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Corn Oil Oleogel Structured with Chicken Skin as A Potential Fat Replacer in Meat Batters

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HIGHLIGHTS

- Beef fat was substituted by corn oil oleogel based on chicken skin in meat batters.
- Microstructure, color, and texture were considerably affected by oleogel utilization.
- Meat batters formulated with oleogel had healthier lipid composition and improved nutritional ratios.
- Water holding capacity and cooking yield improved by the addition of oleogel.
- Reformulated samples had better oxidative stability.

Abstract

This study investigated the effects of replacing beef fat with corn oil chicken skin oleogel on the quality parameters of model meat batters. Four different batches were prepared with varying amounts of oleogel (50% (O50), 75% (O75), 100% (O100)) as a fat substitute, while a control group was prepared with 100% (C) beef fat. Chemical composition, technological properties, color, texture, fatty acid composition, and oxidative changes were evaluated. The results showed that oleogel addition increased moisture and decreased protein content. Water holding capacity and cooking yield improved by the addition of oleogel. Replacing beef fat with oleogel increased lightness and yellowness, and reduced redness compared to control samples. The hardness, gumminess, springiness, and chewiness of the control were significantly higher than the samples formulated with oleogel. The incorporation of oleogel resulted in a reduction in saturated fatty acids (SFA) and an increase in polyunsaturated fatty acids (PUFA). As the level of oleogel increased, the amount of linolenic acid also increased significantly. Replacing beef fat with oleogel resulted in significant reductions in the atherogenicity (IA) and thrombogenicity (IT) indexes. At the end of the storage, the highest TBARS value was recorded in the control sample formulated with 100% beef fat.

Keywords: Fatty acids, Edible oils, Chicken skin, Meat products, Texture, Oxidation

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1. Introduction

Therefore, it is essential to select appropriate fat sources and levels to optimize the sensory and technological quality of meat products while keeping in mind the potential health impacts of excessive fat consumption (Serdaroğlu et al. 2016). Nevertheless, animal fat replacement by vegetable oils resulted in unfavorable technological and sensory changes and decreased oxidative stability. Therefore, incorporating vegetable oils into meat products requires the use of structured emulsion systems like emulsion gels, hydrogels, or oleogels (Serdaroğlu et al. 2017). In particular, the utilization of oleogels as a substitute for fat in meat product formulations has become increasingly popular in recent times. Oleogel systems, formed by gelling vegetable oil with an oleogelator, provide a viable alternative to animal fats high in saturated fatty acids (Martins et al. 2020). These heat-reversible oleogels exhibit solid-like properties and can mimic the behavior of fats, even with a high proportion of unsaturated fatty acids. By reducing overall fat content while maintaining texture and mouthfeel, oleogels offer an appealing option in meat product formulations (Silva et al. 2021). They help control oil relocation, prevent oxidative changes, and improve technological properties while preserving a healthier fatty acid profile (Serdaroğlu et al. 2017). Numerous studies have successfully used oleogels as fat replacers in various meat products, including sausages, patties, and pâtés (Panagiotopoulou et al. 2016; Barbut and Marangoni 2016; Wolfer et al. 2018; Silva et al. 2019). These studies have shown that incorporating oleogels enhances sensory properties, such as texture and juiciness, without compromising nutritional value. Furthermore, oleogels can be tailored to possess functional properties, enabling control over flavor release and the delivery of active compounds, which can be advantageous in meat products. Researchers have utilized various vegetable oils, such as olive, corn, flaxseed, and sunflower oils, to create oleogels as alternatives to animal fat in meat products (Silva et al. 2019; Martins et al. 2020).

Corn oil, in particular, is a popular choice due to its wide availability, cost-effectiveness, and favorable fatty acid composition. It contains high levels of linoleic acid (C18:2n-6) and consists of 54% polyunsaturated fatty acids, 33% monounsaturated fatty acids, and 13% saturated fatty acids, making it a nutritionally valuable option (Wagner et al. 2001). The structure of corn oil oleogels can be achieved using different structurants, including waxes, polymers, proteins, and by-products like pork skin. Researchers have explored various oleogelators to form the structure of corn oil, such as ethyl cellulose, sorbitan monostearate, soy protein concentrate, γ-oryzanol, β-sitosterol, beeswax, and rice wax (Panagiotopoulou et al. 2016; Wolfer et al. 2018; Silva et al. 2019). However, there is currently no specific study on the use of corn oil oleogel as a fat replacer, nor has the potential utilization of chicken skin as a structurant in oleogels been extensively investigated, despite its collagen and fat content, which could contribute to its suitability (Xia et al. 2022). To explore the development of healthier meat products with reduced fat content, one approach is to use oleogels. Oleogels are semi-solid systems that consist of liquid oil structured to provide a solid-like texture. In this study, corn oil oleogels structured with chicken skin were investigated as a potential fat replacer in meat batters. The aim was to assess how different concentrations of chicken skin affect the physicochemical and rheological properties of the oleogels, as well as their performance in meat batters. The research aims to provide valuable insights into the creation of healthier meat products with lower fat content.

2. Materials and Methods

Lean beef (M. semitendinosus; 72.82% moisture, 20.82% protein; 3.12 % fat, 1.6% ash), beef fat, and chicken skin were obtained from a supermarket (İzmir, Turkey). Corn oil (Sırma, Turkey), palmitic acid, 9.6%; palmitoleic acid, 0.9%; stearic acid, 4.6%; oleic acid, 31.5%; linoleic acid, 48.4%; linolenic acid, 4.1%; and arachidic acid, 0.8%).

2.1. Preparation of oleogel

Oleogel was prepared with slight modifications based on the procedures described by Silva et al. (2019). Chicken skin is chopped into small pieces (2 cm x 2 cm) using a knife and then placed in a glass jar. The jar is then subjected to heat treatment by immersing it in a water bath at 90°C for 15 minutes. after the chicken skin was heat-treated and cooled to room temperature, it was mixed with water and corn oil in a ratio of 1:5:5

(chicken skin: water: corn oil). The mixture was then homogenized with a blender (Sinbo, Turkey) for 5 minutes, which helps to break up the chicken skin and create a smooth, uniform mixture. The resulting mixture was then stored at +4°C overnight to allow for gelation, which is the process by which the mixture forms a solid gel-like structure. The final product is an oleogel, which is a semi-solid gel-like substance made up of oil and a gelling agent (in this case, collagen from the chicken skin).

2.2. Experimental design and preparation of meat batters

Meat batters were prepared according to the method of Serdaroğlu et al. (2021) the preparation steps are given in Fig 1. Four batches (as shown in Table 1) were prepared for the experiment. Control samples (C) were formulated using 100% beef fat. In the reformulated treatments, the beef fat was replaced with oleogel at different levels; 50% (O50), 75% (O75), and 100% (O100). To prepare the meat batters (as shown in Fig. 1), the lean beef and beef fat were ground separately using a 3 mm plate meat grinder (Arnica, Turkey). The ground meat was then homogenized for 1 minute at 500 rpm using a Thermomix (Vorwerk, Wuppertal, Germany). NaCl and STPP (sodium tripolyphosphate) were added, followed by iced water, and the mixture was homogenized for an additional 3 minutes at 500 rpm. After the initial homogenization step, beef fat and/or oleogel and the remaining iced water were added to the mixture. The emulsification process was then continued at 1100 rpm for 3 minutes, followed by 2500 rpm for 2 minutes. Throughout the process, the temperature was kept below 12°C to prevent any undesirable changes to the meat batter. To ensure uniformity in the final product, the meat batters were filled into 50 ml centrifuge tubes and centrifuged at 2500 rpm for 1 minute (using a Nüve NF 400 centrifuge, Turkey) to remove any air bubbles. The tubes were then transferred to a water bath (using a Nüve water bath, Turkey) and heat-treated at 70°C for 30 minutes. After the heat treatment, the samples were immediately cooled in a cold water bath (+1°C) and stored at +4°C for 7 days. During this storage period, lipid oxidation analyses were performed in triplicate at 0, 3, 5, and 7 days to assess the oxidative stability of the samples. All other analyses were conducted within 72 hours of production to ensure the freshness.

2.3. Analysis of oleogel

pH meter (WTW pH 330i/SET) equipped with a probe electrode was used to measure the pH of oleogel samples, four readings were taken at four different points. To determine the color parameters, a CR-200 portable colorimeter (Konica Minolta, Japan) equipped with a ten-degree observer angle and D65 illuminant was utilized. Prior to conducting measurements, the colorimeter underwent calibration using traditional white and black plates. CIE L*, CIE a*, and CIE b* values were measured. Oil binding capacity (OBC) was assessed using a modified method described by Fayaz et al. (2017). A plastic centrifuge tube containing 5 g of oleogel sample was weighted and centrifuged for 15 min at 10,000 rpm (Universal 320 centrifuge Hettich, Germany), and the supernatant (oil) was weighed. The following equation was used to calculate the OBC:

$$\%Oil\ released = \frac{Mass\ of\ expressed\ oil\ (g)}{Total\ mass\ of\ sample\ (g)} x\ 100$$

$$OBC = 100 - \%Oil\ released$$

2.4. Proximate composition and pH values of the emulsions

Moisture (AOAC-925.10) and ash (AOAC-923.03) contents were determined according to the Association of Official Analytical Chemists AOAC (2003) methods, chloroform/methanol extraction method was used for fat determination (Flynn and Bramblett 1975). Dumas combustion method was used to analyze protein content (LECO, FP-528, USA).

2.5. Water holding capacity and emulsion stability

The water holding capacity (WHC) was measured using the method described by Hughes et al. (1997). First, 10 g of batter was weighed (W1), transferred to a glass tube, and heated in a 90°C water bath for 10 minutes. After cooling to room temperature, the sample was wrapped with cotton cheesecloth, centrifuged at 1400 rpm for 15 minutes, and weighed again (W2). The WHC was calculated using the following equation:

$$\%WHC = 1 - T/M \times 100 = 1 - (W1 - W2)/M \times 100$$

T: $water\ loss\ after\ heating\ and\ centrifugation$

M: $sample's\ total\ moisture\ content$

The emulsion stability, total expressible fat, and total expressible moisture of meat batters were determined by the following method: 25 g of raw meat batter was placed in a centrifuge tube and centrifuged for 15 min at 6000 rpm. The pellet obtained was heated in a water bath at 70°C for 30 min and then centrifuged again at 6000 rpm for 20 minutes. Afterward, the pellet was weighed, and the supernatant was poured into pre-weighed crucibles and dried overnight at 100°C. The total expressible fluid (TEF) volume and total expressible fat (EFAT) were calculated using the equations outlined by Hughes et al. (1997).

$$TEF = (WCT + WS) - (WT + WP)$$

WCT: $Weight\ of\ centrifuge\ tube$

WS: $Weight\ of\ sample$

WP: $Weight\ of\ pellet$

$$TEF(\%) = (\frac{TEF}{WS}) \times 100$$

$$EFAT(\%) = [(WC + WDS) - (WCT + WS)]/TEF \times 100$$

WC: $Weight\ of\ crucible$

WDS: $weight\ of\ dried\ supernatant$

WCT: $Weight\ of\ centrifuge\ tube$

WS: $Weight\ of\ sample$

2.6. Cooking yield

Weight of meat batter before and after cooking was recorded and the cooking loss was expressed as a percentage difference between the raw and cooked weights.

2.7. Fatty acid composition

The procedure for lipid extraction followed Flynn and Bramblett's (1975) method, and the resulting lipid phase was subjected to methylation using the procedure described by Anon (1987). To analyze the fatty acid methyl esters (FAME), gas chromatography (GC 2010 Plus, Shimadzu Corp., Kyoto, Japan) was employed, with a silica capillary column (SUPELCO SP TM-2560; 100 m × 0.25 mm id., 0.20 μm/m film thickness). After setting the helium injector and detector (FID) at 140°C, they were kept constant at that temperature. The oven temperature was then increased from 140°C to 250°C at a rate of 4°C/min and held at 240°C for 10 minutes. To calculate the atherogenicity (IA) and thrombogenicity (IT) indexes, the equations proposed by Ulbricht and Southgate (1991) were used.

$$IA = [C12{:}0 + (4 \times C14{:}0) + C16{:}0]/\Sigma UFA$$

$$IT = (C14{:}0 + C16{:}0 + C18{:}0)/[(0.5 \times \Sigma MUFA) + (0.5 \times \Sigma n - 6\ PUFA) + (3 \times \Sigma n - 3\ PUFA) + (n - 3\ /\ n - 6)]$$

2.8. Texture evaluation

To evaluate the texture (TPA), a texture analyzer (TA-XT2, Stable Micro Systems, UK) equipped with a 30 kg load cell was used. The following texture parameters were determined from the force and time curves: hardness (N), springiness, cohesiveness, gumminess (N), and chewiness (N.mm). Using an aluminum cylindrical probe with a diameter of 36 mm and a load cell set to 5 kg, cooked meat batters measuring 1 cm x 1 cm x 1 cm were compressed to 50% of their original height. The post-test speed, crosshead speed, and test speed were set to 2 mm/s, 1 mm/s, and 1 mm/s, respectively.

2.9. Microstructure

To assess the microstructure of the samples, scanning electron microscopy (Thermo Scientific Apreo 2, Waltham, MA) was utilized. The meat batters were dried to obtain a powder, which was then filled into the

SEM unit, coated with gold in a vacuum evaporator, and examined under high vacuum. Micrographs were created as a result of the sample's interaction with the electron beam.

2.10. Color parameters

The color of the samples was evaluated using a portable colorimeter (CR-200, Konica Minolta, Japan) equipped with a ten-degree observer angle and D65 illuminant. Color parameters of CIE L*, a* and b* values were measured at four different points of each sample.

2.11. Lipid oxidation

Primary oxidation products were determined by peroxide value (PV) according to AOAC (1990) procedure; results were expressed per mEqO2 (milliequivalent peroxide oxygen)/kg sample. TBARS analysis was performed according to Witte et al. (1970) to detect lipid oxidation second products. Results were expressed as mg malonaldehyde/kg sample.

2.12. Statistical analysis

The entire procedure for the meat batter production was replicated three times (three individual batches) on different days and measurements of related traits were conducted in triplicate for each batch. Within one replication, totally four different meat batter formulations (C, O50, O75 and O100) were prepared. Mean values for measured parameters were calculated by using the SPSS software for windows (SPSS 21.0 for Windows; SPSS Inc. Chicago, IL, USA). Production batches were expressed as a random variable, and each treatment was recognized as a fixed variable. To evaluate the effects of fat reduction and/or oleogel, one-way ANOVA was applied. Means were further compared using the Duncan test. Duncan's multiple range test was employed to compare group values with a significance level of $p<0.05$.

3. Results and Discussions

3.1. Characterization of oleogel

The pH value of oleogel was recorded as 6.16. The obtained result for pH in the present study was higher than the pH of oleogel formulated with pork skin (pH 5.80) (Silva et al. 2019). Lightness, redness, and yellowness values were measured as 69.79, 0.70 and 18.85, respectively. The color of oleogel depends on the color of oil and oleogelator used in the formulation. The pale-yellow corn oil and white chicken skin utilized in the oleogel formulation could be the reason for the high L* value in the present study. The amount of oil entrapment in the 3D network by the gelator is indicated by the OBC, a crucial characteristic of oleogels (Pandolsook and Kupongsak 2017). Although the OBC value for the oleogel was not high (73.96%), this value is in the appropriate range with the literature data (Thakur et al. 2022).

3.2. Chemical composition and pH

Table 2 provides a summary of the chemical composition of cooked meat batters. The substitution level significantly affected the moisture, protein, fat, and pH content ($p<0.05$). Substituting 75% and 100% of beef fat with oleogel increased the moisture content ($p<0.05$), which is consistent with findings from a study on hamburgers by Moghtadaei et al. (2018) using sesame oil-beeswax oleogel. The protein content in the samples ranged from 20.41% to 23.25%. The incorporation of oleogel led to a significant reduction in protein content ($p<0.05$), with the C treatment exhibiting the highest protein content and the O50 treatment having the lowest ($p<0.05$). Similar observations were made in pâté samples by Martins et al. (2020). Regarding fat content, the O100 samples had the highest percentage (13.97%), primarily due to the fat content of chicken skin in the oleogel formulation. However, there were no significant differences observed among the other treatments. The ash content did not show significant differences among the treatments ($p>0.05$), which is consistent with studies using oleogel as a fat replacer (Gómez-Estaca et al. 2019). The replacement of beef fat with oleogel led to an increase in pH values, regardless of the level of incorporation ($p<0.05$). The high pH of the oleogel may

account for this increase. Similar results were reported by Gómez-Estaca et al. (2019) in pâté samples using ethyl cellulose and beeswax as fat substitutes.

3.3. Techno-functional quality

Table 3 presents the techno-functional properties of meat batters based on the quantity of oleogel incorporated. Water holding capacity (WHC), which refers to the meat's ability to retain moisture, was significantly affected by the replacement of beef fat with corn oil oleogel ($p<0.05$). The WHC of the control treatment was lower than that of the reformulated treatments ($p<0.05$), and the highest WHC was observed in the O100 treatment ($p<0.05$). The addition of chicken skin, which contains collagen, has been shown to improve the WHC of meat emulsions in previous studies. The cooking yield, which indicates the amount of moisture retained during cooking, ranged from 95.34% to 98.72%. The addition of oleogel significantly increased the cooking yield ($p<0.05$). The thermal gelation of collagen in the chicken skin oleogel may have contributed to the improved cooking yield by increasing water retention. Similar findings have been reported in studies where the substitution of animal fat with plant oils improved the cooking yield of sausages (Wolfer et al. 2018). Emulsion stability, which refers to the ability of the emulsion to resist separation, was significantly influenced by the addition of oleogel ($p<0.05$). The addition of oleogel led to a significant decrease in the total amount of expressible water ($p<0.05$), indicating improved emulsion stability. The water-binding ability of collagen present in chicken skin may contribute to this effect. However, there was no significant difference in the total amount of expressible oil when oleogel was added to the formulation ($p>0.05$). Overall, the incorporation of oleogel in meat batters improved water holding capacity, cooking yield, and emulsion stability, indicating its potential as a functional ingredient in meat product formulations.

3.4. Fatty Acid Profile and Health Indices

Reducing fat content in meat products is a challenge due to its impact on technological and sensory properties. High intake of saturated fat is associated with adverse health effects (WHO, 2021). To address this, replacing animal fat with healthy plant oils like gelled emulsions or oleogels is gaining importance. The fatty acid profile was affected by the corn oil-chicken skin oleogel and its addition level ($p<0.05$) and increasing oleogel levels led to higher amounts of linolenic and oleic acid. This may be due to the high oleic acid content (43%) in chicken skin. These findings align with studies on reduced-fat beef burgers using olive oil-based oleogel substitutes (Özer and Çelegen 2020). Treatment with PUFA O50, O75, and O100 showed increased levels of polyunsaturated fatty acids (PUFAs) compared to the control. SFA levels in 050, 075 and O100 samples decreased by 30.9, 57.4 and 71.9 % respectively compared to the control samples. Therefore, oleogel added samples can be classified as "reduced in saturated fat" according to the European Parliament's definition, as they achieved a reduction in SFA content of over 30% (European Parliement 2006). Compared to the control, the treatments of PUFA O50, O75, and O100 have shown an increase of 26.34%, 32.05%, and 32.63%, respectively.

Table 4 presents the health indices of the meat batters, with the PUFA/SFA ratio being a commonly used measure of nutritional quality. The control samples had a ratio of 0.06, while the O100 treatment significantly increased it to 1.68. The addition of oleogel reduced the palmitic acid ratio compared to beef fat ($p<0.05$). Nutritional recommendations suggest a PUFA/SFA ratio above 0.45 in the human diet (HMSO 1994). Meat batters with oleogel exhibited significant increases in their PUFA/SFA ratios as oleogel levels increased ($p<0.05$). This suggests that using oleogel can enhance the nutritional quality of meat products, potentially benefiting consumers' health. The USDA (2015) and WHO (2021) recommend a daily intake of up to 3% of energy from PUFAs and 1.4-2.5 g of n-3 PUFAs, while also considering the PUFA/SFA ratio. Incorporating oleogel made from chicken skin and corn oil into meat batters led to a significant decrease in saturated fatty acids, along with increased PUFA/SFA and n-6/n-3 ratios ($p<0.05$). These health indicators are important as high n-6/n-3 ratios in diets can contribute to various illnesses, while higher n-3 content has a suppressive effect. Replacing beef fat with oleogel resulted in a notable decrease in the n-6/n-3 ratio, aligning with dietary

guidelines. Utilizing innovative lipid materials such as oleogels made from plant oils with a favorable fatty acid profile enabled an increase in the PUFA/SFA ratio (from 0.06 to 1.68) and a reduction in the n-6/n-3 ratio towards recommended values. Similarly, in a different study, replacing pork back fat with beeswax oleogel led to an increased PUFA/SFA ratio and decreased n-6/n-3 ratio (Gómez-Estaca et al. 2019). Furthermore, replacing beef fat with oleogel resulted in significant reductions in the atherogenicity (IA) and thrombogenicity (IT) indexes, indicating higher levels of anti-atherogenic fatty acids that can help prevent coronary diseases. The IA and IT indexes were significantly decreased ($p<0.05$) by 73% and 84%, respectively, in the O100 treatment compared to the control samples. Similar reductions in IA and IT indexes were observed when replacing 75% and 100% of pork back fat with oleogel in a previous study (Silva et al. 2019).

3.5. Instrumental quality

Color is a crucial factor influencing consumer preference when it comes to meat products. Reformulation efforts have led to significant changes in color parameters. The L*, a*, and b* values of meat batters are presented in Table 5, ranging from 42.12 to 55.50, 11.76 to 6.81, and 11.64 to 14.42, respectively. Incorporating oleogel in the formulation resulted in higher L* and b* values and lower a* values compared to the control samples ($p<0.05$). The addition of oleogel can contribute to improved homogeneity and compactness of the meat batters' structure, leading to increased L* values. The enhanced L* values may be attributed to the more uniform distribution of the oil phase within the protein matrix, as liquid oil tends to disperse more evenly compared to animal fat. Similar findings have been reported in studies on the use of oleogels as animal fat replacers in breakfast sausages and frankfurters (Barbut et al. 2016). However, variations in oil composition, oleogelator composition, and raw materials can influence the results observed in different studies. Lower redness levels were observed in samples with oleogel compared to the control ($p<0.05$), likely due to color differences between beef fat and oleogel. These results align with the findings of previous studies that demonstrated lower redness values with the addition of oil gel emulsions in emulsion-type sausages (Nacak et al. 2021). All treatments, except for the control group, exhibited an increase in the b* value ($p<0.05$), with no significant difference among the treatments with oleogel ($p>0.05$). The disparity in color between beef fat (creamy white) and corn oil (pale yellow) could account for this observation. Consequently, the b* value of all other treatments is higher than that of the control group. These findings are consistent with similar results reported in studies focusing on b* values (Jimenez-Colmenero et al. 2010; Serdaroğlu et al. 2016).

The reduction and modification of fat significantly impact the texture properties (hardness, cohesiveness, gumminess, springiness, and chewiness) of meat products (Table 5). The texture parameters of the control samples were significantly higher than those of the samples formulated with oleogel, indicating the effect of fat substitution on texture ($p<0.05$). This effect can be attributed to changes in the protein structure of the meat and the emulsion stability of the oleogel. The type and properties of the lipid source and its behavior in the system play a major role in determining the textural quality of fat-substituted meat systems. Similar findings were reported in reduced-fat beef burgers where animal fat was partially replaced with olive oil oleogel-based emulsion (Özer and Çelegen 2020). An increase in moisture retention caused by soybean protein was found to decrease the hardness and chewiness of patties, which may have influenced the results of this research. The hardness value was also observed to decrease in beef burgers produced with olive oil oleogel-based emulsions. Texture parameters play a crucial role in determining the overall quality and sensory properties of meat products. The substitution of animal fat with sesame oil-beeswax oleogel resulted in reduced gumminess and chewiness in burgers (Moghtadaei et al. 2018). The springiness values of meat batters decreased, and the lowest value was observed in the O50 treatment. Reduced springiness was also observed in Frankfurter-type sausages formulated by replacing lard with rice bran wax oleogels. These results can be attributed to the more elastic properties of animal fats. The reduced gumminess of samples containing beef fat substituted with oleogel could be due to weaker internal bonds and a softer network. Cohesiveness values ranged from 0.30 (O100) to 0.39 (C), while gumminess values decreased from 14.57 (C) to 3.22 in the O100 treatment ($p<0.05$).

Chewiness values ranged from 1.07 (O100) to 6.83 (C), with a significant decrease observed as the oleogel ratio increased ($p<0.05$). Hardness values are generally correlated with gumminess and chewiness values.

3.6. Microstructure

The SEM images of beef emulsion samples (1000x magnification) have been shown in Fig 2. Treatments formulated with oleogel had a coarse microstructure. As the amount of beef fat was reduced, the product structure appeared to become more compact. Microstructural impacts of oleogel addition are markedly visible. Control samples formulated with only beef fat had smaller fat globules. Increasing oleogel in formulation resulted more integrated and homogenous sturcture. A study using the bigel (mixing hydrogel and oleogel) made of starch and ethylcellulose as a fat replacer showed that control samples had microstructures with greater gaps (Ghiasi and Golmakani 2022).

3.7. Fat oxidation products: Peroxidases and TBARS

The measurement of peroxide value is crucial in assessing the oxidation status of muscle foods, as hydroperoxides are primary oxidation products associated with quality deterioration. Fig 3A presents the peroxide values of the treatments. Initial peroxide values ranged from 1.86 (O75) to 3.04 (O50) meqO^2/kg. The storage period and fat formulation were found to have a significant effect on peroxide values ($p<0.05$). On the 3rd day, all samples exhibited an increase in peroxide value, with the highest value observed in O75 (4.43 meqO^2/kg) and the lowest in O100 (2.54 meqO^2/kg) samples ($p<0.05$). In the C and O50 samples, peroxide values continued to increase until the 5th day, followed by a decrease on the 7th day. Over time, peroxide values tend to decrease as hydroperoxides break down into secondary oxidation products. At the end of storage, peroxide values were 2.66, 3.54, 2.61, and 2.76 meqO2/kg in the C, O50, O75, and O100 samples, respectively. Some studies have shown that samples containing added oleogel had lower peroxide values than the control on the 5th day (Tabibiazar et al. 2020). The structure of the oleogel formulation, with its solid-like consistency, can offer protection against oxidation. However, there are also studies that have reported higher peroxide values in meat products formulated with oleogel compared to the control (Moghtadaei et al. 2018; Tabibiazar et al. 2020). The variations in oil sources, product formulations, and storage parameters can contribute to these different outcomes. Throughout the storage period, all samples had peroxide values significantly lower than the acceptable limit (25 meqO^2/kg) established by Evranuz (1993).

Fig 3B illustrates the TBARS values. The incorporation of corn oil oleogel did not have an adverse effect on the TBARS values of the meat batters ($p>0.05$). In fact, the addition of oleogel resulted in a significant reduction in TBARS values compared to the control treatment ($p<0.05$). Initially, there was no significant difference in TBARS values between the C and O50 samples. During storage, the control group showed a significant increase in TBARS value ($p<0.05$), while the other treatments experienced minor fluctuations. The lowest TBARS values were observed in the O75 and O100 treatments on the 5th day of storage ($p<0.05$). The control sample formulated with 100% beef fat had the highest TBARS (2.87 mg MDA/kg) value at the end of storage. Most groups, except the control, had TBARS values within the limit of 2 mg MDA/kg (Witte et al. 1970). The variation in TBARS values can be influenced by the fatty acid composition of the vegetable oil used and the antioxidants in the formulation. These findings align with previous studies on meat products formulated with oleogel (Wolfer et al. 2018; Gómez-Estaca et al. 2019). The increase in TBARS values may be attributed to a higher formation ratio of malonaldehydes compared to their disappearance, but over time, the disappearance ratio may surpass the formation ratio, leading to a decrease in TBARS values.

4. Conclusions

Overall, it appears that the addition of corn oil chicken skin oleogel had a positive impact on the technological attributes and textural parameters of the meat batter. Also, beef fat replacement of oleogel positively enhanced the quality attributes of meat batters by higher water holding capacity and cooking yield.

The incorporation of chicken skin into the oleogel matrix can provide a sustainable and cost-effective approach for reducing the amount of saturated and trans fats in meat products. However, it is important to consider the potential effects of any color alterations that may have occurred. Further research is needed to optimize the formulation and processing conditions of chicken skin-based oleogels and evaluate their sensory and nutritional properties in food products. However, more research is needed to optimize the formulation and processing conditions of chicken skin-based oleogels, as well as evaluate their nutritional and sensory properties in various meat products.

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