3^{Ba}	33.5^{Bb}	35.1^{Bc}	68.4^{Ba}	69.9^{Bb}	70.9^{Bc}	3.1^{Ba}	2.8^{Bb}	2.5^{Bc}	62.2^{Ba}	63.9^{Bb}	66.2^{Bc}
420	33.7^{Ca}	35.4^{Cb}	37.3^{Cc}	69.2^{Ca}	70.0^{Cb}	72.3^{Cc}	2.7^{Ca}	2.4^{Cb}	2.1^{Cc}	64.5^{Ca}	66.0^{Cb}	67.3^{Cc}

Different uppercase letters in the column denote a statistically significant difference ($p \leq 0.05$). Different lowercase letters in the row denote a statistically significant difference ($p \leq 0.05$).

Table 2. Effects of frying temperature and time with air drying as pretreatment on the oil uptake, shrinkage, breaking force and total color difference (ΔE) of vacuum fried onion chips.

Time (s)	Oil uptake (%)			Shrinkage (%)			Breaking force (N)			ΔE		
	100°C	110°C	120°C	100°C	110°C	120°C	100°C	110°C	120°C	100°C	110°C	120°C
180	26.4^{Aa}	28.5^{Ab}	31.1^{Ac}	67.2^{Aa}	67.9^{Ab}	69.3^{Ac}	3.1^{Aa}	2.9^{Ab}	2.8^{Ac}	64.8^{Aa}	66.9^{Ab}	68.6^{Ac}
300	28.2^{Ba}	31.5^{Bb}	33.6^{Bc}	68.2^{Ba}	69.8^{Bb}	70.8^{Bc}	2.9^{Ba}	2.7^{Bb}	2.5^{Bc}	66.1^{Ba}	68.1^{Bb}	70.3^{Bc}
420	31.5^{Ca}	33.8^{Cb}	35.7^{Cc}	69.1^{Ca}	69.9^{Cb}	72.3^{Cc}	2.8^{Ca}	2.5^{Cb}	2.3^{Cc}	68.7^{Ca}	69.9^{Cb}	71.7^{Cc}

Different uppercase letters in the column denote a statistically significant difference ($p \leq 0.05$). Different lowercase letters in the row denote a statistically significant difference ($p \leq 0.05$).

Table 3. Effects of frying temperature and time with osmotic dehydration as pretreatment on the oil uptake, shrinkage, breaking force and total color difference (ΔE) of vacuum fried onion chips.

Time (s)	Oil uptake (%)			Shrinkage (%)			Breaking force (N)			ΔE		
	100°C	110°C	120°C	100°C	110°C	120°C	100°C	110°C	120°C	100°C	110°C	120°C
180	24.2^{Aa}	26.4^{Ab}	29.1^{Ac}	63.3^{Aa}	64.8^{Ab}	65.5^{Ac}	2.3^{Aa}	2.1^{Ab}	1.8^{Ac}	63.1^{Aa}	66.2^{Ab}	67.7^{Ac}
300	26.8^{Ba}	28.2^{Bb}	31.1^{Bc}	63.9^{Ba}	65.3^{Bb}	66.1^{Bc}	2.0^{Ba}	1.7^{Bb}	1.5^{Bc}	65.3^{Ba}	67.9^{Bb}	69.1^{Bc}
420	28.5^{Ca}	31.2^{Cb}	33.2^{Cc}	64.5^{Ca}	66.0^{Cb}	67.3^{Cc}	1.8^{Ca}	1.5^{Cb}	1.3^{Cc}	67.2^{Ca}	68.1^{Cb}	70.4^{Cc}

Different uppercase letters in the column denote a statistically significant difference ($p \leq 0.05$). Different lowercase letters in the row denote a statistically significant difference ($p \leq 0.05$).

Table 4. Effects of frying temperature and time with freezing as pretreatment on the oil uptake, shrinkage, breaking force and total color difference (ΔE) of vacuum fried onion chips.

Time (s)	Oil uptake (%)			Shrinkage (%)			Breaking force (N)			ΔE		
	100°C	110°C	120°C	100°C	110°C	120°C	100°C	110°C	120°C	100°C	110°C	120°C
180	29.2^{Aa}	30.9^{Ab}	31.7^{Ac}	60.9^{Aa}	61.5^{Ab}	62.3^{Ac}	3.3^{Aa}	3.0^{Ab}	2.7^{Ac}	66.1^{Aa}	68.8^{Ab}	70.6^{Ac}
300	30.5^{Ba}	32.1^{Bb}	33.4^{Bc}	61.5^{Ba}	62.2^{Bb}	63.7^{Bc}	3.1^{Ba}	2.7^{Bb}	2.5^{Bc}	68.2^{Ba}	70.5^{Bb}	72.2^{Bc}
420	31.7^{Ca}	33.4^{Cb}	35.7^{Cc}	62.3^{Ca}	63.3^{Cb}	64.4^{Cc}	2.8^{Ca}	2.5^{Cb}	2.3^{Cc}	70.6^{Ca}	71.9^{Cb}	73.6^{Cc}

Different uppercase letters in the column denote a statistically significant difference ($p \leq 0.05$). Different lowercase letters in the row denote a statistically significant difference ($p \leq 0.05$).

Krokida et al. (2001) suggested that pre-drying before frying could decrease the proportion of open pores that subsequently increased volume shrinkage. It has been reported that a product with lower initial moisture content and higher initial porosity has more tendency to build up pressure within the pores during frying thus causing an enlargement of the intercellular spaces (Moreira et al., 2014). This may account for the higher volume change in blanched and air-dried products.

3.3. *Breaking force*

Texture is one of the prominent quality factors of fried chips, and crispness in particular is correlated with chip acceptability (Ayustaningwarno et al., 2017). The change of texture in fried products is a result coupled heat and mass transfer together with chemical changes occurring during the frying process. The force required to break the fried chips can be used as an indicator of crispness of the chips (Su et al., 2018). The lower values of breaking force indicated higher crispy texture of vacuum fried onions. The breaking force of vacuum fried onions obtained from different frying temperatures and frying times at different pretreatments is presented in Tables 1-4. It was found that the frying temperature and frying time affected significantly ($p \leq 0.05$) the breaking force. The breaking force was decreased when the frying temperature and frying time increased. Shyu and Hwang (2001) observed that by increasing the frying temperature and frying time, lower values of breaking force were obtained. Shyu and Hwang (2001) found that increasing of frying time (from 5 to 30 min) leads to a higher crispness of apple chips. Osmotic dehydration pretreated onion samples show less breaking force ($p \leq 0.05$) than other pretreatments. Shyu and Hwang (2001) showed that osmotic dehydration by 30-40% fructose resulted in crispy texture of apple chips measured as low maximum breaking force. Additionally, Diamante et al. (2012b) observed immersion with dextrose 55% increases crunchy texture of gold kiwifruit. Air-dried pretreated onion samples less breaking force ($p \leq 0.05$) than blanching and freezing pretreatments. Such phenomenon could have been caused by a large formation of crust due to microstructural changes in the tissues of fried products (Garcia-Segovia et al., 2016). Wang et al. (2014) suggested that the breaking force of products can be appropriately affected by the pre-drying treatment. Kothakota et al. (2013) reported that the pre-drying treatment have a significant impact on texture of potato chips. Blanching and Freezing pretreatment resulted in minimum crispiness as a result of substantial dissolution, depolymerization and apparent destruction of cell wall pectins. Roy et al. (2001) reported that freezing or blanching of carrots slices resulted in considerable softening of tissues and loss in firmness.

3.4. *Total color difference (ΔE)*

Color is a critical parameter in the frying industry as it is usually the first quality attribute evaluated by consumers. Total color difference (ΔE) is the important physical characteristics of fried products and directly related to the acceptability of food products. The changes in total color difference (ΔE) of vacuum fried onion chips at various pretreatments are shown in Tables 1-4. Results showed ΔE value increased significantly ($p \leq 0.05$) with increasing frying temperature and frying time. These results indicate that non-enzymatic reactions, which depend on the content of reducing sugars and amino acids or proteins on the surface, took place at a higher rate when the process time and temperature was increased, regardless of pretreatment is applied. Oztop et al. (2007) found that the total color difference (ΔE) of potato chips increased as frying time increased. On the other hand, Dueik and Bouchon (2011) found that time and temperatures are the factors with the greatest influence on ΔE. Shyu et al. (2005) observed that ΔE of carrot chips increased with increasing temperature (between 70 and 110 ºC) and frying times (between 300 and 1800 s). Vacuum frying of potato chips was studied by Garayo and Moreira (2002). They reported that the change in total color difference was affected by frying conditions. The effects of pretreatments on the total color changes of vacuum-fried onion chips can be seen in Tables 1-4. The statistical analysis showed that pretreatments significantly affected the total color difference (ΔE) of onion chips ($p \leq 0.05$). At the same temperatures and frying times, the lowest levels of ΔE were observed in blanched samples, followed by osmotic dehydrated and then the air-dried samples. Freezing pretreated onion samples show the highest levels of ΔE ($p \leq 0.05$) than other pretreatments. Similar trends were reported for fried potato chips (Pedreschi et al., 2005).

4. Conclusion

Statistical analysis of the experimental data showed that an increase of frying temperature and frying time have a negative effect on vacuum fried onion chips characteristics at all pretreatments. The results showed that the different pretreatments before vacuum frying influenced significantly the quality characteristics of vacuum fried onion chips. The lowest oil uptake and breaking force were observed in osmotic dehydrated samples than the other pretreatments, while freezing pretreatment resulted in minimum shrinkage, compared to other pretreatments. The lowest levels of total color difference were observed in blanched samples.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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