

## Studying the Physicochemical Alterations of Oil after Frying and Cooling Chicken Nugget under Vacuum and Atmospheric Conditions

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### ABSTRACT

The present study investigated the effects of frying and cooling of chicken nuggets under vacuum and atmospheric pressure on the qualitative properties of frying oil. For this purpose, first, two cooling treatments were applied to nuggets fried at 170°C under atmospheric pressure. One treatment was subsequently cooled at atmospheric pressure (control) and the other at 10 kPa. Other treatments included frying at temperatures of 115 and 170°C under the pressure of 10 kPa before cooling at pressures of 10 kPa and atmospheric levels. Results indicated that frying and cooling at 170°C increased acid value, polar compounds, viscosity, redness, yellowness, and oil oxidation. Also, this treatment reduced the oil's unsaturated fatty acids. On the other hand, minimum values of acid content, viscosity, and oxidation rate were observed in the oil used to vacuum fry at 115°C and subsequently cooled at 10 kPa pressure. Moreover, these samples exhibited the highest quantities of oleic, linoleic, and linolenic acids due to the lower oxidation taking place in such unsaturated fatty acids under the vacuum rather than the atmospheric pressure. Based on the results obtained, frying and cooling at 115°C under vacuum seems to have the least unfavorable effects on frying oil.

**Keywords:** Deep fat frying, Fatty acids, Frying oil, Oil quality.

### INTRODUCTION

Frying is one of the oldest and most popular methods used for both domestic and industrial food preparation (Teruel *et al.*, 2014). Deep fat frying is a dry cooking method basically consisting of deep immersion of food pieces in edible oils at temperatures above water boiling point (150–200°C), during which process temperature and mass (moisture) are simultaneously transmitted to the foodstuff (Asokapandian *et al.*, 2020).

Frying oil degeneration occurs as a result of chemical reactions, including oxidation, hydrolysis, and polymerization. Such reactions cause the production of toxic compounds such as trans fatty acids, non-volatile compounds, acrylamide (in the

presence of reducing sugar), reactive oxygen species, and reduction of antioxidants (Xu *et al.*, 2019). Besides, visible physical changes occur in the frying oil, including increased viscosity, color changes, decreased smoke point, and increased foam (Abriana *et al.*, 2019). Once these physical and chemical changes take place, the frying oil can no more be used. Therefore, there is a need to substitute other deep fat frying methods that arrest the production of toxic compounds. Furthermore, the longer shelf-life and stability of oil should be considered. Frying under vacuum is one such method that provides these targets (Juvvi *et al.*, 2020). Vacuum frying might avoid the changes and significantly improve the qualitative properties of frying oil. In this method, frying is carried out in an enclosed system at pressures below the atmospheric so that

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frying can be performed at lower temperatures with the least exposure to oxygen (Teruel *et al.*, 2014).

It is proved that frying under vacuum reduces oil absorption by foodstuff and enhances the quality of the final product. It is also associated with reduced detrimental effects on oil quality parameters. Crosa *et al.* (2014) studied the effects of frying under vacuum and atmospheric conditions on the quality of oil. They found that frying under vacuum conditions extended the shelf-life of their fried product as well as the durability of the oil used due to the significantly reduced chances and rates of destructive reactions in the frying oil such as oxidation. They attributed the findings to the absence of oxygen and the low temperatures of frying under vacuum compared to those under atmospheric pressure. Belkova *et al.* (2018) examined the quality of frying oil used for frying potato slices under vacuum and atmospheric conditions. Their results revealed that frying under vacuum, rather than under atmospheric pressure, led to significantly enhanced oil quality, as evidenced by the decline in total alkyl pyrazine content, triacylglycerol polymers, and volatile compounds. Albertos *et al.* (2016) investigated the effects of vacuum frying on fish oil's organoleptic and nutritional properties, compared to atmospheric pressure. They found that the vacuum played a protective role for the unsaturated  $\omega$ 3 fatty acids.

Not only vacuum frying, but also vacuum cooling might have favorable effects on frying oil quality. Tarmizi *et al.* (2013) studied the effects of cooling under both vacuum and atmospheric conditions on the quality of oil used for frying under atmospheric pressure. They found that cooling under vacuum rather than atmospheric pressure decreased the free fatty acid content by 50%. Most studies conducted so far have considered the effect of the frying phase during deep-fat frying on the properties of frying oil, ignoring the significant effects of the cooling phase. To fill this gap, the present study aimed to

evaluate the simultaneous effects of frying and cooling phases under both atmospheric and vacuum conditions on the properties of frying oil.

## MATERIALS AND METHODS

Frying oil was obtained from Bahar Co., Iran. Chloroform, methanol, ammonium thiocyanate, trichloroacetic acid, iron (II) sulfate, and barium chloride were procured from Merck Company, Germany. Thiobarbituric acid was purchased from Sigma Co., USA.

### Frying Treatments

Raw nuggets were obtained from Mahoor Co., Iran. The samples were randomly allocated to six groups, nine nuggets in each group with total weight of 180 g, to be subjected to one of the six frying treatments. The samples in each group were placed in a lace basket, and the fryer was filled with 2.25 liters of frying oil to give a nugget to oil weight ratio of 0.08.

1. A: Frying at 170°C for 90 seconds under atmospheric pressure followed by cooling under the same pressure. This treatment served as the control because the temperature and the pressure used were the same as those used for frying nuggets in the food factory.

2. B: Frying at 115°C and 10 kPa followed by cooling under the same pressure. Given the critical role mass transfer plays in the frying process, temperature in this treatment was selected in such a way that a driving force i.e., the difference between the oil temperature during the frying phase and the boiling point of water at the frying phase pressure would be achieved similar to that obtained under the control treatment. Given the boiling point of water (about 95°C) at the experimental site (i.e., Isfahan, central Iran) and considering the fact that the boiling point of water at 10 kPa is 40°C, the driving force in the control treatment was

estimated to be around 75°C. Thus, the fryer temperature must be set at 115°C to obtain a driving force similar to that of the control. Briefly, the pressure inside it was decreased to 10 kPa. Subsequently, temperature was raised to 115°C, and the samples were immersed in the oil for 4 min. To determine frying duration, the temperature at the sample core was measured to ensure that it reached 40°C, which is the boiling point of water at the applied pressure. At the end of the frying process, the nugget basket was removed out of the oil to cool in the top space of the fryer while pressure was maintained at the same level.

3. C: Frying at 170°C and 10 kPa followed by cooling at the same pressure. Due to the role of temperature in the chemical reactions taking place during the frying process, the nuggets were fried at 170°C (the control temperature) while pressure was reduced to 10 kPa. Once the oil temperature rose to 170°C, the nuggets were immersed in frying oil for 60 seconds. The treatment was terminated by cooling the nuggets in the top space of the fryer at 10 kPa.

4. D: Frying at 170°C under atmospheric pressure followed by cooling at 10 kPa. Frying in this treatment was performed at 170°C under atmospheric pressure, and the nuggets were cooled at 10 kPa. The vacuum pump was turned on after 55 s from frying for the pressure to reach 10 kPa after 90 seconds, when the cooling phase started. The nuggets were maintained at this pressure during the cooling phase.

5. E: Frying at 115°C and 10 kPa followed by cooling at atmospheric pressure. Once the fryer temperature rose to 115°C at 10 kPa, the nuggets were immersed in oil to fry for 4 minutes before pressure was raised back to the atmospheric level by pulling out the safety valve.

6. F: Frying at 170°C and 10 kPa followed by cooling at atmospheric pressure. The nugget samples were fried at 170 °C under vacuum for 60 seconds. Then, pressure was raised to the atmospheric level at which the nuggets were allowed to cool.

In all the treatments, the cooling step lasted 3 minutes under centrifugation at 400 rpm. At the end of the cooling process, frying oils were immediately sampled for the experiments while the remaining were packed in polyethylene terephthalate containers and stored at -18°C for three months to evaluate hydroperoxide and thiobarbituric acid monthly.

### Acid Value

The acid value of oil denotes the free fatty acid content of an oil sample as measured according to AOCS (2017). Briefly, 50 mL of ethanol 98% was added to 7 g of the oil sample. The solution was then titrated by 0.1N alcoholic KOH after 2–3 drops of the phenolphthalein reagent had been added. Titration was continued until a fixed pink color was observed. Acid value was obtained using the Eq. 2.

$$AV = \frac{V \times N \times 56.1}{m} \quad (1)$$

Where, AV represents Acid Value (mg KOH g<sup>-1</sup> oil), V is the Volume of KOH (mL) used for the sample, and N is the normality of KOH, m is the weight of the oil sample (g).

### Peroxide Value

The peroxide value was evaluated according to the method of AOCS (2017).

Thiobarbituric Acid Reactive Substances (TBARS) Measurement

An amount of 50-200 mg of the oil sample was completely dissolved in 1-butanol and made to a volume of 25 mL by adding more 1-butanol before 5 mL of the solution thus obtained together with 5 mL of the thiobarbituric acid solution (2 mg mL<sup>-1</sup> in 1-butanol) was transferred into a clean dried test tube. The tube was then maintained in a water bath at 95°C for 60 minutes for the color to appear. Absorbance was read at 530 nm and the amount of malondialdehyde was calculated according to Equation (2) (Dehghan *et al.*, 2020):



$$\text{MDA} = \frac{A532 \times 50}{W_s} \quad (2)$$

Where, MDA represents mg Malondialdehyde  $\text{kg}^{-1}$ , A532 is the Absorbance (532 nm) of the assay solution,  $W_s$  is the oil sample Weight (mg), and 50 is a constant.

### Fatty Acid Composition

The methyl ester of the fatty acids was prepared by adding 100  $\mu\text{L}$  of the 0.5N methanolic sodium methoxide solution and 1 mL hexane to 50  $\mu\text{L}$  of the oil sample. The solution thus obtained was vortexed for 15 minutes at room temperature. The hexane layer containing the oil was separated from the bottom phase and passed through anhydrous sodium sulfate. Finally, 1 mL of the sample was injected into an Agilent 6890 N gas chromatograph. An HP88 capillary column (length 100 m, external diameter 0.25 mm, and internal diameter were 0.2 mm, Agilent, USA) was used to determine the fatty acid profile. Nitrogen was applied as the carrier gas at a rate of 10  $\text{mL min}^{-1}$ . The initial temperature of the column was adjusted to 140°C and maintained at this temperature for 5 min before it was increased to 240°C at a rate of 4°C  $\text{min}^{-1}$  and held constant for 25 minutes. The flame ionization detector and injector temperatures were set to 300 and 240°C, respectively (Selani *et al.*, 2016).

### Color

A reflectance colorimeter was used to determine  $L^*$ ,  $a^*$ , and  $b^*$  values (Nippon Denshoku, Japan).

### Viscosity

The oil viscosity was measured with a Brookfield viscometer (DVII, USA). All the measurements were performed at 25°C using spindle 1 run at a torque of 12 and a speed of 60 rpm (Sahasrabudhe *et al.*, 2019).

### Polar Compounds

The cooking oil tester (Testo 270, Germany) was employed to determine the polar compound content. The sample temperature was set at 45±5°C during the measurement.

### Statistical Analysis

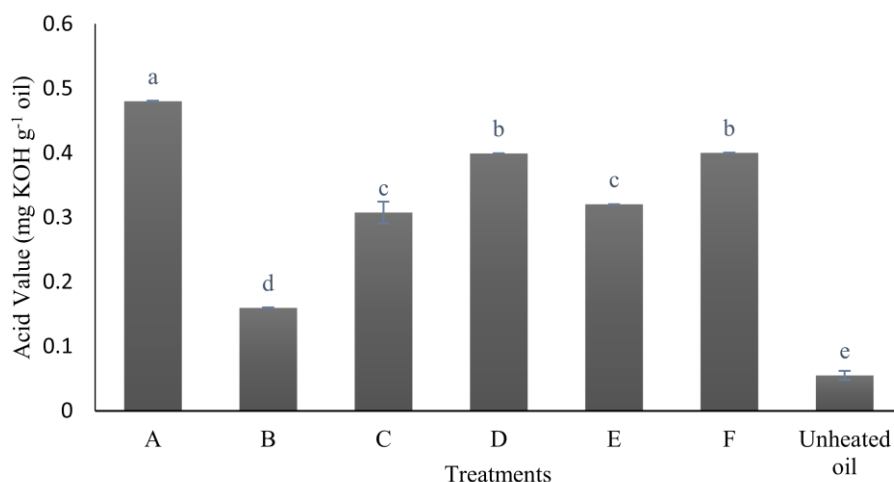
Each frying treatment was carried out in triplicate. Using the Statistical Analysis System (SAS), the data were subjected to the General Linear Model Test, and mean comparisons of oils properties were accomplished using the Least Significant Difference (LSD) Test. The confidence interval was set to a significance level of  $P < 0.05$ .

## RESULTS AND DISCUSSION

### Acid Value

According to Figure 1, treatment A exhibited the highest quantity of acid value, followed by D. This is while the least acid value was obtained for those heated under vacuum. The changes observed in acid value may be due to the presence of water. Low amounts of water could not significantly promote or inhibit the oxidation and decomposition of triglycerides. However, with increasing water content, the steam formed above the oil increases to play the protective role shown by an inert gas such as nitrogen (Gomna *et al.*, 2019). Ogata *et al.* (2018) found that excessive amounts of water added to frying oil enhanced the quality of fried oil. Other researchers reported that slight amounts of water in oil could intensify thermal oxidation and hydrolytic decomposition (Aniolowska and Kita, 2016; Ghobadi *et al.*, 2018).

When oil was heated under atmospheric pressure, less moisture was observed to be extracted from the nuggets (data not shown). Moisture might enter the oil to intensify its hydrolytic decomposition. Hence, the high



**Figure 1.** The acid value of frying oil after vacuum and atmospheric pressure frying and cooling of chicken nuggets. A: Atmospheric frying at 170°C- atmospheric cooling, B: Vacuum frying at 115°C- vacuum cooling, C: Vacuum frying at 170°C- vacuum cooling, D: Atmospheric frying at 170°C- vacuum cooling, E: Vacuum frying at 115°C- atmospheric cooling, F: Vacuum frying at 170°C-atmospheric cooling. Different letters in each column indicate a significant difference between treatments ( $P < 0.05$ ).

acid value obtained in this experiment may be attributed to the low moisture content of the oil.

In treatments with heating and cooling cycle conducted under vacuum, production of free fatty acids diminished. The amount of moisture extracted from these nuggets was noticeably more than that extracted from nuggets fried under atmospheric pressure. Hence, the moisture extracted from the latter changed into steam to serve as an inert gas and protect the oil against decomposition, thereby reducing the acid value. Moreover, heating the oil to higher temperatures under vacuum increased the acid value, indicating the role of temperature in oil decomposition.

Significantly lower acid values were recorded for oils heated under atmospheric pressure and cooled under vacuum than those obtained for oils subjected to heating and cooling cycles under atmospheric conditions. Similar results were reported by Tarmizi *et al.* (2013). The authors stated that cooling under vacuum reduced the saturation temperature of water so that more water vaporized and leached out. The reduced

water content of oil reduces the produced free fatty acids.

Oil samples heated under vacuum and cooled under atmospheric conditions produced significantly higher amounts of acid value than those subjected to the frying and cooling cycles under vacuum. Comparing nuggets moisture content revealed the highly reduced moisture content in samples fried under vacuum and cooled under atmospheric conditions. Even though high amounts of moisture in oil seemingly play a protective role, high acid values were measured in these treatments. It might be due to the enhanced atmospheric pressure during cooling that condenses the water evaporated from the nuggets during frying under vacuum. The condensed water then returns into the oil so that no saturated steam exists above the oil to act as an inert gas and inhibiting oil decomposition. Likewise, higher frying temperatures can decompose frying oil, which in turn increases the acid value. Overall, the acid value in all treatments was lower than the standard value for discard point of frying oil in Austria (2.5 mg KOH g<sup>-1</sup> oil) and Germany (2.5 mg KOH g<sup>-1</sup> oil) (Firestone, 2007).



### Fatty Acid Composition

Frying and cooling (atmospheric or vacuum) conditions had no significant effects on the amounts of palmitic (16:0) and stearic (18:0) saturated fatty acids, although they had significant effects on oleic (18:1), linolenic (18:2), and linolenic (18:3) fatty acids (Table 1). It seems that more of the latter three were oxidized under atmospheric pressure than under vacuum. This extensive oxidation may be attributed to the presence of oxygen and high frying temperatures.

Based on the results obtained, only the linoleic acid was significantly affected by the cooling conditions following frying under atmospheric pressure. In fact, less of this acid was oxidized when cooled under vacuum than under atmospheric pressure. This finding is consistent with the results reported by Tarmizi *et al.* (2013), who studied the effects of cooling under vacuum and atmospheric conditions on frying oil properties. Meanwhile, cooling condition (vacuum or atmospheric) was found to have no significant effects on oxidation of unsaturated fatty acids present in oils used for frying under vacuum. Comparing the amounts of oleic and linoleic acids present in oils subjected to vacuum frying revealed the significant effect of frying temperature on the oxidation rate of fatty acids, such that lower reductions were observed in unsaturated fatty acids after frying at 115°C

rather than at 170°C. Tyagi and Vasishtha (1996) also reported that the loss of unsaturated fatty acid in soybean oil after frying potato chips at 180°C (38.8%) was lower than 190°C (43.6%).

### Oil Oxidation

The first products of fat and oil oxidation are hydroperoxides that are extremely unstable, as they decompose to a wide range of chemicals such as alcohols, furans, ketones, acids, dimers, trimers, polymers, and aromatic compounds (Shahidi and Oh, 2020).

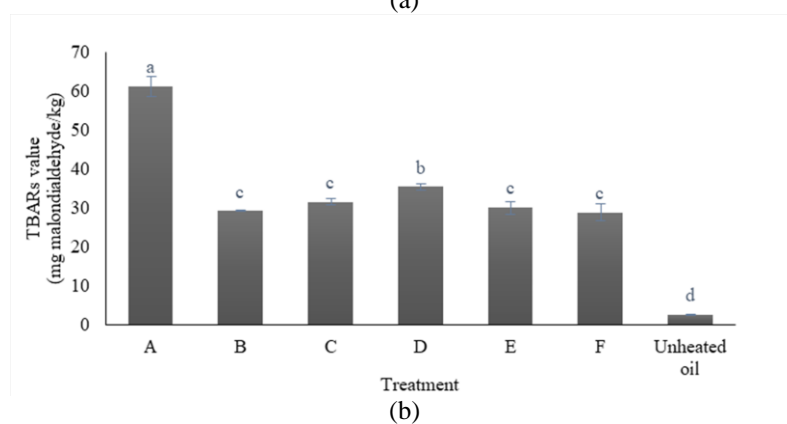
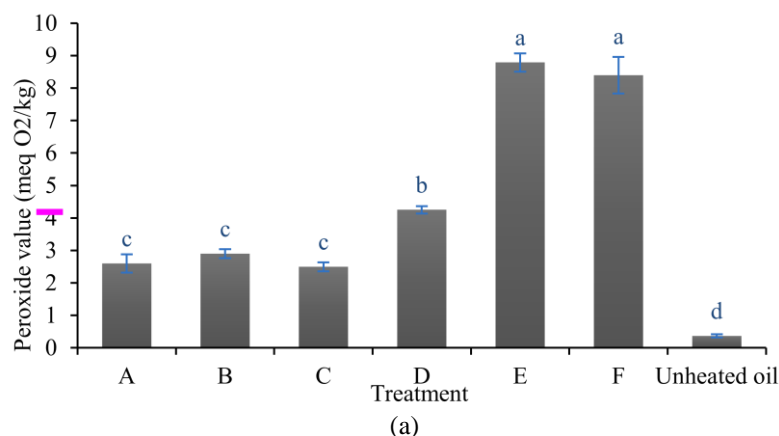
The peroxide value in all frying oil heated during nugget frying was higher than standard value of 2 meq O<sub>2</sub> kg<sup>-1</sup> determined in Iran and Austria as standard value for reuse of oil (Figure 2) (Firestone, 2007; Institute of Standards and Industrial Research of Iran, 2016).

Based on Figures 2-A and -B, despite the originally low amounts of initial oxidation products (i.e., peroxide value) in the treatment A, frying and cooling under atmospheric pressure had the most significant effect on oil oxidation, with the highest amounts of malondialdehyde (as a secondary oxidation product), indicating the severe oxidation taking place in this treatment. Similar results were reported by Crosa *et al.* (2014) and Kusucharid *et al.* (2009), who experimented with frying under

**Table 1.** Fatty acid composition (%) of frying oil after chicken nugget frying and cooling under atmospheric and vacuum pressure.

Treatment <sup>a</sup>	Palmitic acid (C16:0)	Stearic acid (C18:0)	Oleic acid (C18:1)	Linoleic acid (C 18:2)	Linolenic acid (C18:3)
A	24.37 ± 0.50 <sup>A</sup>	3.88 ± 0.01 <sup>A</sup>	33.94 ± 0.07 <sup>D</sup>	26.50 ± 0.12 <sup>D</sup>	2.23 ± 0.03 <sup>D</sup>
B	24.54 ± 0.03 <sup>A</sup>	3.87 ± 0.03 <sup>A</sup>	39.22 ± 0.02 <sup>B</sup>	28.46 ± 0.04 <sup>B</sup>	2.75 ± 0.00 <sup>B</sup>
C	24.71 ± 0.36 <sup>A</sup>	3.89 ± 0.01 <sup>A</sup>	37.59 ± 0.07 <sup>C</sup>	28.43 ± 0.21 <sup>B</sup>	2.23 ± 0.02 <sup>C</sup>
D	24.21 ± 0.03 <sup>A</sup>	3.84 ± 0.03 <sup>A</sup>	34.08 ± 0.01 <sup>D</sup>	27.36 ± 0.00 <sup>C</sup>	2.25 ± 0.04 <sup>D</sup>
E	24.44 ± 0.38 <sup>A</sup>	3.87 ± 0.01 <sup>A</sup>	38.88 ± 0.70 <sup>B</sup>	28.57 ± 0.03 <sup>B</sup>	2.76 ± 0.02 <sup>B</sup>
F	24.28 ± 0.11 <sup>A</sup>	3.90 ± 0.04 <sup>A</sup>	37.03 ± 1.16 <sup>C</sup>	28.40 ± 0.45 <sup>B</sup>	2.34 ± 0.01 <sup>C</sup>
Unheated oil	24.05 ± 0.07 <sup>A</sup>	3.82 ± 0.07 <sup>A</sup>	40.45 ± 0.13 <sup>A</sup>	29.05 ± 0.07 <sup>A</sup>	2.86 ± 0.02 <sup>A</sup>

<sup>a</sup> A: Atmospheric frying at 170°C- atmospheric cooling, B: Vacuum frying at 115°C- vacuum cooling, C: Vacuum frying at 170°C- vacuum cooling, D: Atmospheric frying at 170°C- vacuum cooling, E: Vacuum frying at 115°C- atmospheric cooling, F: Vacuum frying at 170°C-atmospheric cooling. Different letters in each column indicate a significant difference between treatments (P < 0.05).



**Figure 2.** Peroxide (A) and TBARs (B) values of frying oil after vacuum and atmospheric pressure frying and cooling of chicken nuggets. A: Atmospheric frying at 170°C-atmospheric cooling, B: Vacuum frying at 115°C-vacuum cooling, C: Vacuum frying at 170°C-vacuum cooling, D: Atmospheric frying at 170°C-vacuum cooling, E: Vacuum frying at 115°C-atmospheric cooling, F: Vacuum frying at 170°C-atmospheric cooling. Different letters in each column indicate a significant difference between treatments ( $P < 0.05$ ).

vacuum and atmospheric conditions. Comparison of frying and cooling under vacuum with frying and post-frying treatment under atmospheric pressure revealed the significant influence of both oxygen and reduced pressure on oxidation rate, as reflected in the small amount of malondialdehyde produced under vacuum relative to that produced under atmospheric pressure. Frying temperature did not exhibit any significant effect on oxidation intensity. Thus, compared to temperature, oxygen may be claimed as a factor with a greater contribution to oxidation reactions. Further support for this claim may be derived from Crosa *et al.* (2014), who reported only slight amounts of secondary oxidation products

generated from frying oil under vacuum rather than atmospheric pressure.

Oxidation intensity was observed to be significantly influenced by frying and cooling under non-identical pressures such that significantly lower amounts of malondialdehyde were produced in samples fried under atmospheric conditions and subsequently cooled under vacuum. However, their peroxide values were higher than those treated thoroughly under the same pressure. This bears witness to the effect of cooling pressure on the oxidation rate. It is in agreement with Tarmizi *et al.* (2013), who reported a reduction of 12 percent in the secondary products formed as a result of cooling oil under vacuum.



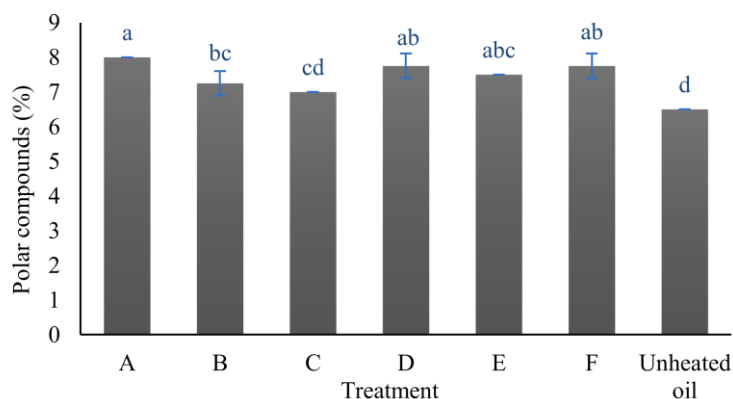
Interesting findings were derived from the comparison of oils heated under vacuum and cooled under atmospheric conditions with those subjected to the whole frying and cooling cycle under vacuum. For instance, the oils cooled under atmospheric pressure exhibited significantly higher peroxide values than those cooled under vacuum. This is while no significant difference was observed in malondialdehyde production between the two oil samples. In this case, the abrupt increase in pressure from vacuum to atmospheric level seems to have resulted in the formation of free radicals that increased the primary oxidation products, which failed to decompose and form secondary products due to the short time of pressure rise. Frying under atmospheric pressure and cooling at 10 kPa also exposed oil to pressure change; however, oxidation proceeded more rapidly during frying at atmospheric pressure, which led to the production of secondary oxidation products and reduction of peroxide value, as can be seen in Figure 2.

### Polar Compounds

The increase of polar compounds in oils indicates the formation of high polarity

compounds that result from secondary oxidative reactions (Crosa *et al.*, 2014). The polar compound content of unheated oil was 6.5%, which increased to 8% after frying and cooling under atmospheric pressure (Figure 3), lower than the standard value of 25% polar compounds in reusable oil (Firestone, 2007; Institute of Standards and Industrial Research of Iran, 2016). During frying nuggets under atmospheric conditions, polar compounds such as epoxides, aldehydes, ketones, alcohols, acids, and diglycerides are produced due to oil oxidation or hydrolysis, resulting in significantly increased polar compounds in the oil (Xu *et al.*, 2019). Oxidation and hydrolysis rates diminish significantly in the absence of oxygen during the frying and cooling cycle under vacuum; hence, lower polar compounds are produced.

In contrast, different pressures applied during the frying and cooling stages might significantly increase the extent of hydrolysis. This is evidenced by the significantly higher amounts of polar compounds produced in samples subjected to vacuum frying-atmospheric cooling than those subjected to vacuum frying and cooling. These results indicate the unfavorable effects of frying and cooling under different pressures.



**Figure 3.** Polar compounds of frying oil after chicken nuggets frying and cooling under vacuum and atmospheric pressure. A: Atmospheric frying at 170°C-atmospheric cooling, B: Vacuum frying at 115°C-vacuum cooling, C: Vacuum frying at 170°C-vacuum cooling, D: Atmospheric frying at 170°C-vacuum cooling, E: Vacuum frying at 115°C-atmospheric cooling, F: Vacuum frying at 170°C-atmospheric cooling. Different letters in each column indicate a significant difference between treatments ( $P < 0.05$ ).



**Table 2.** Color parameters of frying oil after chicken nugget frying and cooling under atmospheric and vacuum pressure.

Treatment <sup>a</sup>	L*	a*	b*
A	93.08 ± 0.10 <sup>B</sup>	-0.23 ± 0.02 <sup>A</sup>	31.48 ± 0.14 <sup>A</sup>
B	91.48 ± 0.46 <sup>C</sup>	-0.94 ± 0.03 <sup>D</sup>	21.61 ± 0.71 <sup>D</sup>
C	91.08 ± 0.15 <sup>C</sup>	-0.70 ± 0.08 <sup>C</sup>	21.44 ± 0.68 <sup>D</sup>
D	93.23 ± 0.28 <sup>B</sup>	-0.33 ± 0.01 <sup>A</sup>	27.40 ± 0.28 <sup>B</sup>
E	84.61 ± 0.39 <sup>D</sup>	-1.02 ± 0.07 <sup>D</sup>	25.25 ± 0.26 <sup>C</sup>
F	84.05 ± 0.28 <sup>D</sup>	-0.48 ± 0.04 <sup>B</sup>	26.04 ± 0.60 <sup>C</sup>
Unheated oil	94.57 ± 0.03 <sup>A</sup>	-1.98 ± 0.01 <sup>E</sup>	17.80 ± 0.01 <sup>E</sup>

<sup>a</sup> A: Atmospheric frying at 170°C- atmospheric cooling, B: Vacuum frying at 115°C- vacuum cooling, C: Vacuum frying at 170°C- vacuum cooling, D: Atmospheric frying at 170°C- vacuum cooling, E: Vacuum frying at 115°C- atmospheric cooling, F: Vacuum frying at 170°C-atmospheric cooling. Different letters in each column indicate a significant difference between treatments (P < 0.05).

### Oil Color

The oils used for the vacuum frying of nuggets exhibited more significant reductions in lightness than those used for atmospheric frying (Table 2). The most significant reduction was observed in samples fried under vacuum and cooled under atmospheric pressure. Kusucharid *et al.* (2009) also reported reductions in lightness values for oils used in vacuum frying of potatoes. They attributed these changes to Maillard reactions due to the longer time of vacuum frying.

The post-frying lightness value seems to have been reduced due to the water released from the nuggets entering the oil along with other compounds. The highest moisture losses (data not shown) were recorded for nuggets subjected to vacuum frying and atmospheric cooling, reducing the color's lightness. In contrast, the least moisture losses were recorded for nuggets fried under atmospheric pressure, with only slight changes in oil lightness value. Finally, oxidation might be claimed as another reason for the reduced lightness value in oils subjected to atmospheric frying relative to unheated oil.

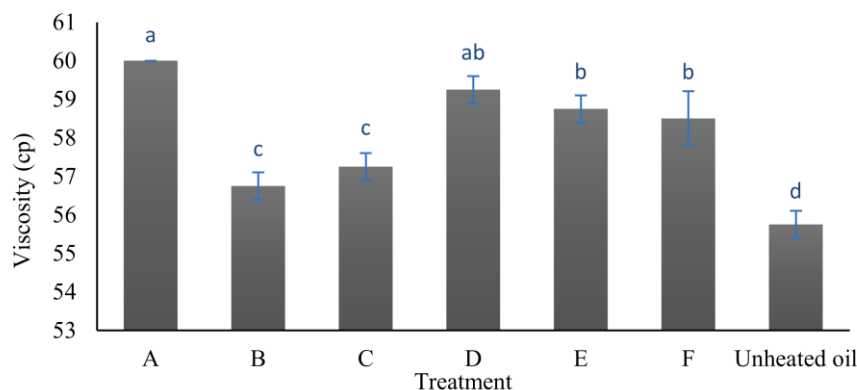
Higher a\* and b\* values were recorded for oils subjected to atmospheric frying, probably due to severe oxidation in such samples. However, a\* and b\* values were

reduced with frying under vacuum due to the lower oxidation in these treatments. Moreover, the lowest and highest redness values were recorded for samples fried at 115 and 170°C, respectively. Clearly, the frying temperature has a significant effect on oil redness value.

Measurements of yellowness values indicated lower b\* values for samples cooled under vacuum than those subjected to atmospheric cooling. Similar results were reported by Tarmizi *et al.* (2013), who stated that cooling under vacuum rather than atmospheric conditions had considerable effect on reducing the yellowness and redness values of the oils used.

### Oil Viscosity

According to Figure 4, unheated oil recorded a viscosity of about 56 cp, which increased to 60 cp after frying and cooling under atmospheric pressure due to the high frying temperature and the presence of oxygen. In contrast, the oils used for vacuum frying recorded significantly lower viscosity values than those subjected to atmospheric pressure; the difference might be attributed to the reduced vapor saturation temperature and the absence of oxygen in the latter samples (Kusucharid *et al.*, 2009). Moreover, oil viscosity reduced significantly as a result of cooling under vacuum. Tarmizi *et al.* (2013) also reported reduced viscosity



**Figure 4.** Oil viscosity of frying oil after chicken nuggets frying and cooling under vacuum and atmospheric pressure. A: Atmospheric frying at 170°C-atmospheric cooling, B: Vacuum frying at 115°C-vacuum cooling, C: Vacuum frying at 170°C-vacuum cooling, D: Atmospheric frying at 170°C-vacuum cooling, E: Vacuum frying at 115°C-atmospheric cooling, F: Vacuum frying at 170°C-atmospheric cooling. Different letters in each column indicate a significant difference between treatments ( $P < 0.05$ ).

for oils used for atmospheric frying as a result of cooling under vacuum rather than atmospheric pressure.

## CONCLUSIONS

During the last 20 years, the beneficial effect of vacuum over the typical atmospheric frying has been considered. Although the frying process seems to be terminated at the end of heating time, chemical reactions continue during the cooling phase due to the high temperature of oil. Therefore, the condition of the cooling phase can have considerable effect on oil characteristics. To obtain a more comprehensive view of physicochemical events occurring in frying oil during the frying process, different heating and cooling conditions were applied to frying of nugget, and their effect on frying oil properties was evaluated. Results indicated that vacuum frying must be followed by cooling under vacuum to reduce oxidation rate to the minimum amount. The sudden pressure changes before decreasing the oil temperature can accelerate production of peroxide. The absence of air (or oxygen) during the frying phase and even the short

drainage period could significantly retard oxidative degradation. The use of higher temperature during frying, the presence of oxygen during the frying and cooling phase, and the pressure change immediately after the frying phase increased not only the oxidative rate but also the unsaturated fatty acid degradation, the amount of polar compounds, and the oil viscosity. Therefore, to decrease the detrimental effect of the frying process on oil quality, vacuum frying and cooling at the lowest possible temperature for frying is suggested.

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## بررسی تغییرات فیزیکوشیمیایی روغن پس از سرخ کردن و سرد کردن ناگت مرغ تحت خلا و فشار اتمسفری

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### چکیده

در مطالعه حاضر، اثر سرخ کردن و سرد کردن تحت خلاء و فشار اتمسفری ناگت مرغ بر روی ویژگی های کیفی روغن سرخ کردنی مورد بررسی قرار گرفت. بدین منظور، در دو تیمار، سرخ کردن در دمای ۱۷۰ درجه سلسیوس و تحت فشار اتمسفری انجام گرفت. یکی از این تیمارها پس از اتمام فرایند سرخ کردن در فشار اتمسفری سرد شد (شاهد) و در تیمار دیگر، سرد کردن در فشار ۱۰ کیلوپاسکال انجام گرفت. سایر تیمارها شامل سرخ کردن در دمای ۱۱۵ و ۱۷۰ درجه سلسیوس تحت فشار ۱۰ کیلوپاسکال و سپس سرد کردن در فشار اتمسفری و ۱۰ کیلوپاسکال بودند. نتایج نشان داد که سرخ کردن و سرد کردن در دمای ۱۷۰ درجه سلسیوس، عدد اسیدی، میزان ترکیبات قطبی، ویسکوزیته، زردی، قرمزی و اکسیداسیون روغن را افزایش داد. همچنین این فرایند موجب کاهش میزان اسیدهای چرب غیراشباع شد. از سوی دیگر، حداقل مقدار عدد اسیدی، ویسکوزیته و سرعت اکسیداسیون در روغنی مشاهده شد که برای سرخ کردن تحت خلاء در دمای ۱۱۵ درجه سلسیوس مورد استفاده قرار گرفته و سپس در فشار ۱۰ کیلوپاسکال سرد شده بود. بیشترین میزان اسیدهای اولئیک، لینولئیک و لینولنیک نیز در همین نمونه به دست آمد زیرا حداقل میزان اکسیداسیون در اسیدهای چرب غیراشباع در خلاء نسبت به فشار اتمسفری رخ می دهد. براساس نتایج به دست آمده، به نظر می رسد سرخ کردن و سرد کردن در دمای ۱۱۵ درجه سلسیوس تحت خلاء، حداقل تغییرات نامطلوب را بر روی روغن سرخ کردنی به همراه دارد.