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Quality Changes in Nuggets and Frying Oils due to Repeated Deep Frying: A Comprehensive Study

Zehra Eygü, Şeyma Şişik Oğraş* and Hatice Kaya

Institute of Food Sciences and Technology, Ataturk University, Erzurum, Turkey

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Abstract:

In this study, it was aimed to determine the effects of nuggets produced using turkey meat by repeated frying in olive oil under atmospheric and pressure frying conditions on some physicochemical and instrumental texture properties of nuggets and some quality properties (free fatty acid, peroxide value and total polar compound) of frying oil. While pressure frying increased the moisture value of the samples, the moisture values of the samples decreased as the number of frying repetitions increased. A higher TBARS value was determined in atmospheric frying compared to pressure frying (p<0,01), and the TBARS value of the samples increased as the number of frying repetitions increased. Pressure frying increased the L* and b* values and decreased the a* value in the internal and external surface of the samples (p<0,05). While the number of frying factor did not cause a significant difference (p>0,05), on the color values in the internal surface, as the number of frying increased, the L* and b* values of the samples decreased and the a* values increased. While pressure frying process increased the hardness, resilience, cohesiveness, springiness, gumminess and chewiness values in nuggets (p<0,01), frying method had no significant effect on adhesiveness (p>0,05). It was determined that the frying method and the number of frying repetitions factors had a very significant effect (p<0,01) on the free fatty acid, peroxide value and total polar substance content of the oils.

*Corresponding Author
E-mail: seymasisik@atauni.edu.tr

INTRODUCTION

Deep frying is one of the oldest cooking methods [1] and is widely used in households and industries due to its simple and convenient preparation method and the sensory characteristics of the product [2-5]. Deep frying can be done in three ways depending on the temperature and pressure conditions applied: atmospheric, vacuum [6] or high-pressure conditions [7]. Atmospheric frying, one of the most widely used frying methods, is a process of immersing food in a solid/liquid oil at 150 to 200 °C [8]. This method is one of the best cooking techniques to obtain more delicious foods with golden color [9], good taste and desired texture by completely immersing the food in frying oil [10]. However, since this method can produce negative results in the production of some vegetable and meat products, studies on alternative frying methods have increased in recent years. Vacuum frying at low pressure (<6.65 kPa), a method used to fry delicate products [6], and high pressure frying at a pressure of ˜184 kPa, which is usually used for deboned poultry meat (legs, wings, etc.), are alternatives to traditional frying [7]. Such alternatives should contain less oil and more original properties than fried foods [11]. Compared to traditional deep-frying at room temperature, pressure frying can produce juicier, well-cooked and crispier products [7] and therefore it is considered a better solution for producing healthy and high-quality products [12]. For adequate and balanced nutrition, the human body requires animal proteins and essential components. This need is the best met by the production and consumption of poultry meat [13]. Poultry meat consumption is a cost-effective and efficient source to meet human protein needs [14]. Processed poultry meat products are preferred by consumers with a wide range of products and by manufacturers due to their high added value and profitability [15]. When comparing slaughtered animal meat with poultry meat, the protein content in poultry meat is higher [16]. Chicken meat has a large share in poultry meat consumption in our country. Recently, turkey meat is increasingly consumed not only for the traditional New Year meal, but also as carcasses, piece meat and minced meat or processed meat products such as salami, sausage and smoked meat [17]. Turkey meat, with a protein content of 20%, is an important alternative to products usually made from chicken meat [18, 19]. Breaded products in particular have an important share in this respect [15]. Chicken nuggets are the most demanded product among poultry meat products and are a type of meat product that is breaded with a liquid and then coated with a dry breading such as flour [20-23]. There is only one study in the literature on the use of turkey meat in nugget production [24]. However, no study on repeated frying of turkey nuggets under pressure and atmospheric conditions was found in the literature. On the other hand, atmospheric frying is the generally preferred frying method for frying this type of products. There are also very few studies on the use of pressure frying in this type of products [7, 25, 26]. In this study, the effects of turkey meat-derived nuggets on various physicochemical and instrumental textural parameters and some quality characteristics such as peroxide value, free fatty acids and the amount of polar substances of the olive oil used in frying were investigated by repeated frying (6 repetitions) in olive oil under atmospheric and pressurized frying conditions.

MATERIALS AND METHODS

Material

In the study, the meat used (turkey legs and breast) was purchased from a national market. Before using the meat, excess fat and bone parts of the meat with bones were removed. The meat was passed through a meat grinder (3 mm mirror) to be used in the nugget dough. The prepared minced meat was stored at 4±1 ˚C. The olive oil used for frying was supplied from the Erzurum market. Spices for making nuggets, breadcrumbs, wheat flour, salt, onion, garlic were supplied from the Erzurum market. The bread crumbs and eggs required for the outer coating of the nugget dough were supplied from Erzurum, and ascorbic acid was supplied from Istanbul.

Methods

Nugget Preperation and Frying Process

In the preparation of nugget dough, 550 g of breast meat, 200 g of leg meat, 135 g of water, 60 g of breadcrumbs, 25 g of wheat flour, 12 g of salt, 2 g of sweet paprika, 1 g of hot paprika, 1 g of black pepper, 1 g of ginger, 10 g of onion and 3 g of ascorbic acid were used for 1 kg of dough and the preparation was carried out in 2 repetitions. After all the ingredients were added, the dough was kneaded well and left to rest at ±4°C for 1 hour. The rested dough was shaped using 6 × 3 × 3 mm nugget molds. The shaped dough was placed on the tray. Egg white was beaten well for the outer coating. The shaped dough was first coated with egg white and then with breadcrumbs. The prepared nuggets were kept at -18°C until deep-frying.

The frying process was carried out using a 1014 PD fryer (MARKFRY). For both methods, 10 liters of olive oil were used as frying oil. The frying process was repeated 6 times with the same oil without adding new oil. Two methods were used to fry the nuggets: atmospheric frying and pressure frying. Atmospheric frying was carried out at 180 °C for 2 minutes and pressure frying was carried out at 160 °C for 3 minutes. Pressure frying was carried out under 2 bar pressure.

Analysis

After the frying process, the nuggets were cooled to room temperature after frying and samples were taken from each treatment group. Samples were taken for moisture, pH, color, TBARS and TPA in the nuggets. For oil analysis, the oil was cooled after frying and samples were taken. The samples were stored at −18 °C until analysis.

Nugget Analysis

pH, Moisture and TBARS Value

The pH values of the samples were determined according to the method given by Gökalp *et al*., 2004 [27]. 10 grams of nugget samples were weighed and 100 ml of pure water was added. The samples were mixed for 1 minute using an Ultra-Turrax (IKA T 25, Germany) for homogenization. The pH values of the samples obtained after homogenization were measured using a pH meter (Mettler Toledo Ion S220, Switzerland).

To determine the moisture content of the nugget samples, aluminum drying containers were dried at 105±1°C until a constant weight was reached. The dried containers were tared and 10 g of the analysis sample was weighed on them. The samples were dried at 105±1°C until a constant weight was reached. The moisture content of the nugget samples (%) was calculated by determining the weight loss [27]. The analysis was carried out according to the spectrophotometric method established in Lemon, 1975 [28]. After the samples were homogenized, 2 grams were weighed and 12 ml of TCA (trichloroacetic acid) solution was added. It was homogenized with Ultra-Turrax (IKA T 25, Germany) and filtered through Whatman 1 filter paper. 3 ml of the filtrate was added to the test tube and 3 ml of 0.02 M TBA solution was added and mixed. The tubes were kept in a boiling water bath for 40 minutes and cooled for 5 minutes. The absorbance values of the samples were measured at 532 nm in a spectrophotometer (Shimadzu UV-120-01) and the TBARS results were expressed as µmol MDA/kg [28].

Color Attributes

The color values of the samples were measured using a Minolta colorimeter (CR-200, Japan) on the inner and outer cross-sectional areas of the nuggets. The parameters L*, a* and b* were determined according to the International Commission on Illumination (CIELAB). According to the data of this commission, white; a*: +a; red, -a; green; L*: L;0, black; L;100, b*: +b; yellow, -b; blue represents the indicator of color intensity.

Texture Profile Analysis (TPA)

The texture properties of the nugget samples were determined using a TPA device (CT3, USE). The samples were taken with a diameter of 20 mm and a height of 10 mm. The samples were analyzed using a cylindrical probe in the TPA device at room temperature. The analysis test speed in the texture profile analyzer was determined to be 1 mm per second, the pre-test speed was 1 mm per second, the post-test speed was 2 mm per second and the compression was 50%. The time between two compressions was 5 seconds. The texture parameters determined were hardness, adhesiveness, resilience, cohesiveness, springiness, gumminess, and chewiness [29].

Oil Analysis

Free Fatty Acid, Peroxide Number and Total Polar Compound

14.00 ± 0.2 g of the homogenized samples were weighed and 50 ml of neutralized ethyl alcohol was added. After the samples were well mixed, 2 ml of indicator solution (phenolphthalein) was added and titrated with 0.1 N NaOH solution until a pink color was observed. The results were calculated as % oleic acid.

To determine the peroxide number, the samples were homogenized and 5 g of the sample was weighed. 18 ml of acetic acid and 12 ml of chloroform solution were added. After thorough mixing, 0.5 ml of saturated KI solution was added and waited for 1 minute. At the end of this period, 30 ml of pure water was added and titration was carried out with 0.01 N sodium thiosulfate. When the color changed from yellow to transparent at the end of the titration, starch solution (2 ml) was added and titration was carried out with 0.1 N sodium thiosulfate until the blue color disappeared. The same procedure was applied to the blank sample [30].

The content of polar substances in the oil samples was determined using a polarimeter (Testo 270 Lenzkirch, Germany).

Statistical Analysis

For the study, frying method (atmosphere and pressure conditions) and number of frying repetitions (6 times) were selected as factors. It was conducted according to the experimental design (random complete blocks) with 2 replications. The results were subjected to analysis of variance using the IBM SPSS Statistics 20 program. Statistically significant sources of variation ($p<0.01$ (very significant), $p<0.05$ (significant) and $p>0.05$ (not significant) were evaluated using the Duncan multiple comparison test.

RESULTS AND DISCUSSION

Moisture Content, pH and TBARS Value

The results for pH, TBARS and moisture content of nugget samples fried with olive oil under atmospheric and pressure conditions are shown in Table **1**. Measuring the changes in pH of raw materials and final products in food provides information on food safety and product quality [31]. The effect of frying method, frying repetition and the frying method × frying repetition number interaction on pH was found to be insignificant ($p>0.05$) (Table **1**). Likewise, in a study on meatball samples fried under atmospheric and pressure conditions, it was found that frying method and number of fryings did not affect the pH of the samples [32]. Das *et al*., 2013 [33] reported that frying conditions had no effect on the pH of breaded chicken meat.

It was found that frying method and number had a significant effect on the moisture content of the nuggets ($p<0.01$). However, it was found that the FM × FR interaction had no effect on the moisture content of the samples ($p>0.05$) (Table **1**). For turkey nuggets fried under atmospheric and pressure conditions, the moisture content of the samples fried under pressure (60.79%) was higher than that of the samples fried under atmospheric conditions (59.95%). In addition, in this study, the moisture content of the samples after the first frying was determined to be 61.26%, while this value decreased to 58.96% when the number of frying repetitions reached 6 (Table **1**). The frying temperature and the pressure applied during frying have a significant effect on the moisture content of the products [26]. It is reported that moisture loss is higher at high frying temperatures due to the increased evaporation rate [34]. In the present study, it is considered that the observation of higher moisture content in samples fried under pressure conditions compared to samples obtained from frying under atmospheric conditions is the result of applying the pressure frying process at lower temperatures. In the study conducted by Das *et al*., 2013 [33], higher moisture values (52.5 – 53.9%) were observed in chicken meat fried under pressure conditions than in samples fried under atmospheric conditions (48.5 – 51.3%). In another study that determined the effect of using different types of oil under atmospheric and pressure conditions on various parameters in nuggets,

Table 1: Results of pH, TBARS and Moisture Contents of Nuggets Fried Using Olive Oil in Atmospheric and Pressurized Conditions

		pH	Moisture (%)	TBARS (µmolMDA kg^{-1})
Frying Method (FM)	Atmospheric	$5.87±0.033^{a}$	$59.95±1.22^{a}$	$6.84±0.54^{a}$
	Pressure	$5.86±0.038^{a}$	$60.79±1.02^{b}$	$6.18±0.75^{b}$
Significance		NS	**	**
Frying Repetition (FR)	1	$5.87±0.035^{a}$	$61.26±0.72^{a}$	$5.99±0.60^{a}$
	2	$5.88±0.031^{a}$	$60.79±0.57^{a}$	$6.15±0.87^{a}$
	3	$5.87±0.031^{a}$	$60.93±0.86^{a}$	$6.46±0.64a^{b}$
	4	$5.87±0.034^{a}$	$60.53±0.93^{ab}$	$6.46±0.61a^{b}$
	5	$5.87±0.037^{a}$	$59.73±0.69^{bc}$	$7.02±0.68^{b}$
	6	$5.86±0.041^{a}$	$58.96±1.52^{c}$	$6.98±0.43^{b}$
Significance		NS	**	**
FM*FR		NS	NS	NS

Any two means in the same column having the same letters in the same section are not significantly diffrent. **: p <0 .01; *: p <0.05; NS: Not Significance.

moisture values of samples fried under pressure and atmospheric conditions were found to be 58.50 and 57.39, respectively [24]. In another study on the effect of number of frying repetitions and different frying methods on meatball samples made with hazelnut oil, a higher moisture content of 55.99% was found in meatballs fried under pressure conditions and 54.84% in meatballs fried under atmospheric conditions [32].

During the frying process, oil and food are exposed to moisture and oxygen at high temperatures, resulting in important chemical reactions such as oxidation, hydrolysis and polymerization [35]. Lipid oxidation in meat and meat products is an important factor that provides information about the quality and reliability of the final product. The TBARS value, which measures the secondary oxidation products that cause unpleasant aroma and bad odor in meat, is the most commonly used method to determine the lipid oxidation level. The frying method and the number of fryings, which are the main sources of variation in the TBARS value, were influenced to a very significant extent ($p<0.01$). However, the FM×FR interaction had no significant effect on the TBARS value of the samples ($p>0.05$) (Table **1**). When pressure was used in frying, a decrease in the TBARS value of the samples was observed. Repeated use of oil in deep frying had significant effects on TBARS value. The TBARS value, which was found to be 5.99 µmol MDA/kg in the 1st frying, increased from the 2nd frying and by the 6th frying, this value was found to be 6.98 µmol MDA/kg. However, the increase in the 3rd and 4th frying was not found to be statistically different from that in the 5th and 6th frying ($p>0.05$) (Table **1**). The physical and chemical changes that occur in the frying oil during the frying process significantly affect both the frying performance and the quality of the fried product and the repeated use of the oil at high temperatures in deep frying causes thermal and oxidative decomposition reactions due to the action of moisture and air [36]. The results of the study suggest that the higher amount of oxygen in atmospheric frying and the greater oxidation compared to pressure frying are due to this situation, and that the repeated use of the oil in both types of frying is due to its greater susceptibility to decomposition reactions, as mentioned above. Similar results have been found in studies on this topic. It has been reported that the TBARS values of meatballs in repeated frying processes under different frying conditions were found to be 39.35 µmol MDA/kg under atmospheric conditions and 29.44 µmol MDA/kg under pressure conditions [32]. In another study on turkey nuggets, a higher TBARS value of 4.29 µmol MDA/kg and 29.44 µmol MDA/kg was found under atmospheric conditions compared to pressure conditions [24]. Similar results were obtained regarding TBARS in another study, with TBA values ranging between 0.35 and 0.56 mg MDA/kg in chicken samples fried under atmospheric conditions and between 0.28 and 0.31 mg MDA/kg in samples fried under pressure conditions [33].

Color Attributes

Color is one of the important parameters in fried products, and the conditions of the frying process should be very well controlled to obtain bright products, which influence the purchasing intention of consumers who prefer deep frying [37]. It was found that the factor of frying method on the inner sections of the nuggets had a significant effect on the b* value expressing the intensity of yellow color ($p<0.05$), while this source of variation had no significant effect on the L* or a* value ($p>0.05$) (Table **2**). It was found that the interaction of frying method × frying repetition number had a significant effect only on the b* parameter ($p<0.01$) (Table **2**). The result for the L* value (brightness indicator) revealed a higher average value in pressure frying, but this value was found to be statistically insignificant. The a* value gave a higher average result for the atmospheric frying method, but similar to the L* value, no statistically significant difference was found between the methods ($p>0.05$). The b* value (yellow color intensity indicator) gave a higher average value of 18.40 for the pressure frying method than for the atmospheric frying method (18.07). A decrease was observed for the frying repetition number L* and the b* values in the 6th frying compared to the 1st frying, but this decrease was found to be statistically insignificant ($p>0.05$) (Table **2**). As can be seen from Figure **1**, the b* value in the 1st frying was higher for the atmospheric and pressure frying methods than for the 6th frying (Figure **1**).

Brightness value (L*), an important parameter for quality control of fried foods, is of great importance in terms of the color quality of the product [38]. It is found that the decrease in L* values in the outer region is related to non-enzymatic browning reactions [5]. Bordin *et al.*, 2013 [2] reported that non-enzymatic browning occurs faster at temperatures above 150 °C. It was found that the factors of frying method and frying number had a very significant effect on the L* value (brightness indicator) in the outer region areas of the nugget samples ($p<0.01$). It was found that the factors

Table 2: Color Analysis Results of Nuggets Fried Using Olive Oil in Atmospheric and Pressurized Conditions

Factors		Color					
		Internal			External		
		L*	a*	b*	L*	a *	b *
Frying Method (FM)	Atmospheric	59.04±2.18^{a}	5.79±1.32^{a}	18.07±0.78^{a}	33.73±4.57^{a}	13.68±1.22^{a}	16.94±2.71^{a}
	Pressure	59.46±2.24^{a}	5.68±0.64^{a}	18.40±0.67^{b}	38.38±4.48^{b}	11.71±2.26^{b}	19.21±1.67^{b}
Significance		NS	NS	*	**	**	**
Frying Repetition (FR)	1	59.85±1.01^{a}	5.83±0.83^{a}	18.42±0.64^{ab}	41.82±3.45^{a}	10.37±2.11^{c}	20.42±1.30^{a}
	2	60.09±1.48^{a}	5.19±0.41^{a}	18.24±0.81^{ab}	40.32±2.69^{b}	10.84±1.94^{c}	19.86±0.69^{a}
	3	58.90±3.08^{a}	5.54±0.51^{a}	18.54±0.68^{a}	35.99±3.60^{c}	13.41±1.00^{b}	18.41±2.22^{b}
	4	59.28±2.59^{a}	5.57±1.09^{a}	17.88±0.98^{b}	35.63±2.55^{c}	13.32±0.97^{b}	18.15±1.75^{b}
	5	59.57±1.82^{a}	6.07±1.06^{a}	18.33±0.44^{ab}	32.94±3.19^{d}	14.04±1.10^{ab}	16.85±1.90^{c}
	6	57.82±2.24^{a}	6.18±1.66^{a}	17.99±0.72^{ab}	29.64±2.32^{e}	12.70±2.06^{a}	14.77±1.93^{d}
Significance		NS	NS	NS	**	**	**
FM*FR		NS	NS	**	NS	**	**

Any two means in the same column having the same letters in the same section are not significantly different. **: p <0 .01; *: p <0.05; NS: Not Significance.

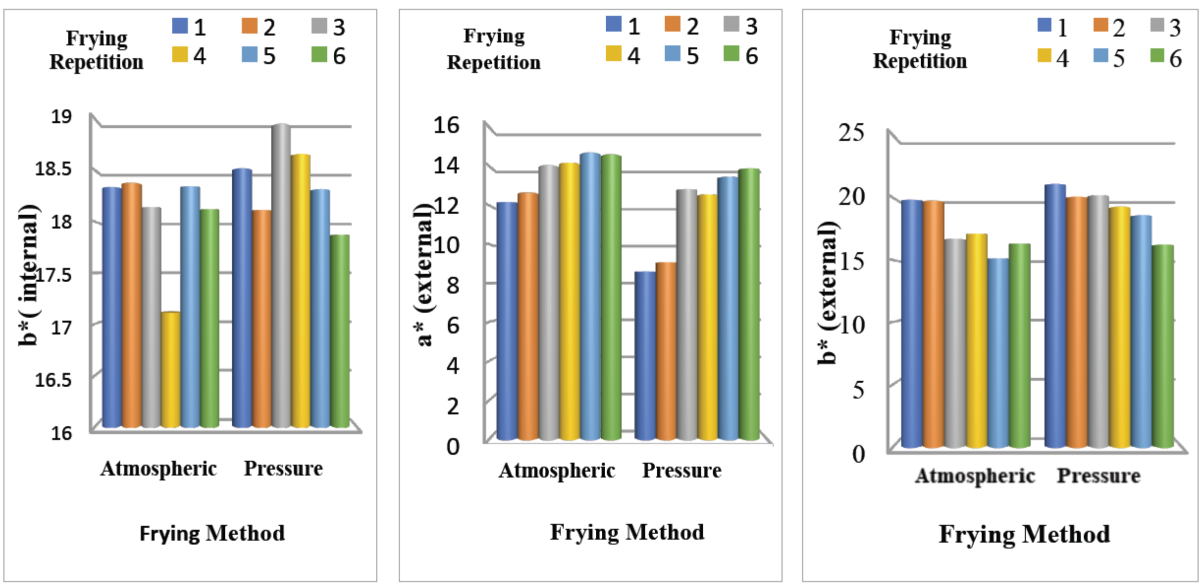

Figure 1: The effect of frying method × frying repetition interaction on b* value (internal), a* and b* value (external) parameters of turkey nugget samples.

of frying method and frying repetition had a very significant effect on the a* and b* values as well as on the L* value (p<0.01). It was found that the interaction between frying method and frying number had a very significant effect on the a* and b* values (p<0.01) (Table **2**). Many reactions occur during frying such as protein denaturation, starch gelatinization and browning of batter and breading and all these reactions cause color changes in the shell [33]. It was observed that the L* value in the frying method performed under pressure conditions is higher than that in the frying under atmospheric conditions. In other words, the turkey nugget samples fried under pressure conditions were found to have a lighter outer shell color. With increasing number of frying repetitions, the outer color of the samples became darker. While the L* value was found to be 41.82 in the 1st frying, this value decreased with increasing number of fryings and was found to be 29.64 in the 6th frying. However, the results of the 3rd and 4th frying showed no statistical difference (p>0.05) (Table **2**). In a study on this topic, Şişik Oğraş and Kaplan, 2022 [24] found higher values in the shell brightness value of nuggets fried with different frying oils under different frying conditions in pressure frying.

In a study to determine the effect of increasing frying temperature on color change, it was found that the L* and b* values of the shell were low and the a* value was high depending on the increase in temperature [26]. The atmospheric frying method resulted in higher a* and lower b* values at the outer cross-sectional area (Table **2**). The pressure frying method caused an increase in the b* value. However, as can be seen from the frying method × frying repetition interaction diagram in Figure **1**, the a* value at the outer cross section was higher when frying was carried out under atmospheric conditions than under pressure conditions. For both manufacturing methods, the a* value increased with increasing number of frying cycles. The b* value of the outer cross section of the nugget samples decreased with increasing number of frying cycles. The highest yellowing intensity was observed in the 1st frying cycle for the samples fried under pressure frying conditions (Figure **1**).

Texture Properties

Texture is an important and desirable property of food [39]. Processing conditions and content characteristics of food directly affect the texture of food [40]. The results of texture parameters of turkey nugget samples fried with olive oil under atmospheric and pressure conditions are shown in Table **3**. Among the texture properties, hardness is considered to be the most important property of meat products [41]. The influence of frying method on hardness value was found to be significant ($p<0.01$). The number of fryings and FM×FR interaction were found to have significant ($p<0.05$) influence on hardness value (Table **3**). The hardness parameter in deep frying under atmospheric condition was lower than that in pressure frying method. In addition, it can be observed that the hardness decreases from the 1st to the 6th frying (Table **3**). In a study conducted by Yu *et al*. (2020), it was reported that the hardness of surimi increases with increasing frying time and frying temperature when fried under atmospheric frying condition. It is well known that juicier and softer fried products are obtained in pressure frying [42]. The effect of interaction between frying method and frying number on the hardness parameter of turkey nugget samples is shown in Figure **2**. Accordingly, it can be observed that the hardness value decreases from the 1st to the 6th frying in atmospheric frying and increases in pressure frying (Figure **2**).

Adhesiveness (mJ) indicates the viscoelastic properties of food [40]. The results of adhesiveness of nuggets fried with olive oil under atmospheric and pressure conditions are shown in Table **3**. It was found that the factors and mean values of stickiness value of nuggets were not statistically significant with each other ($p>0.05$) (Table **3**).

According to the results on the resilience of nuggets fried in olive oil under atmospheric and pressure conditions, the differences between the average values of frying numbers were not statistically significant ($p>0.05$). It was found that frying method and frying method × frying number interaction have very significant effects on the resilience parameter ($p<0.01$) (Table **3**). In a study conducted by Yu *et al*., 2020 [37],

Table 3: Texture Analysis Results of Nuggets Fried Using Olive Oil in Atmospheric and Pressurized Conditions

Factors		Texture Parameters						
		Hardness (N)	Adhesiveness [mJ]	Resilience	Cohesiveness	Springiness [mm]	Gumminess [N]	Chewiness [mJ]
Frying Method (FM)	Atmospheric	17.92 ± 2.81^{a}	0.39 ± 0.42^{a}	0.11 ± 0.14^{a}	0.32 ± 0.037^{a}	6.47 ± 055^{a}	5.76 ± 1.36^{a}	37.58 ± 104^{b}
	Pressure	20.48 ± 2.53^{b}	0.39 ± 0.38^{a}	0.13 ± 0.02^{b}	0.38 ± 0.044^{b}	6.69 ± 0.49^{b}	7.68 ± 1.34^{b}	51.55 ± 10.67^{a}
Significance		**	NS	**	**	**	**	**
Frying Repetition (FR)	1	20.23 ± 2.39^{a}	0.30 ± 0.32^{a}	0.12 ± 0.0131^{a}	0.33 ± 0.035^{c}	6.88 ± 0.66^{a}	6.78 ± 1.16^{ab}	47.02 ± 11.08^{a}
	2	19.18 ± 3.09^{abc}	0.40 ± 0.36^{a}	0.12 ± 0.0203^{a}	0.34 ± 0.056^{bc}	6.56 ± 0.58^{bc}	6.72 ± 1.90^{ab}	44.65 ± 14.64^{ab}
	3	19.96 ± 3.15^{ab}	0.32 ± 0.32^{a}	0.12 ± 0.087^{a}	0.36 ± 0.029^{a}	6.65 ± 0.46^{ab}	7.38 ± 1.48^{a}	48.87 ± 9.29^{a}
	4	18.95 ± 2.75^{abc}	0.44 ± 0.28^{a}	0.12 ± 0.0160^{a}	0.35 ± 0.038^{ab}	6.50 ± 0.37^{bc}	6.84 ± 1.59^{ab}	44.72 ± 11.89^{ab}
	5	18.58 ± 2.67^{bc}	0.47 ± 0.43^{a}	0.12 ± 0.0190^{a}	0.33 ± 0.036^{c}	6.57 ± 0.51^{bc}	6.23 ± 1.30^{b}	41.35 ± 10.94^{b}
	6	18.30 ± 3.44^{c}	0.38 ± 0.47^{a}	0.12 ± 0.0165^{a}	0.34 ± 0.59^{bc}	6.33 ± 0.49^{c}	6.38 ± 2.28^{b}	40.79 ± 16.17^{b}
Significance		*	NS	NS	**	**	*	*
FM*FR		*	NS	**	**	NS	**	**

Any two means in the same column having the same letters in the same section are not significantly different. **: $p <0.01$; *: $p <0.05$; NS: Not Significance.

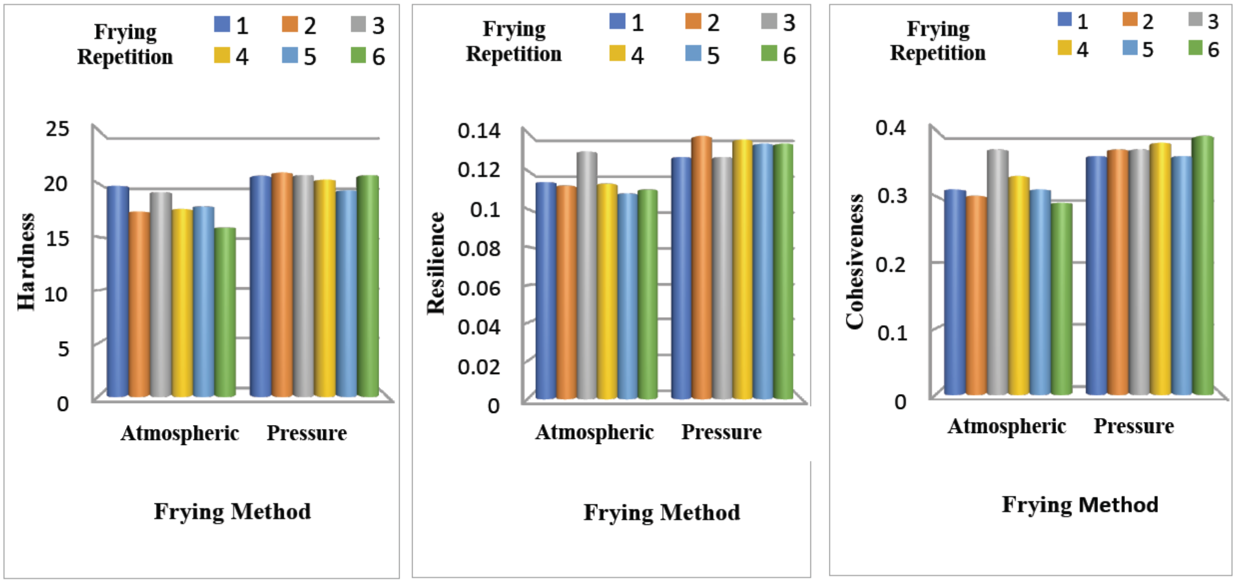

Figure 2: The effect of FM×FR interaction on Hardness, Resilience, and Cohesiveness parameters.

it was reported that the flexibility of atmospheric fried surimi increased with increasing temperature, and a sudden decrease in resilience was observed at a temperature of 200 °C. It was reported that this flexibility behavior was temporarily caused by the thermal denaturation of myosin and actin, which are the main components of myofibrillar proteins [43]. Based on the effect of the interaction between frying method and frying number on the resilience value of the turkey nugget samples, it was found that the resilience value increased at the 6th frying compared to the 1st frying in pressure frying (Figure **2**).

Cohesiveness, a measure of the deformation effect of food before breaking [44], had a very significant ($p<0.01$) effect on frying method, number of frying sessions and frying method × frying repetition interactions (Table **3**) according to Table **3**. The atmospheric frying method (0.32) showed a lower cohesiveness value than the pressure frying method (0.38) (Table **3**). It was observed that the cohesiveness value in atmospheric frying decreases relatively from the 1st to the 6th frying session, while it increases in pressure frying (Figure **2**).

Springiness (mm) is the return of the sample to its original shape after the deformation force applied [44]. Table **3** shows the elasticity values of nuggets fried with olive oil under atmospheric and pressure conditions. It can be seen that the frying method and the number of fryings have a very significant ($p<0.01$) effect on the springiness. In the table, it was found that the frying method caused a large increase in the springiness value of the product compared to the frying method under atmospheric conditions. When the frying repetitions was examined, the highest elasticity value was found in the 1st frying (Table **3**). Oğraş, 2022 [32] reported in a study that the frying method had no significant effect on the springiness value ($p>0.05$).

Gumminess is defined as the property of being sticky [37]. In Table **3**, it can be seen that the frying method and the interaction of frying method × frying repetition have a very significant ($p<0.01$) effect on the gumminess parameter. The frying number had a significant ($p<0.05$) effect on the gumminess (Table **3**). As can be seen from the results presented, the gumminess value, which was determined to be 7.68 N in the frying process under pressure conditions, decreased to 5.76 N in the frying process under atmospheric conditions (Table **3**). It can be seen that the gumminess value decreases from the 1st to the 6th frying in atmospheric frying and increases in the pressure frying (Figure **3**).

Chewiness (mJ) is the time required to reduce the food to a size suitable for swallowing and to chew the food evenly [37]. In Table **3**, it was found that chewiness had a very significant effect ($p<0.01$) on frying method and frying method × frying repetition interaction and a significant effect ($p<0.05$) on frying number. While the chewiness value was 37.58 mJ in the frying method conducted under atmospheric conditions, this value was 51.55 mJ in the frying method conducted under pressure conditions (Table **3**). It was observed that the chewiness value in atmospheric frying decreased from the 1st to the 6th frying (Figure **3**).

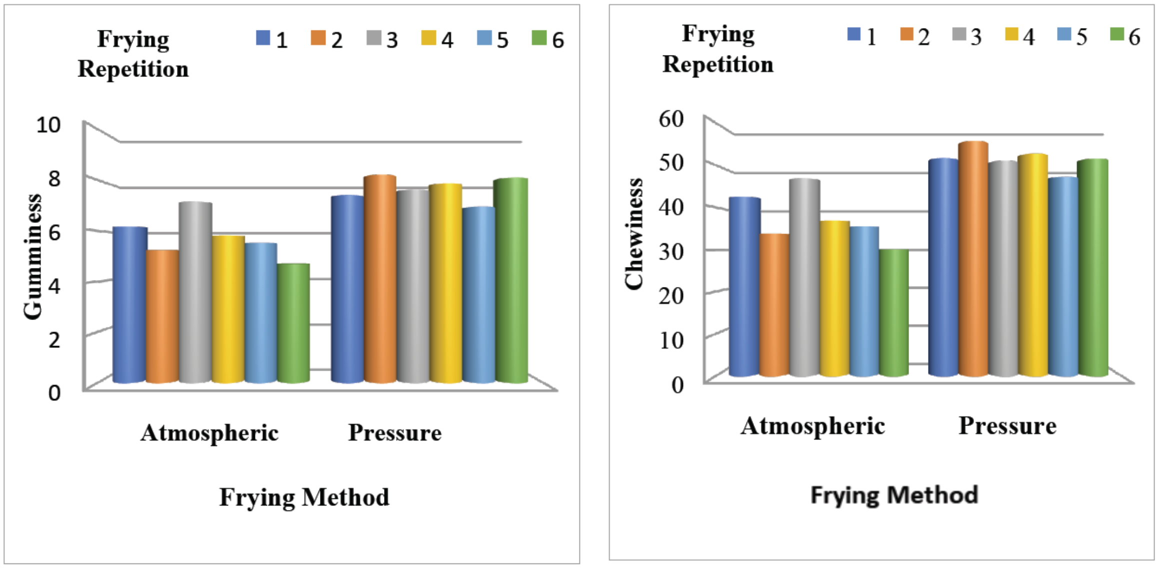

Figure 3: The effect of FM×FR interaction on Gumminess and Chewiness parameters.

Free Fatty Acid, Peroxide Value, and Total Polar Material of Fried Oils

Overall effects of frying method and frying repetation on free fatty acid, peroxide value, and total polar material of fried oil samples are given in Table **4**. Free fatty acids are degradation products formed during the hydrolysis of triacylglycerols. Although the content of free fatty acids in oils is considered an indicator of the spoilage of frying oil, it is an important criterion for the quality of fried foods. Although the content of free fatty acids does not affect the performance of the frying process, it has significant negative effects on human health and the sensory evaluation of foods [45]. The content of free fatty acids in Riviera olive oil is not more than 1,0 gram per 100 grams in terms of oleic acid [46]. It is found that the frying method and the number of frying processes have a very significant ($p<0.01$) influence on the content of free fatty acids (Table **4**). On the other hand, the FM × FR interaction was found to have no effect on the content of free fatty acids ($p>0.05$) (Table **4**). The free fatty acid values of the oil samples of turkey nuggets fried with olive oil under atmospheric and pressure conditions were higher in the atmospheric frying process than in the pressure frying process (Table **4**). In the study conducted by Şişik Oğraş and Kaplan, 2022 [24] on the frying of turkey nuggets in hazelnut and sunflower oil, it was again found that the atmospheric frying process had a higher

Table 4: Results of Free fatty acid, Peroxide volue and Total polar material of Nuggets Fried Using Olive Oil in Atmospheric and Pressurized Conditions

		Free fatty acid [oleic acid%]	Peroxide value [meq O_2 kg^{-1} oil]	Total polar material [%]
Frying Method (FM)	Atmospheric	0.50±0.042^a	21.98±9.38^a	7.98±0.86^a
	Pressure	0.47±0.039^b	17.25±8.32^b	7.66±0.87^b
Significance		**	**	**
Frying Repetition (FR)	1	0.44±0.34^a	6.50±1.70^a	6.62±0.23^a
	2	0.46±0.38^b	12.45±2.36^b	7.12±0.35^b
	3	0.47±0.45^{bc}	17.22±3.01^c	7.62±0.35^c
	4	0.49±0.30^{cd}	22.75±3.61^d	8.12±0.35^d
	5	0.50±0.33^d	27.29±2.78^e	8.44±0.18^e
	6	0.52±0.34^e	31.51±3.86^f	9.00±0.53^f
Significance		**	**	**
FM*FR		NS	NS	NS

Any two means in the same column having the same letters in the same section are not significantly different. **: p <0 .01; *: p <0.05; NS: Not Significance.

content of free fatty acids than the pressure frying process. Casal *et al.*, 2010 [47] determined the free acid content of Riviera olive oil to be 0.3% and 0.1% in the frying process in olive oil with potatoes at 170 ˚C for 3 hours. In the present study, it was observed that the amount of free fatty acids increases with the number of frying repetitions (Table **4**).

Hydroperoxides are the primary products of oxidation. The peroxide number provides information about the primary products of oxidation. The decomposition of hydroperoxides produces free radicals that cause the initiation and acceleration of branched reactions of oil oxidation. The peroxide number is one of the most important quality criteria, especially for stored oils [48]. Frying method and frying number have a statistically significant ($p<0.01$) influence on the peroxide number value in oil samples from turkey nuggets fried with olive oil under different conditions. It was found that the interaction frying method × frying number had no significant influence on the peroxide number value ($p<0.05$). The results show that frying under atmospheric conditions gives higher values than frying under pressure conditions. It was found that the peroxide number increases with the number of frying repetitions (Table **4**). Sağlam and Kutluay, 1983 [49] determined that the initial peroxide value of the oil used in frying with olive oil was on average 0.92 mE/kg. At the end of the first frying it was 0.66 mE/kg, at the end of the second frying 0.81 mE/kg, at the end of the third frying 0.72 mE/kg and at the end of the fourth frying 0.59 mE/kg.

The total amount of polar substances is considered a simple criterion to assess the quality of frying oils. The acceptable limits of the total amount of polar substances have been reported to be 24–27% [50]. In the frying process under atmospheric and pressurized conditions, the frying method and the number of frying cycles have a statistically significant ($p<0.01$) effect on the total amount of polar substances. On the other hand, the interaction between frying method and frying repetition cycles was found to have no significant effect on the total amount of polar substances ($p>0.05$) (Table **4**). The limit of 25% was not exceeded for the amount of polar substances in the oil samples of turkey nuggets fried with olive oil under different conditions. It was also found that the total amount of polar substances increases with the number of frying cycles (Table **4**).

CONCLUSION

It was found that under pressure frying conditions, positive results were obtained in terms of product brightness, red color density and lipid oxidation compared to atmospheric frying conditions, pressure frying positively affected some textural parameters and gave lower values in criteria affecting oil quality such as peroxide number and free fatty acid content compared to atmospheric frying, but repeated use of frying oil increased free fatty acid content, peroxide number and TPM amount and with increasing number of frying repetitions, Tbar, moisture, color and texture parameters in the product were negatively affected. Therefore, it was concluded that frying under pressure conditions can be a better alternative to frying under atmospheric conditions, but repeated use of frying oils can have negative effects on both product quality and oil quality.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship.

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