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LIPID MODULATION IN MEAT EMULSIONS USING SIMPLE AND GELLED OIL-IN-WATER EMULSIONS

MODULAÇÃO LIPÍDICA EM EMULSÕES CÁRNEAS USANDO EMULSÕES ÓLEO EM ÁGUA SIMPLES E GELIFICADAS

MODULACIÓN LIPÍDICA EN EMULSIONES CÁRNICAS UTILIZANDO EMULSIONES ACEITE EN AGUA SIMPLES Y GELIFICADAS

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Abstract

Emulsified meat products formulated with a high content of mechanically deboned chicken meat (MDCM) are widely consumed in Brazil. Therefore, improving their nutritional profile and understanding how structured oils affect their physicochemical properties is of practical relevance. This study compared the incorporation of simple and gelled oil-in-water emulsions based on an olive and chia oil blend as pork fat replacers in meat emulsion model systems with high MDCM content. Sodium caseinate (SC) and soy protein isolate (SPI) were used as emulsifying agents, while carrageenan served as the gelling agent. The gelled emulsion stabilized with SC resulted in the highest emulsion stability, whereas the treatment containing the non-emulsified oil blend exhibited the lowest stability. No significant differences were observed between the remaining treatments and the control formulated with pork back fat. Meat emulsions containing simple and gelled emulsions stabilized with SC also showed improved oxidative stability compared with the other oil-containing treatments. Compressive resistance increased with the incorporation of both simple and gelled emulsions, whereas pH and protein and lipid contents did not differ among treatments. Overall, both simple and gelled emulsions enhanced emulsion stability and rheological properties in meat systems with high MDCM content. However, oil-in-water emulsions stabilized with SC provided superior oxidative stability.

Keywords: Meat emulsion; Mechanically deboned meat; Texture; Lipid profile; Lipid oxidation.

Resumo

Produtos cárneos emulsificados formulados com alto teor de carne mecanicamente separada de frango (MDCM) são amplamente consumidos no Brasil. Assim, é de relevância prática aprimorar seu perfil nutricional e compreender como óleos estruturados afetam suas propriedades físico-químicas. Este estudo comparou a incorporação de emulsões simples e gelificadas do tipo óleo-em-água, à base de uma mistura de óleos de oliva e chia, como substitutos da gordura suína em sistemas modelo de emulsões cárneas com elevado teor de MDCM. O caseinato de sódio (SC) e o isolado proteico de soja (SPI) foram utilizados como agentes emulsificantes, enquanto a carragena foi empregada como agente gelificante. A emulsão gelificada estabilizada com SC apresentou a maior estabilidade da emulsão, enquanto o tratamento contendo a mistura de óleos exibiu a menor estabilidade. Não foram observadas diferenças significativas entre os demais tratamentos e o controle formulado com gordura suína. As emulsões cárneas contendo emulsões simples e gelificadas estabilizadas com SC também apresentaram maior estabilidade oxidativa em comparação aos demais tratamentos contendo o blend de óleos. A resistência à compressão aumentou com a incorporação de emulsões simples e gelificadas, enquanto o pH e os teores de proteínas e lipídios não diferiram entre os tratamentos. De modo geral, tanto as emulsões simples quanto as gelificadas melhoraram a estabilidade da emulsão e as propriedades reológicas dos sistemas cárneos com alto teor de MDCM. Entretanto, as emulsões óleo-em-água estabilizadas com SC proporcionaram maior estabilidade oxidativa.

Palavras-chave: Emulsão Cárnea; Carne Mecanicamente Separada; Textura; Perfil Lipídico; Oxidação Lipídica.

Resumen

Los productos cárnicos emulsificados formulados con un alto contenido de carne de pollo mecánicamente separada (MDCM) son ampliamente consumidos en Brasil. Por lo tanto, resulta de relevancia práctica mejorar su perfil nutricional y comprender cómo los aceites estructurados afectan sus propiedades fisicoquímicas. Este estudio comparó la incorporación de emulsiones simples y

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gelificadas de tipo aceite-en-agua, basadas en una mezcla de aceites de oliva y chía, como sustitutos de la grasa porcina en sistemas modelo de emulsiones cárnicas con alto contenido de MDCM. El caseinato de sodio (SC) y el aislado proteico de soja (SPI) se utilizaron como agentes emulsificantes, mientras que la carragenina se empleó como agente gelificante. La emulsión gelificada estabilizada con SC presentó la mayor estabilidad de la emulsión, mientras que el tratamiento que contenía la mezcla de aceites no emulsificada mostró la menor estabilidad. No se observaron diferencias significativas entre los demás tratamientos y el control formulado con grasa dorsal porcina. Las emulsiones cárnicas que contenían emulsiones simples y gelificadas estabilizadas con SC también mostraron una mayor estabilidad oxidativa en comparación con los otros tratamientos que contenían aceites. La resistencia a la compresión aumentó con la incorporación de emulsiones simples y gelificadas, mientras que el pH y los contenidos de proteínas y lípidos no difirieron entre los tratamientos. En general, tanto las emulsiones simples como las gelificadas mejoraron la estabilidad de la emulsión y las propiedades reológicas en sistemas cárnicos con alto contenido de MDCM. Sin embargo, las emulsiones aceite-en-agua estabilizadas con SC proporcionaron una estabilidad oxidativa superior.
Palabras clave: Emulsión Cárnica; Carne Mecánicamente Separada; Textura; Perfil Lipídico; Oxidación Lipídica.

1. Introduction

The consumption of processed meats that normally have a high concentration of salt, saturated fatty acids, cholesterol, and additives has been discouraged worldwide due to its association with increased risks of developing several chronic diseases, such as cardiovascular disorders and diabetes type II and some type of cancer (Li-Hua & Bajinka, 2025). It is also recommended to replace saturated fatty acids for unsaturated fatty acids, especially polyunsaturated ones, to reduce the risk of cardiovascular diseases (Kris-Etherton et al., 2018)

Nevertheless, the substitution of animal fat by oils, which present higher levels of unsaturated fatty acids and low melt points, raises questions about the oxidative stability, texture, and cooking yield of meat products (Lima et al., 2022). Lipid oxidation is particularly important because it can lead to the appearance of unpleasant odors and flavors that interfere in products' sensory quality. Moreover, lipid oxidation may even compromise food safety in certain situations due to the potentially toxic compounds formation as well as the nutritional value reduction (Vieira et al., 2017).

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The incorporation of oils using pre-emulsion systems provides better stability of the meat matrices, whereas oil droplets are already immobilized by protein at their inclusion into the meat system, which mitigates the chances of the oil separating from the product (Forell et al., 2010; Kim et al., 2020). However, lipid oxidation may occur faster in emulsions due to their large surface area that facilitates interactions between lipids and water-soluble prooxidants (Waraho et al., 2011). Although certain proteins exhibit the ability to stabilize free radicals, chelate prooxidant metal ions, and even prevent their passage into the oil phase due to the electrostatic repulsion (Hu et al., 2003; Waraho et al., 2011).

The gelled emulsions, which consist of a complex colloidal system wherein the emulsion and gel structures coexist, are another alternative to improve the quality of meat systems (dos Santos et al., 2020; Paglarini, Furtado, et al., 2019; Pintado et al., 2018; Serdaroğlu et al., 2017). The combination of proteins and hydrocolloids may contribute to emulsion stabilization as well as to improved oxidative stability, as a result of the entrapment of the emulsion within a gelled matrix, which restricts the mobility of oil droplets and, consequently, emulsion destabilization, while also limiting oxygen diffusion (Paraskevopoulou et al., 2007). Both strategies, simple and gelled emulsions, could be a suitable approach for meat emulsions elaborated with a high content of mechanically deboned meat (MDM). In Brazil, the MDM is widely used in emulsified meat products, enabling the addition of up to 60% in sausages (Brazil., 2000). The use of mechanically separated meat obtained under hygienic and safe conditions is an important strategy to reduce the costs of meat products, increase the utilization of by-products, and decrease environmental impact. However, the incorporation of MDM may decrease the meat product quality due to its propensity to oxidation, MDM contains more hemoproteins than lean meat and is essentially more susceptible to oxidation (Horita et al., 2014).

Therefore, lipid profile modification can be considered more challenging in meat products elaborated with MDM than in those formulated with lean meat. Thus, the present work aimed to evaluate the influence of pork back fat replacement with a blend of olive and chia oils, incorporated either in isolation or as part of simple and

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gelled O/W emulsions, on the physicochemical and technological characteristics of meat emulsion model systems with high MDM content.

2. Methodology

2.1. Materials

Pork (*M. longissimus dorsi*) and pork back fat were purchased from Frigo Seleta slaughterhouse (Betim, MG, Brazil). Visible fat and connective tissue were trimmed from the pork meat prior to grinding, and both raw materials were ground through a 5-mm plate. MDCM was supplied by Pif Paf (Visconde do Rio Branco, MG, Brazil). Sodium chloride (NaCl) and extra-virgin olive oil (Cocinero, Rosario, Argentina) were obtained from a local market, while cold-pressed chia oil was purchased from Pazze Food Industry (Panambi, RS, Brazil). Sodium caseinate Excellion EM7DVM (93% protein) and soy protein isolate SUPRO® 500EIP (90% protein) were supplied by Globalfood (SP, Brazil). Carrageenan gum CL350H was provided by Danisco (Cotia, SP, Brazil). Curing salt Curamax C (83.2% NaCl, 9.5% sodium nitrite, and 7.3% sodium nitrate), polyphosphates Fosmax E, and sodium erythorbate were supplied by New Max Industrial Ltda (Americana, SP, Brazil).

2.2. Elaboration of the simple and gelled O/W emulsions

Two simple O/W emulsions formulations were prepared with 50% of olive/chia oils blend (1:1 v/v) and SC (3.5%) or SPI (3.5%) and two gelled emulsions were elaborated with the combination of proteins mentioned and carrageenan (CA) (1.5%), as shown in Table 1. The emulsions were prepared according to the methodology described in a previous study (Poyato et al., 2014). The emulsions were stored at 4 °C for approximately 24 hours before use.

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Table 1. Meat emulsions formulations (g/100g)

Treat-ments	Description of the O/W emulsions	Pork meat	MDCM	Pork backfat	Oil blend[1]	O/W Emulsions	Water
FC	-	40	30	10	0	0	17.5
FO	-	40	30	0	10	0	17.5
F1-SPI	50% oil blend, 3.5% SPI, and 46.5% water	40	30	0	0	10	17.5
F2-SC	50% oil blend, 3.5% SC, and 46.5% water	40	30	0	0	10	17.5
F3-SPI/CA	50% oil blend, 3.5% SPI, 1.5% CA, and 45% water	40	30	0	0	10	17.5
F4-SC/CA	50% oil blend, 3.5% SC, 1.5% CA, and 45% water	40	30	0	0	10	17.5

[1]Blend of olive and chia oils (1:1 v/v). Additives and ingredients: 1.5% NaCl, 0.3% sodium polyphosphate, 0.12% sodium erythorbate and 0.09% curing salt.

2.3. Elaboration of meat emulsions

All experiments were conducted in three independent replicates using the same ingredients and formulations. Six treatments were evaluated (Table 1): a control formulation containing 10% pork back fat (FC1) and five formulations with total replacement of pork back fat by an oil blend (FC2), simple emulsions (F1 and F2), or gelled emulsions (F3 and F4). Meat emulsions were prepared in a 4 L cutter (Metvisa, Brazil) using ground pork meat, MDCM (−1.0 °C), sodium chloride (2.0%), sodium phosphate (0.3%), and part of the ice. After initial homogenization, sodium nitrite and sodium erythorbate were added, followed by the remaining ice and lipid components. Comminution continued until the batter temperature reached 12 °C. The emulsions were stuffed into plastic tubes and cooked in a shaking water bath until reaching an internal temperature of 75 °C for 40 min. After cooking, the samples were cooled, packed, and stored at 4 °C until analysis, which was performed after 48 h.

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2.4. Fatty acid composition of pork back fat and oil blend

The fatty acid composition of pork back fat and the blend of chia and olive oils (1:1 v/v) was performed according to the American Oil Chemist's Society method Ce 1-62 (AOCS, 2009), in a capillary gas chromatograph - GC Agilent 6850 Series GC System (Santa Clara, CA, USA). The fatty acids methyl esters were prepared following the methodology described by Hartman & Lago (Hartman & Lago, 1973). The qualitative composition was determined by comparing the peak retention times with those of the respective fatty acid standards. The quantitative composition was calculated by area normalization and expressed as a percentage by mass. The analysis was carried out in duplicate.

2.5. Proximal composition, pH and color

The moisture, protein, ash, and lipid contents were performed according to the methodology of the Association of Official Analytical Chemists (AOAC, 2005). The pH measurement was achieved following the procedure described by Salcedo-Sandoval et al. (Salcedo-Sandoval et al., 2015), using the W3B pH meter (BEL Engineering, Monza, Italy). The color was measured using a CR-400 spectrophotometer (Konica Minolta, Tokyo, Japan), operating with D65 illuminant, 10° observer angle, and CIELab color system. The color parameters of the meat emulsions were measured only on the internal part of the samples. L*, a*, and b* values were determined as indicators of lightness, redness, and yellowness, respectively. The analyses were conducted in triplicate per treatment/batch.

2.6. Meat emulsion stability

The emulsion stability was evaluated in triplicate according to a previous methodology (Hughes et al., 1997), briefly: the raw meat emulsions (approximately 40g) were stuffed into 50 mL plastic tubes and centrifuged at 3750 rpm for 5 minutes. The meat emulsions were heated in a water bath at 70 °C for 30 minutes. The supernatant liquid released from the samples was collected and measured. Subsequently, the released liquid was oven-dried at 100 °C for 12 h and weighed to determine fat release.

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Jelly and fat separation analysis (JFS) was carried out in triplicate according to Bloukas & Honikel (Bloukas & Honikel, 1992), with adaptations: approximately 40 g of the raw meat emulsions were submitted to heat treatment at 90 °C for 35 minutes. The samples were stored at 4 °C for 24 h and then subjected to an additional heat treatment at 40 °C for 60 minutes. After complete cooling, the released liquid was removed from the surface of the sample, and the final emulsion weight was achieved. The JFS was expressed as the percentage of the difference between the initial and final sample weights. The analyses were conducted in triplicate per treatment/batch.

2.7. Thiobarbituric acid reactive substances (TBARS) analysis

TBARS analysis was performed according to Raharjo et al. (Raharjo et al., 1992), with some modifications: 5.0 g of sample was homogenized for 2 minutes in 40 mL of 5 % w/v trichloroacetic acid (TCA) and 1 mL of BHT (0.3%, in ethanol). The sample was filtered, and the volume completed to 50.0 mL of TCA. An aliquot of 2.0 mL of this solution was transferred to a test tube, where 2.0 mL of 2-thiobarbituric acid (0.08 M) was added in sequence, and then it was heated at 95°C for 10 minutes. After cooling at room temperature, the absorbance was determined on a UV 5100 spectrophotometer (Global Trade Technology, Monte Alto, Brazil) at 532 nm. The standard curve was obtained using the 1,1,3,3-tetraethoxypropane (Sigma Aldrich, São Paulo, Brazil). The experiments were performed in triplicate and expressed in mg of malonaldehyde (MDA)/kg of product.

2.8. Compression test

Uniaxial compression test was accomplished in universal mechanical test equipment (Instron series 3367, United States, 2005), according to previous methodology (Pereira et al., 2013). The meat emulsions were cut in cylindrical shapes (2.0 cm of height and 2.4 cm of diameter) and compressed to 80.0% original height with a speed of 1.0 mm/s using a cylindrical probe (55 mm diameter). The force versus the time/deformation curve was obtained, where the following parameters were calculated according to describe by Pereira et al. (2013): true

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rupture stress (σrup), true rupture strain (εrup), modulus of elasticity (Young's modulus - E), rupture work (Wrup). The analysis was conducted in triplicate per batch.

2.9. Statistical analysis

All formulations were elaborated in three independent batches. The results were analyzed by analysis of variance (ANOVA) at 95% confidence level ($P< 0.05$). The significant differences between treatments were analyzed by the Scott-Knott test at the 5% level of significance using the software Sisvar 5.6 (Ferreira, 2014).

3. Results and Discussion

3.1. Fatty acid composition of oils and pork fat

Predominant fatty acid composition and the percentage of SFAs, MUFAs, and PUFAs of oils and pork fat are demonstrated in Figure 1. Pork back fat presented elevated SFAs content (38.24 %) and a high ω-6/ω-3 ratio (14.7). SFAs promote increased blood cholesterol, which is strongly correlated with cardiovascular disease development (Kris-Etherton & Fleming, 2015; Nettleton et al., 2017). High levels of ω-6/ω-3 ratio may be associated with an increased risk of developing both cardiovascular and inflammatory diseases. A protective effect against the development of these diseases was reported when the concentration of ω-3 in the diet increases, and the relation between ω-6/ω-3 becomes more balanced (Abdel-Razek et al., 2022).

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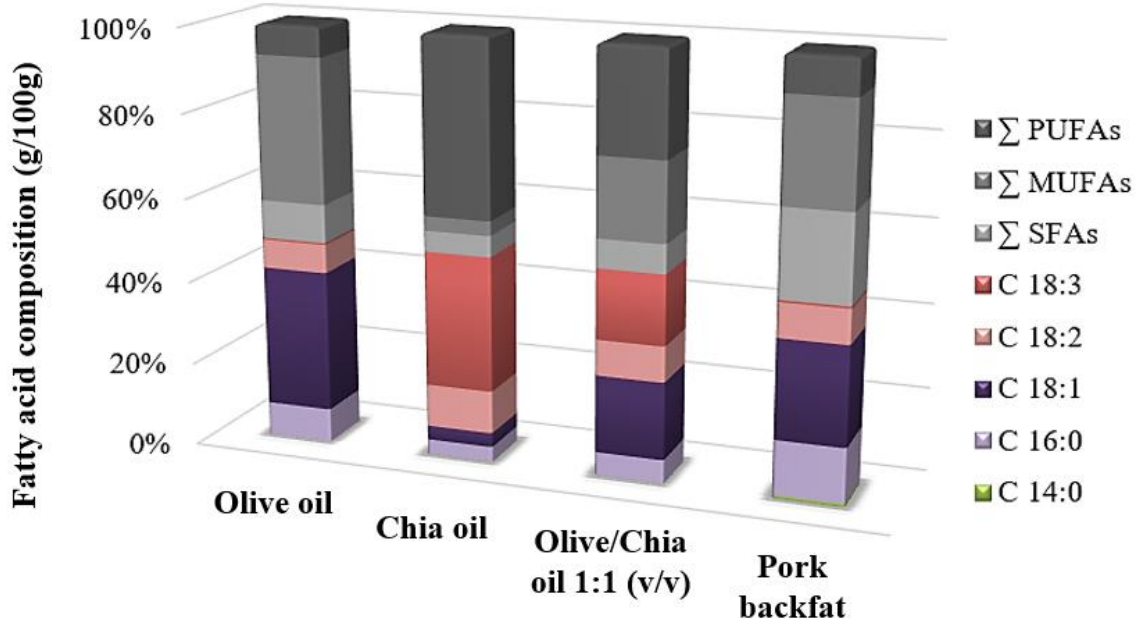
Figure 1. Fatty acid composition (g/100g) of vegetable oils and pork back fat



SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid.

In this context, chia oil and olive oil blend exhibited a suitable lipid profile to replace pork back fat in meat products. Olive oil has a high content of oleic acid that is associated with blood pressure reduction and, consequently, with a diminution of developing cardiovascular diseases, besides the polyphenol fraction of olive oil have protective effects against inflammatory events (Gorzynik-Debicka et al., 2018).

Chia oil, in turn, is one of the vegetable oils with the highest content of linolenic acid (C18:3). It also presents phenolic compounds, such as kaempferol, myricetin, quercetin, and chlorogenic acid (Marineli et al., 2014). The increase in C18:3 consumption may lead to beneficial effects on health (Kris-Etherton & Fleming, 2015). According to the European Commission Regulation No. 432 of 2012, the consumption of 2 g/day of C18:3 contributes to the maintenance of normal blood cholesterol levels (EU, 2012).

In comparison with pork back fat, the combination of olive and chia oils (1:1 v/v) promoted approximately a reduction of 63.4 % of SFAs content and a 3-fold increase in PUFAs content of lipid phase added to the meat emulsions. Moreover, the ω6/ω3 ratio of 0.51 obtained with the oils blend in this work was very similar to

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the levels reported by other works focusing on lipid profile improvement of meat products (Delgado-Pando et al., 2011; Freire et al.,2016).

3.2. Proximate composition of meat emulsions

The physicochemical characterization of meat emulsions is exhibited in Table 2. Despite the proximate composition of meat emulsions, the treatment FC showed the highest moisture content, while the other formulations presented no significant differences regarding this parameter. The meat emulsions FC and FO presented the same water added, and it was a little higher than the water added to other treatments (Table 1). The treatment FO exhibited higher water loss during cooking, which explained the less moisture compared to the treatment FC. Protein and lipid content did not show significant differences between treatments as expected. Ash content was lower in meat emulsion FO. The other treatments did not differ regarding the ash level, probably the connective tissue fraction present in pork backfat and the inclusion of soy and caseinate into meat emulsions containing simple and gelled emulsions contributed to the slight increase of ash content.

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Table 2. Physicochemical characterization of meat emulsions formulated with pork back fat or an olive-chia oil blend incorporated as isolated oil, simple emulsions, and gelled emulsions

Parameters	Treatments						SEM
	FC	FO	F1-SPI	F2-SC	F3-SPI/CA	F4-SC/CA	
Proximate composition (g/100g)							
Moisture	69.10 ^{a}	66.81 ^{b}	66.67 ^{b}	66.75 ^{b}	66.77 ^{b}	66.53 ^{b}	0.20
Lipid	11.23 ^{a}	11.04 ^{a}	11.34 ^{a}	12.27 ^{a}	12.21 ^{a}	11.40 ^{a}	0.17
Protein	12.63 ^{a}	13.26 ^{a}	13.96 ^{a}	14.04 ^{a}	13.32 ^{a}	13.48 ^{a}	0.26
Ash	3.39 ^{a}	3.22 ^{b}	3.36 ^{a}	3.33 ^{a}	3.44 ^{a}	3.40 ^{a}	0.02
Physicochemical parameters							
pH	6.69 ^{a}	6.66 ^{a}	6.69 ^{a}	6.69 ^{a}	6.71 ^{a}	6.74 ^{a}	0.012
TBARS (mg MDA/kg)	0.212 ^{c}	0.601 ^{a}	0.478 ^{a}	0.396 ^{b}	0.630 ^{a}	0.336 ^{b}	0.039
L*	67.28 ^{c}	70.15 ^{b}	69.37 ^{b}	70.21 ^{b}	70.99 ^{a}	70.73 ^{a}	0.30
a*	17.70 ^{a}	16.97 ^{b}	17.17 ^{b}	17.58 ^{b}	17.24 ^{b}	17.63 ^{a}	0.09
b*	13.22 ^{a}	11.64 ^{c}	11.80 ^{b}	11.85 ^{b}	11.58 ^{c}	11.69 ^{c}	0.05
Rheological parameters							
σ_{rup} (kPa)	22.42 ^{c}	30.66 ^{b}	36.89 ^{a}	34.89 ^{a}	36.22 ^{a}	35.85 ^{a}	1.16
ε_{rup}	0.53 ^{b}	0.55 ^{b}	0.60 ^{a}	0.58 ^{a}	0.60 ^{a}	0.60 ^{a}	<0.01
E (kPa)	38.06 ^{c}	53.56 ^{b}	60.51 ^{a}	60.43 ^{a}	62.90 ^{a}	60.14 ^{a}	1.93
W_{rup} (kJ/m^2)	6.68 ^{c}	9.38 ^{b}	12.34 ^{a}	11.56 ^{a}	12.32 ^{a}	12.13 ^{a}	0.47

σ_{rup}: true rupture stress; ε_{rup}: true rupture strain; E: Modulus of elasticity; W_{rup}: work of rupture. SEM: standard error of the mean. Different letters in the same line indicate significant differences according to Scott-Knott' test ($p < 0.05$). FC: pork back fat; FO: olive/chia oil blend; F1-SPI: O/W emulsion with soy protein isolate; F2-SC: O/W emulsion with sodium caseinate; F3-SPI/CA: O/W gelled emulsion with soy protein isolate and carrageenan; F4-SC/CA: O/W gelled emulsion sodium caseinate and carrageenan.

3.3. Physicochemical parameters of meat emulsions

The meat emulsion stability was evaluated considering the water and fat exudates of the meat emulsions during the heat treatment (Figure 2A-B) The water released ranged from 2.19 to 4.87% and was significantly influenced by treatments. The meat emulsion FO presented higher water loss compared to the other treatments. Otherwise, the simple and gelled emulsions improved the meat emulsion stability compared to the treatment FO, and they were comparable to the

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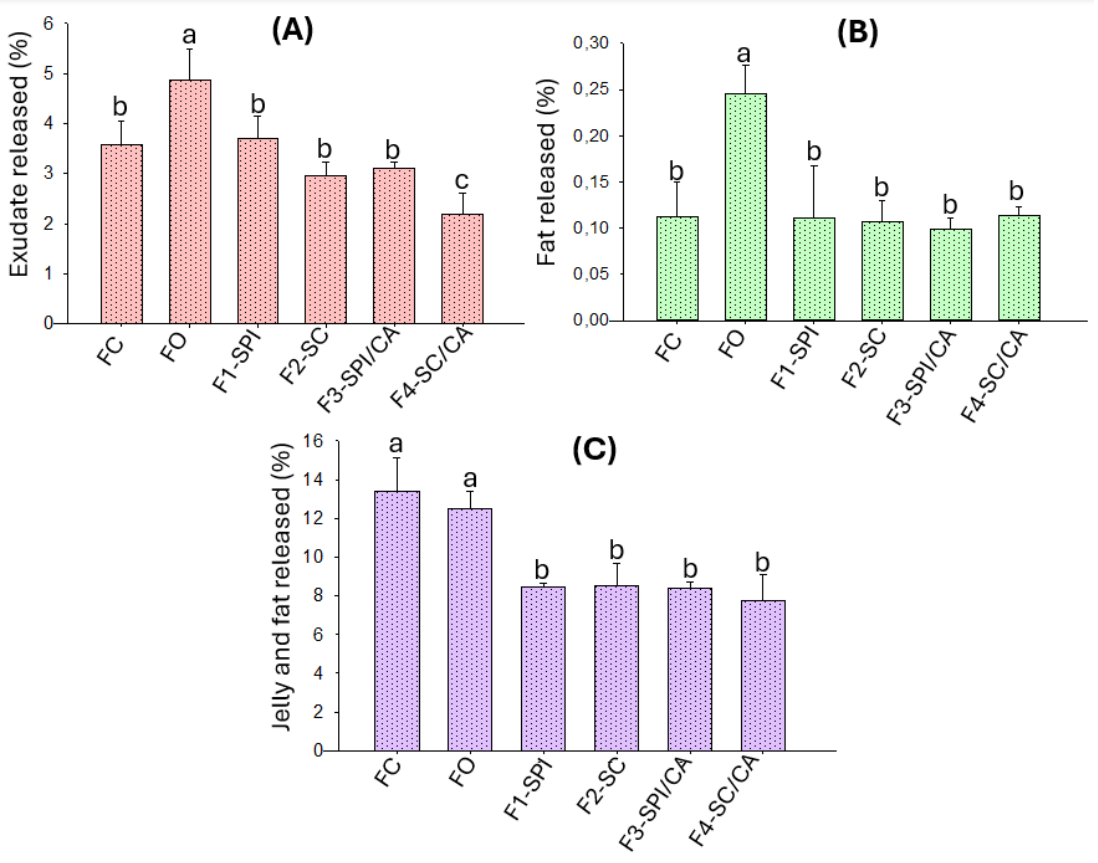
control treatment FC, this result may be related to reinforcing of meat matrix due both non-meat protein and carrageenan. Regarding the comparison between simple emulsions made with SPI or SC, no difference ($p > 0.05$) in ES was observed. However, the gelled emulsion elaborated with SC and carrageenan showed the highest ($p \leq 0.05$) ES. The interaction of sodium caseinate and κ-carrageenan is driven by electrostatic forces and hydrogen bonding that allowed a strong network (Tang et al., 2021). Regarding the fat released, the treatment FO presented the highest value of this parameter, which confirmed that the oil was not sufficiently bonded by the protein network in the meat emulsion system.

Figure 2. Meat emulsion stability and jelly and fat separation during heat treatment



Emulsion stability measured by exudate released (A) and fat released (B) and jelly and fat separation (C). Different letters in the same column indicate significant differences according to Scott-Knott' test ($p < 0.05$). FC: pork back fat; FO: olive/chia oil blend; F1-SPI: O/W emulsion with soy protein isolate; F2-SC: O/W emulsion with sodium caseinate; F3-SPI/CA: O/W gelled emulsion with soy protein isolate and carrageenan; F4-SC/CA: O/W gelled emulsion sodium caseinate and carrageenan.

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Jelly and fat separation analysis (JFS) evaluates the stability of meat emulsion at higher temperature and exposure time. The meat emulsions containing pork back fat or isolated oils blend showed higher JFS ($p \leq 0.05$). The other treatments containing the simple and gelled emulsions showed no difference in JFS ($p > 0.05$), as shown in Figure 2C. Therefore, the presence of non-meat proteins had a protective and similar effect against exudate loss. The absence of differences between treatments contained simple and gelled emulsions under the higher temperature protocol (90°C) may be associated with the thermal behavior of carrageenan. At elevated temperatures, carrageenan undergoes helix-coil transition and gel network dissociation, leading to a sol state in which its structuring capacity is reduced. Consequently, emulsion stability becomes predominantly governed by interfacial protein functionality rather than by the polysaccharide network. In contrast, at 70°C, temperature of the emulsion stability analysis protocol, partial structural organization of carrageenan may still contribute to water and fat retention, explaining the observed differences among systems. Serdaroğlu et al. (2016) reported a similar result regarding jelly and fat separation when double emulsions (non-gelled) were added in meat emulsions as a fat replacer.

The pH values were not affected ($p > 0.05$) either by the incorporation of oil isolated nor by simple and gelled emulsions. A similar outcome was noticed by Salcedo-Sandoval et al. (2015) in frankfurters with oil added through different strategies. Similar pH values for meat emulsions produced with MDM have been reported in other studies. This behavior is attributed to the release of calcium from the bone marrow during the grinding and mechanical separation processes (Pereira et al., 2011; Trindade et al., 2006).

TBARS results (mg MDA/kg) are presented in Table 2. Meat emulsions with pork back fat had the lowest TBARS value ($p \leq 0.05$), which could be justified by the low proportion of PUFAs in pork fat composition compared to the oil blend used (Figure 1). Similar results were related by other researches (Freire et al., 2016; Salcedo-Sandoval et al., 2015). Proteins, such as soy protein isolate and sodium caseinate, can act to prevent oxidation in emulsions by inhibiting the passage of pro-oxidant metals from the aqueous phase to the oil phase both by electrostatic

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repulsion and thickness effects of the emulsion droplet interface (Elias et al., 2008). The meat emulsions incorporated with simple and gelled emulsions within SC did not differ ($p > 0.05$) from each other and presented superior oxidative stability to meat emulsions comprising isolated oils blend or the O/W emulsions formed by SPI. Faraji et al., (2004) demonstrated that sodium caseinate presented higher metal ion chelation capacity in O/W emulsions than soy protein isolate, mainly due to the presence of phosphorylated serine residues. TBARS values between 0.5 and 1.0 mg MDA/kg are commonly considered the threshold for sensory perception of rancidity in meat however, this limit may vary depending on product formulation and sensory masking effects (Greene & Cumuze, 1982). Considering this range, the formulations with SC simple and gelled O/W emulsions were likely below the sensory threshold for rancidity. This result is interesting since products formulated with MDM often exhibit higher susceptibility to lipid oxidation due to the higher levels of phospholipids, heme pigments, and pro-oxidant metal ions presented in MDM (Horita et al. 2014).

3.4. Color parameters of meat emulsions

The color parameters of meat emulsions were slightly affected by the incorporation of oil, simple or gelled emulsions; the lightness was higher ($p \leq 0.05$) in these treatments (Table 2). Similar results were found by other studies (Jiménez-colmenero et al., 2010; Paglarini, Martini, et al., 2019). The increase in color parameters may be related to the smaller oil globule diameter in meat emulsions, which reflect more light than larger animal fat globules (Poyato et al., 2014). The redness and yellowness were slightly higher in meat emulsion FC prepared with pork back fat. These variations can be caused by differences between the pork back fat and its replacers (Jiménez-Colmenero et al., 2010).

3.5. Uniaxial compression

A sufficiently high deformation is used to promote the material rupture in the compression tests since at this point it is possible to determine the properties that provide information about the material traits as well as correlate them with the

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product texture (Bayarri et al., 2007). As shown in Table 2, the parameters of uniaxial compression were higher ($p \leq 0.05$) in treatments with oil, both in the isolated and structured forms (simple and gelled emulsions). The treatment FO showed the most significant water and fat releases, which may have reflected on the superior hardness presented by FO when compared to the treatment control FC. The incorporation of pre-emulsified oil (simple or gelled emulsions) into meat matrix may contribute to a more cohesive texture due to the prior dispersion and stabilization of oil droplets that promotes the formation of smaller and more uniformly distributed lipid droplets, increasing the interfacial area available for protein adsorption and protein/lipid interactions. Consequently, the meat matrix tends to exhibit improved structural integrity and cohesiveness compared with FO formulation. Other studies reported similar results in meat emulsions added with pre-emulsified O/W emulsions (Asuming-Bediako et al., 2014; Bolger et al., 2018). In this study, the increase in texture parameters is particularly interesting, since MDM tends to give the final product a weak texture due to the lower protein content presented by this raw material compared to lean meat.

4. Conclusion

Simple and gelled emulsions presented good technological characteristics for emulsified meat products. Regarding the best combination of stabilizing agents, the results suggest that the gelled emulsion elaborated with sodium caseinate and carrageenan promoted greater stability of the meat matrix compared with the control formulation containing pork back fat. In several aspects, the incorporation of the gelled emulsions did not differ from the simple emulsions. However, when we compared them with the meat emulsion elaborated with non-emulsified oil blend, parameters like emulsion stability, jelly and fat separation, and rheological properties were improved. Considering the whole technological characteristics, it was found that the gelled emulsion elaborated with sodium caseinate showed the best results in terms of performance and oxidative stability of meat emulsion. However, the results obtained had some limitations, as they were not evaluated over the product shelf life. In addition, although the meat emulsion model system

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provides important insights, it does not reflect the characteristics of a final product, such as Bologna sausage, which include the addition of several other ingredients that may influence the observed outcomes. Finally, sensory analysis is essential to indicate the potential of the olive-chia oil blend incorporated through simple and gelled O/W emulsions. Therefore, additional studies are needed to confirm and expand these findings.

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