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RHEOLOGICAL AND TEXTURAL ANALYSIS OF VIENNA SAUSAGE PRODUCTION: THE EFFECTS OF SUBSTITUTING ANIMAL FAT WITH SUNFLOWER OIL

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ABSTRACT

Background. Meat processing involves the use of saturated fatty acids that are characteristic of animal fats, but their repeated consumption is associated with various adverse health effects. The present research investigates the effects of the complete substitution of pork backfat with sunflower oil as a source of unsaturated fatty acids in meat processing on texture, rheology and fat loss.
Materials and methods. The impact of the replacement on meat batters and meat pastes was analyzed in terms of texture, rheology and fat loss. Finished products were analyzed both uncooked and after having been prepared for consumption (cooked for 5 minutes) with and without casings. Two experimental prototypes were designed and produced: Vienna sausages with 100% refined sunflower oil as a fat source and conventional Vienna sausages with 100% pork backfat as a fat source.
Results. Texture analysis revealed no significant differences in hardness, cohesiveness, and gumminess between conventional and reformulated meat batters. However, after thermal treatments, meat pastes obtained with pork backfat exhibited higher hardness values (32.17 N and 35.67 N) than those processed with sunflower oil (10.93 N and 14.09 N). Fat loss assessments indicated optimal fat retention in sunflower oil-based samples, particularly in cooked sausages (5.77%), suggesting better stability during processing and consumption than in the conventional cooked sample (11.61%). Rheological analysis demonstrated higher values for viscoelastic properties in pork backfat samples than in those containing sunflower oil; for all samples, no crossover points were observed, as the storage modulus G′ was higher than the loss modulus G″ and both moduli increased with increasing frequency. Concerning the characterization of finished products, for uncooked sausages with casings, the sausages reformulated with sunflower oil had higher hardness values than conventional ones (53.90 N vs 40.93 N). Despite this difference, both samples prepared for consumption (cooked) without a casing exhibited similar hardness values (7.81 N and 7.43 N).
Conclusion. From the point of view of physical and structural characterization, the replacement of pork backfat (saturated fat) with sunflower oil can preserve the properties of meat batters and cooked products. Additionally, there is the advantage of using the current production process and the potential to obtain healthier, more nutritious meat products due to the lipid profile of vegetable oil.

Keywords: fat replacer, sunflower oil, meat batter, rheology, stability, texture

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INTRODUCTION

Meat provides a significant dietary supply of proteins that have high biological value. Additionally, it contains essential minerals such as iron, selenium, zinc, and phosphorus, as well as vitamins B12 and B6 (Pereira and Vicente, 2013). Meat products are widely consumed in the human diet, but their high fat content (30–40%) must also be taken into consideration. The perception of meat and meat products as having an unhealthy nutritional profile, characterised by high levels of saturated fatty acids and cholesterol, has led to a continuous need for improvement in product quality in order to more consistently satisfy consumer preferences for meat products with functional incorporated ingredients. Many solutions involve the utilisation of vegetable oils rich in monounsaturated fatty acids and polyunsaturated fatty acids to reduce the levels of saturated fat and cholesterol associated with animal fat.

Repeated consumption of saturated fat is associated with an increased risk of developing cardiovascular disease, obesity, and oxidative stress. According to the World Health Organisation, the intake of saturated fats should be less than 10% of a person's total energy intake (World Health Organization, 2020). Considering this recommendation and the negative effects of these fats on health, it is necessary to obtain food products with a reformulated lipid profile, rich in unsaturated fatty acids. The consumption of polyunsaturated fatty acids instead of saturated fatty acids decreases serum total cholesterol, low density lipoprotein cholesterol, and triglycerides. Thus, replacing saturated fatty acids may represent a strategy to reduce diseases associated with repeated consumption (Mozaffarian et al., 2010). Moreover, due to the presence of phytosterols and phytostanols, the absorption of dietary cholesterol can be reduced by using vegetable oils (Beriain et al., 2018).

When replacing or reducing saturated fatty acids with unsaturated fats, it is necessary to consider the food's textural properties, the higher tendency of liquid oils to oxidise, the food's appearance, and sensory properties (flavour, mouthfeel, juiciness) (Muguerza et al., 2002). Thus, although conventional fat substitutes may be nutritionally valuable, they must also possess the fundamental characteristics of saturated fat so they must not affect the food's sensorial and physicochemical characteristics (Wongpattananukul et al., 2022).

The meat industry is aware of the health issues and recommendations related to saturated fats, and thus there are many researches in order to improve the nutritional profile of meat products using vegetable oils, specifically: flaxseed (Bolger et al., 2018), olive (Ansorena and Astiasaran, 2004; Jiménez-Colmenero et al., 2010; Muguerza et al., 2002; Shin et al., 2022; Zhu et al., 2020), peanut (Wongpattananukul et al., 2022), hazelnut (Urgu-Ozturk et al., 2020), grapeseed (Stajić et al., 2014), linseed (Berasategi et al., 2014), canola (Utama et al., 2019; Youssef and Barbut, 2011), soybean (Trindade et al., 2011) and fish oils (Josquin et al., 2012; Marchetti et al., 2014; Valencia et al., 2008). In the study conducted by Berasategi et al. (2014), Bologna sausages were reformulated by replacing the animal fat with an oil-in-water emulsion made of linseed and algae oil. The finished product presented a healthier lipid profile: 85 kcal/100 g, 3.6% fat, 0.6 g α-linolenic acid and 0.44 g docosahexaenoic acid per 100 g product and a ω-6/ω-3 ratio of 0.4, without processing or sensory problems. By substituting beef fat with pre-emulsified hazelnut oil in the production of sausages, the amount of saturated fatty acids decreased from 47.2% to 13.6%, while the amount of monounsaturated fatty acids increased from 41.8% to 71.3% and polyunsaturated fatty acids from 3.7% to 11.2% (Urgu-Ozturk et al., 2020). Asuming-Bediako et al. (2014) studied the effect of replacing pork fat in UK-style sausages with preformed rapeseed and sunflower oil emulsions. While the proportion of saturated fatty acids decreased from 38% to 14%, monounsaturated fatty acids increased from 45% to 59%, and polyunsaturated fatty acids from 15% to 25%. The colour and lipid oxidation were not affected negatively. The partial or total replacement of pork fat with soybean oil in the manufacturing of mortadella had no effect on the food's physicochemical properties, but the fatty acid profile was enhanced. The 50% substitution was the optimal option in terms of nutritional and sensory benefits (Trindade et al., 2011). An amount of 15% pork backfat was substituted with linseed or fish oil in pork sausages; α-linolenic acid increased from 1.34% (control) to 8.91% when linseed oil was used, while eicosapentaenoic acid increased from 0.05% (control) to 2.81% when fish oil was used. Sensory scores were not affected and oxidation was reduced for both uncooked and cooked samples obtained with linseed oil (Valencia et al., 2008).

In addition to its nutritional advantages, the substitution of animal fat with oil can also maintain the physicochemical properties of meat products. Jiménez-Colmenero et al. (2010) found that substituting pork backfat in frankfurters with an olive oil-in-water emulsion, stabilized with non-meat proteins, improved fat and water binding and increased hardness, cohesiveness, and chewiness. In a study by Shin et al. (2022), olive oil sausages exhibited superior emulsion and oxidative stability compared to those obtained with pork backfat. At a cutting time of 60 seconds and a cooking temperature of 73°C, the olive oil sausage demonstrated results that were comparable to or better than those of the control sausages in terms of cooking yield, expressible fluid, and texture. Fat reduction and the substitution of beef fat with canola oil or pre-emulsified canola oil revealed positively impacted yield and restored textural parameters (Youssef and Barbut, 2011). In a study by Wongpattananukul et al. (2022), the emulsion stability of sausages was improved when chicken fat was substituted without affecting cooking loss or the lipid and protein oxidation levels. As an alternative to animal fat in chicken sausages, an oil-in--water (o/w) emulsion composed of perilla and canola oil maintained an acceptable appearance, flavour, and overall impression comparable to the control while enhancing emulsion stability and reducing cooking loss during sausage production (Utama et al., 2019).

Sunflower oil mainly consists of polyunsaturated fatty acids, specifically linoleic acid (~65%), and monounsaturated fatty acids, particularly oleic acid (~20%). These essential fatty acids cannot be synthesised and are therefore a required dietary component. A minor proportion of palmitic and stearic acids (~15% for both fatty acid) is also present in sunflower oil. Additionally, sunflower oil is rich in carotenoids, tocopherols, phenols, and tocotrienols, which exhibit antioxidant properties. It has the advantage of easy accessibility, which facilitates its widespread use. Additionally, its consumption has been associated with several health advantages, including the control of cholesterol levels and low-density lipoproteins in the human body (Petraru et al., 2021; Rabail et al., 2021).

Vienna sausages belong to the category of emulsion sausages, in which up to 30% of the total content is represented by fat, emulsified with water and meat proteins (Shin et al., 2022). They are popular meat products frequently consumed globally due to their low cost and ease of consumption, both directly and in hot dog food. The aim of the current research was to reduce the saturated fatty acid content of Vienna sausages by completely replacing pork backfat with refined sunflower oil. The effect of animal fat substitution in terms of texture, rheology and fat loss was evaluated for both semi-finished (meat batter and meat paste) and finished products (uncooked and cooked sausages). Due to the unsaturated fatty acids and bioactive phytochemicals, refined sunflower oil can easily be incorporated into the existing production process for Vienna sausages, modifying the fatty acid composition and providing functionality.

MATERIALS AND METHODS

The manufacturing process of Vienna sausages

The raw materials used to obtain Vienna sausages – prime beef, pork backfat, refined sunflower oil, white pepper, nutmeg, red sweet pepper powder, and garlic powder – were purchased from a local store. Polyphosphate was purchased from Solina Romania. The Vienna sausages were manufactured according to the process flow diagram (Fig. 1). The ingredients of the formulations are presented in Table 1. Prime beef was thawed at 18–20°C for 24 hours before being cut into pieces

Table 1. The recipe used in the production of Vienna sausages with refined sunflower oil (RSF) or pork backfat (PBF) (expressed in kg)

Ingredients	F	O
Prime beef	4.000	4.000
Pork backfat	1.500	–
Refined sunflower oil	–	1.500
Ice flakes	1.640	1.640
White pepper	0.004	0.004
Nutmeg	0.004	0.004
Red sweet pepper powder	0.004	0.004
Garlic powder	0.008	0.008
Polyphosphate	0.020	0.020

F – 100% pork backfat, O – 100% refined sunflower oil.

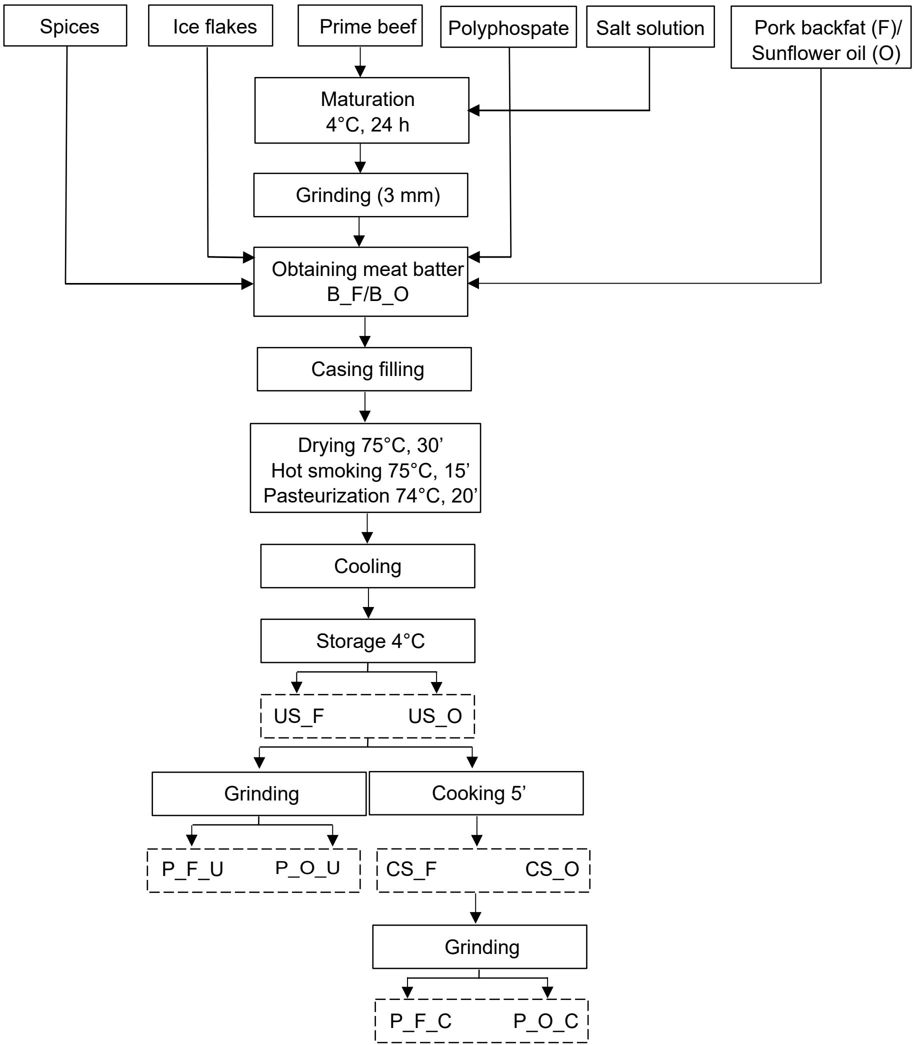


Fig. 1. Process flow diagram for the production of Vienna sausages

and combined with a 2% salt solution and matured for 24 hours at 4°C. In order to obtain ground beef from the salted and matured meat, a meat grinder with a 3 mm sieve was used (Bizerba SE & Co. KG, Balingen, Germany). To prepare the meat batter, ground beef, refined sunflower oil or pork backfat (depending on the sample), ice flakes, spices and polyphosphate were added to the bowl cutter (Meprotec GmbH, Pasching, Austria) and finely chopped until a paste with a maximum temperature of 12°C, adhesive properties, and homogenous structure was obtained. The composition was stuffed into edible collagen casings (20 mm in diameter) using a vacuum filling machine (Düker-REX Fleischereimaschinen GmbH, Laufach, Germany) and manually portioned and linked by twisting (120 mm in length). The air bubbles under the casings were punctured. The Vienna sausages were placed on a meat rack and subjected to a series of thermal treatments in a smoking and scalding chamber (H. Maurer & Söhne Rauch- und Wärmetechnik GmbH & Co. KG, Reichenau, Germany), including air drying at 75°C for 30 minutes, hot smoking at 75°C for 15 minutes (until the casing turned reddish), and pasteurization in a water bath at 74°C for 20 minutes (until a temperature of 69°C was reached at the geometric center of the product). The meat products were cooled in basins containing cold water and vacuumed in special bags. The shelf life of the products was 21 days when stored at 2–4°C. The meat batters, meat pastes and finished products were analyzed the day after production. The meat pastes were prepared by removing the casings for uncooked sausages and cooked sausages (cooked for 5 minutes in boiling water in order to replicate the consumption process) and grinding until a fine paste was obtained using a Retsch RM 200 mortar grinder (Retsch GmbH, Haan, Germany).

Characterization of meat batters and meat pastes

Texture profile analysis

The cylindrical probe TA11/1000 (25.4 mm diameter × 35 mm length) of the Brookfield CT3 texture analyzer (Brookfield Engineering Labs, Middleboro, MA, USA), which is attached to a 10 kg compression cell, was used to achieve a deformation of 95% from the sample surface (45 mm height × 45 mm diameter) according to the method described by Zheng et al. (2015) with several modifications. The two-cycle deformation was performed at a speed of 1 mm/s. Hardness [N], cohesiveness [n.a.] and gumminess [N] were the parameters examined in this textural measurement. The samples were stored and analyzed at a temperature of 4°C.

Determination of fat loss

The fat-binding potential of meat batters and meat pastes was evaluated by exposing the samples to a centrifugal force according to the method described by Jiménez-Colmenero et al. (2010) with slight modifications. Approximately 10 g of each sample were placed in 50 ml conical tubes with screw caps and centrifuged (DLAB DM0412 Centrifuge, DLAB Scientific Co., Ltd., Beijing, China) at 4,500 rpm for 30 minutes. After centrifugation, the fat released was drained by inverting the tubes at ambient temperature for 30 minutes. Comparing the sample mass before and after a centrifugation cycle allowed the calculation of fat loss as a percentage of the sample mass before centrifugation with the following formula:

$$\text{Fat loss [\%]} = (A - B)/C \cdot 100;$$

where: A = initial mass (sample + tube before centrifugation in grams); B = final mass (sample + tube after centrifugation and drainage in grams); C = sample mass (in grams).

Rheological analysis

A frequency sweep test was performed using the Anton Paar MCR302 rheometer (Anton Paar, Graz, Austria) and the PP50 parallel plate measuring geometry (50 mm diameter) at a constant strain of $\gamma = 1\%$ (Schuh et al., 2013) in the frequency range 0.01–10 Hz. The frequency range was selected according to Zhu et al. (2020) because the impact of frequency was most significant within the range 0–10 Hz. The samples were placed between the parallel plates and compressed to obtain a gap of 2 mm and the excess sample was trimmed. The samples were kept at 4°C for 5 minutes to avoid stresses induced during loading. The storage modulus (G′) and loss modulus (G″) were recorded.

Characterization of finished products

Texture analysis

The texture evaluation of uncooked and cooked sausages (cooked for 5 minutes) was performed according to the method described by Güemes-Vera et al. (2018) by compressing the samples (120 mm length × 20 mm diameter) with a TA7 acrylic blade (60 mm width). The samples were compressed in a single cycle, until breaking, at a speed of 1 mm/s. The load [N] as a function of time [s] was recorded by the Brookfield CT3 texture analyzer (Brookfield Engineering Labs, Middleboro, MA, USA). Hardness was the characteristic under examination in this textural analysis. After production, the sausages were stored in vacuum-sealed bags at 2–4°C. The uncooked sausages were analyzed directly at this temperature and the cooked sausages were analyzed immediately after boiling and cooling.

Statistical analysis

The analyses were carried out in triplicate. Minitab software was used to analyze the differences. The one-way analysis of variance (ANOVA) and Tukey's comparison test were applied at a significance level of $p < 0.05$. All results are presented as mean ±standard deviation.

RESULTS AND DISCUSSIONS

Characterization of meat batters and meat pastes

Texture profile analysis

Pork backfat is frequently used in meat products, mainly for its textural attributes, including hardness, gumminess and juiciness, which are attributed to the presence of saturated fatty acids (Ospina et al., 2012).

Hardness, expressed in Newton (N) represents the maximum force of a compression cycle (Brookfield Engineering Labs). Considering the meat batters, there was no statistically significant difference between the conventional sample with pork backfat (B_F), which exhibited a slightly lower value of 11.03 N, and the meat batter with sunflower oil, which had a value of 13.19 N (B_O). In the case of meat pastes obtained from uncooked (only the thermal treatment from the pilot station, Fig. 1) and cooked (boiled for 5 minutes) sausages, samples containing pork backfat had noticeably higher hardness values, namely 32.17 N (P_F_U) and 35.67 N (P_F_C), in contrast to 10.93 N (P_O_U) and 14.09 N (P_O_C) for uncooked and cooked samples containing sunflower oil. A potential explanation for the difference is that an increase in fat loss (11.61% for P_F_C) can lead to a higher protein concentration in cooked products, resulting in the formation of denser matrices (Youssef et al., 2011). When investigating the impact of heat treatments (during the production process and for consumption), it was observed that there were no significant differences between the meat batter and meat pastes obtained from uncooked and cooked sausages when sunflower oil was used. However, in the case of the conventional sample, the hardness value almost tripled (from 11.03 to 32.17 N) due to the specific heat treatment involved in the technological process (drying at 75°C for 30’, hot smoking at 75°C for 15’, pasteurization at 74°C for 20’).

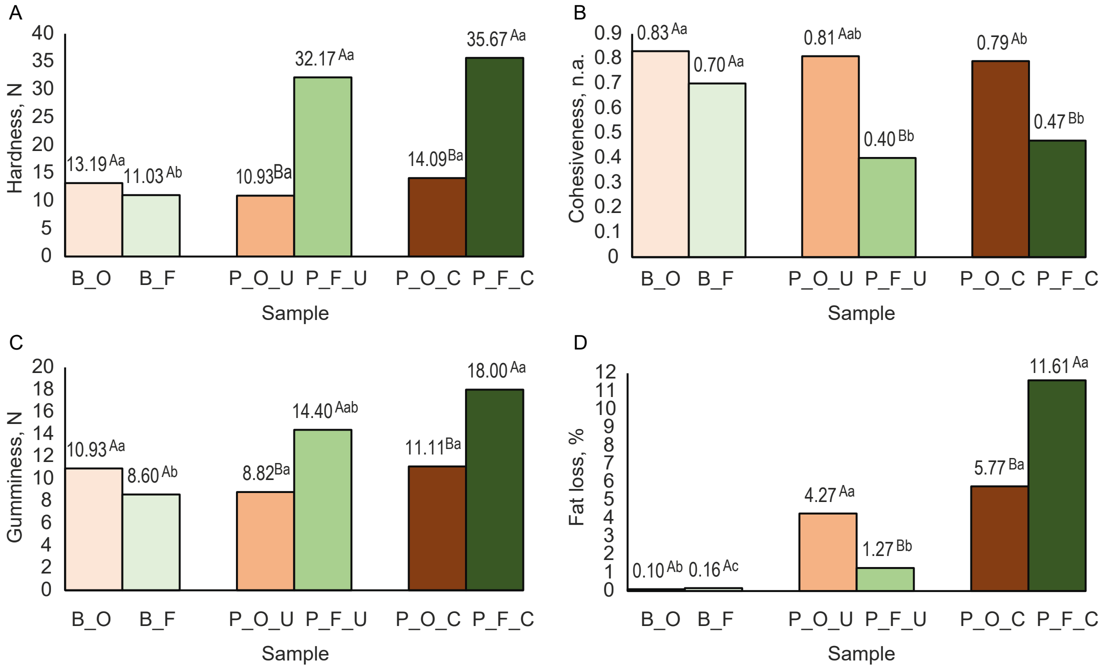
Cohesiveness [N] is an indicator for the strength of the internal bonds that form the food structure. The B_O had the highest cohesiveness value of 0.83, followed by P_O_U and P_O_C values of 0.81 and 0.79, respectively. Although the pork backfat samples were harder, they were less cohesive, probably due to differences in fat composition that influence the formation of protein matrices and the distribution and size of fat particles. According to Youssef et al. (2011), the higher number of small fat globules contributes to higher resistance to compression. The meat pastes prepared from samples containing pork backfat had lower values of 0.40 and 0.47, results consistent with those obtained by Youssef et al. (2011) when replacing beef fat with canola oil in meat batters. Cohesiveness decreased with each heat treatment applied except for the cooked meat paste with pork fat, after which it increased from 0.40 N (P_F_U) to 0.47 N (P_F_C). Similar to hardness, conventional and reformulated meat batters showed no major differences (0.70 N and 0.83 N respectively) (Fig. 2).

Gumminess [N] is a measure of how much energy it takes to break down a semi-solid food into a form that is ready to swallow. In the present study, the gumminess results showed the same trend as the hardness results. A reduction in saturated fat was associated with a higher value of gumminess for meat batter but a lower value for meat pastes. For the samples prepared with sunflower oil, the gumminess values of the meat batter (10.93 N) and uncooked (8.82 N) and cooked (11.11 N) meat pastes were similar. Regarding the conventional samples obtained with pork backfat, the gumminess values gradually increased with the application of thermal treatment from 8.60 N for B_F to 14.40 N for P_F_U and to 18.00 N for P_F_C.

Because the textural profile of meat products represents a critical acceptability parameter, it is important to mention that the statistically insignificant differences between the conventional meat batters with pork backfat and those reformulated with sunflower oil for all textural parameters represent major advantages in production technology, because the same technology and parameters can be used for products made with sunflower oil as for those made with pork backfat.

Determination of fat loss

The capacity of meat batter and meat pastes to retain the fatty phase inside the matrix provides information about their stability, the efficacy of the network structure developed through the interaction with meat proteins, and the possibility of application in emulsion-type products. The capacity of the protein matrix to immobilize both fat and water is very significant. Compared to emulsion formation, the gelling and water retention capacities of non-meat constituents might be more important in determining the thermal



B_O – meat batter with refined sunflower oil; B_F – meat batter with pork backfat; P_O_U – meat paste with refined sunflower oil from uncooked sausages; P_F_U – meat paste with pork backfat from uncooked sausages; P_O_C – meat paste with refined sunflower oil from cooked sausages; P_F_C – meat paste with pork backfat from cooked sausages. Identically superscript capital letters indicate no significant differences (p > 0.05) between conventional and reformulated samples (B_O vs B_F, P_O_U vs P_F_U, P_O_C vs P_F_C); identically superscript lowercase letters indicate no significant differences (p > 0.05) between meat batters and meat pastes with the same fat source (B_O vs P_O_U vs P_O_C and B_F vs P_F_U vs P_F_C).

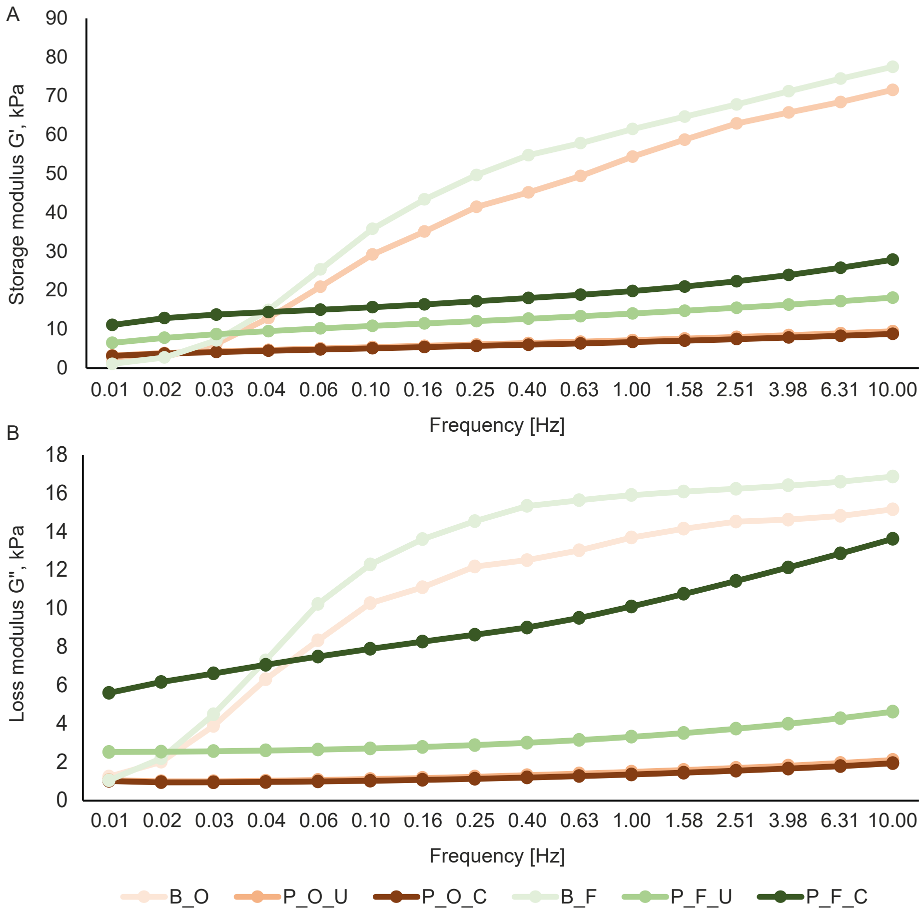
Fig. 2. Textural properties (A – hardness, B – cohesiveness, C – gumminess) and fat loss (D) for meat batters and meat pastes

stability of meat products (Marchetti et al., 2014). The fat loss of meat batter and uncooked and cooked meat pastes formulated with pork backfat or sunflower oil is presented in Figure 2. The highest fat loss, 11.61%, was recorded after preparing the meat paste with pork backfat for consumption. The lowest fat loss was recorded for the B_O (0.10%) and B_F (0.16%), which indicates the optimal structuring, adhesiveness and consistency of meat batters. While the value of meat batter obtained with sunflower oil was the lowest, the fat loss increased to 4.27% with thermal processing and to 5.77% after thermal treatment for consumption. Similarly, in other studies, fat loss was reduced in the meat batter for chicken sausages prepared with a perilla-canola oil emulsion compared to a tallow sample (Utama et al., 2019), in flaxseed oil that had been pre-emulsified or encapsulated (Bolger et al., 2018), and in frankfurters when emulsified olive oil was used to replace pork backfat (Jiménez-Colmenero et al., 2010).

Only in the case of meat paste obtained from uncooked sausages, the fat loss was higher for the sample with sunflower oil (4.27%) compared to the traditional sample (1.27%). This may be because sunflower oil, unlike animal fats, consists primarily of unsaturated fatty acids. The results obtained for cooked sausages suggest that the total fat release decreased considerably when sunflower oil was used instead of pork backfat. This effect could be attributed to the formation of networks between the sunflower oil and the meat proteins, which leads to a firmer protein structure that minimizes the release of liquid (Wongpattananukul et al., 2022). According to Shin et al. (2022) the optimum temperature range for myofibrillar protein gelation is between 70°C and 80°C. This temperature range is considered optimal, as it induces moderate denaturation of the protein, resulting in the formation of a gel with the highest capacity to retain water. On the other hand, excessive denaturation and aggregation of the myofibrillar protein occur when the heating temperature exceeds 80°C, resulting in the formation of a denser structure that may lower water retention.

Rheological analysis

The analysis of viscoelastic behavior was carried out by conducting frequency measurements to assess the samples' dynamic rheological properties. Figure 3 shows the impact of frequency on the viscoelastic characteristics of meat batters and meat pastes. In the case of the meat batter, the G' and G'' values exhibited a rapid increase until they reached a frequency of 0.40 Hz, after which they increased gradually. According to the results, the storage modulus (G') exhibited higher values than the loss modulus (G'') in the 0.01–10 Hz range, indicating a preponderance of elastic over viscous behavior. In the present study, the meat batter obtained with pork backfat had the highest values of both moduli among all samples, with values of 77.56 kPa for G' and 16.88 kPa for G'' (Table 2). The use of refined sunflower oil led to the formation of a meat batter with slightly lower



B_O – meat batter with refined sunflower oil; P_O_U – meat paste with refined sunflower oil from uncooked sausages; P_O_C – meat paste with refined sunflower oil from cooked sausages; B_F – meat batter with pork backfat; P_F_U – meat paste with pork backfat from uncooked sausages; P_F_C – meat paste with pork backfat from cooked sausages.

Fig. 3. Storage modulus G' (A) and loss modulus G'' (B) curves for meat batter and meat pastes during the frequency test

Table 2. Rheological characteristics of meat batters and meat pastes

Sample/Characteristics	B_O	P_O_U	P_O_C	B_F	P_F_U	P_F_C
Rheology						
G' max [kPa]	$71.62^{Aa}\pm10.91$	$9.53^{Bb}\pm0.45$	$8.83^{Bb}\pm0.99$	$77.56^{Aa}\pm22.70$	$18.17^{Ab}\pm2.23$	$27.93^{Ab}\pm9.06$
G'' max [kPa]	$15.17^{Aa}\pm1.38$	$2.12^{Bb}\pm0.09$	$1.95^{Ab}\pm0.25$	$16.88^{Aa}\pm3.70$	$4.63^{Aa}\pm0.59$	$13.64^{Aa}\pm7.92$

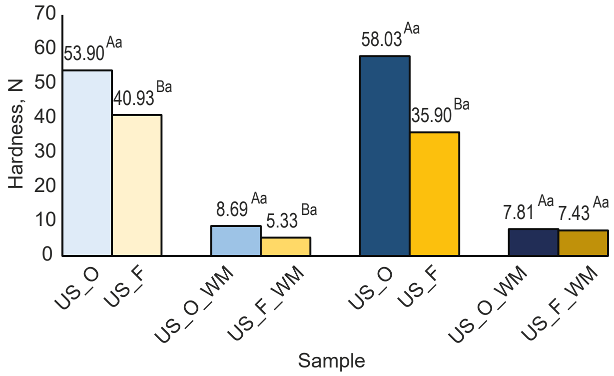
*Values are expressed as mean ± standard deviation. B_O – meat batter with refined sunflower oil; P_O_U – meat paste with refined sunflower oil from uncooked sausages; P_O_C – meat paste with refined sunflower oil from cooked sausages; B_F – meat batter with pork backfat; P_F_U – meat paste with pork backfat from uncooked sausages; P_F_C – meat paste with pork backfat from cooked sausages; G' – storage modulus; G'' – loss modulus. Identically superscript capital letters indicate no significant differences ($p>0.05$) between conventional and reformulated samples (B_O vs B_F, P_O_U vs P_F_U, P_O_C vs P_F_C); identically superscript lowercase letters indicate no significant differences ($p > 0.05$) between meat batters and meat pastes with the same fat source B_O vs P_O_U vs P_O_C and B_F vs P_F_U vs P_F_C.

viscoelastic properties, comparable to the conventional sample, with a G' of 71.62 kPa and a G'' of 15.17 kPa. The samples' rheological behavior during heat treatments was investigated to develop a better understanding of how fat affects viscoelastic properties. The technological heat treatment, as well as the treatment for consumption, led to a gradual decrease in the values of both moduli in the samples for which sunflower oil was used from 9.53 kPa (P_O_U) to 8.83 kPa (P_O_C) for G' and from 2.12 kPa to 1.95 kPa for G''. On the other hand, in the case of conventional samples, the technological treatment led to a decrease in the storage and loss modulus (compared to meat batter), and cooking for consumption led to an increase. This may be due to the denser structure formed at cooking temperatures higher than 80°C (Shin et al., 2022) compared to that formed by the production heat treatment, during which the geometric centre of the product reaches a temperature of 69°C. On the other hand, in the study carried out by Bolger et al. (2018), the viscoelastic characteristics of the chicken sausage formulations with flaxseed oil (direct addition and pre-emulsified) were similar to those of the control, which did not contain oil. The rheological behavior of the conventional meat pastes was consistent with that obtained in the present study for hardness and gumminess, with higher values for the pork backfat samples, probably due to the liquid oil modifying the interaction with the meat proteins. The viscoelastic characteristics exhibit variations due to temperature because of the denaturation and aggregation of myosin structures, which results in the formation of a rigid elastic matrix (this phenomenon appears within the temperature range of 55–75°C) (Bolger et al., 2018).

Characterization of finished products

Texture analysis

Considering the similar composition of the products in this study, the only difference in texture is due to the fat type, thus the textural characteristics are determined by the fat type and its capacity for association with the other components (Jiménez-Colmenero et al., 2010). Hardness is an essential characteristic in the context of meat products, as it has a direct impact on consumer acceptance. From a sensory perspective, hardness indicates the maximum force required to compress the product between the molars (Brookfield Engineering Labs). The hardness values of sausages with casing varied from 35.90 N for cooked sausage with pork backfat (CS_F) to 58.03 N for cooked sausage with refined sunflower oil (CS_O); on the other hand, for the samples without casing, the hardness values varied from 5.33 N for uncooked sausage with pork backfat (US_F_WC) to 8.69 N for uncooked sausage with refined sunflower oil (US_O_WC). However, there was no statistically significant difference between the samples prepared for consumption without the casing: the values were 7.81 N for the sample with refined sunflower oil and 7.43 N for the sample with pork backfat (Fig. 4). In addition, the influence of the thermal treatment for consumption on cooked and uncooked samples with the same fat source (US_O vs CS_O, US_F vs CS_F, US_O_WC vs CS_O_WC, US_F_WC vs CS_F_WC) was also evaluated. The heat treatment conducted for consumption does not result in significantly different hardness values from those of the uncooked samples (only the heat treatment attributed to the production technology): the values were 53.90 N



US_O – uncooked sausages with refined sunflower oil; US_F – uncooked sausages with pork backfat; US_O_WC – uncooked sausages with refined sunflower oil without casings; US_F_WC – uncooked sausages with pork backfat without casings; CS_O – cooked sausages with refined sunflower oil; CS_F – cooked sausages with pork backfat; CS_O_WC – cooked sausages with refined sunflower oil without casings; CS_F_WC – cooked sausages with pork backfat without casings. Identically superscript capital letters indicate no significant differences ($p > 0.05$) between conventional and reformulated samples (US_O vs US_F, US_O_WC vs US_F_WC, CS_O vs CS_F, CS_O_WC vs CS_F_WC); identically superscript lowercase letters indicate no significant differences ($p > 0.05$) between uncooked and cooked sausages with casing (US_O vs CS_O, US_F vs CS_F) and without casing (US_O_WC vs CS_O_WC, US_F_WC vs CS_F_WC).

Fig. 4. Textural properties of uncooked and cooked sausages with and without casings

for US_O, 58.03 N for CS_O, 5.33 N for US_F_WC and 7.43 N for CS_F_WC.

The samples reformulated with sunflower oil exhibited higher hardness values in comparison to the conventional samples. Higher temperatures may create optimal conditions for the integration of sunflower oil into the structure of the meat through protein-lipid interactions (Shin et al., 2022). In another study, the hardness values substantially increased when beef fat was substituted with canola oil. This can be attributed to the formation of considerably smaller fat globules in the canola oil samples, which increased the surface area covered by proteins, facilitating the production of firmer products (Youssef and Barbut, 2011). Also, the hardness value of chicken sausages was higher when perilla-canola oil pre-emulsified mixture was used instead of tallow (2.90 kg vs 2.53 kg) (Utama et al., 2019), when olive oil was used instead of pork backfat (47.92 N vs 29.17 N) and when animal fat was replaced with soybean oil in mortadella sausages (61.50 N vs 58.00 N) (Trindade et al., 2011). Reducing the fat content of Harbin dry sausages with a mixture of 2% Jerusalem artichoke powder and 4% pre-emulsified olive oil (Zhu et al., 2020) and reducing the fat content of frankfurter sausages with emulsified olive oil (Jiménez-Colmenero et al., 2010) led to an increase in the hardness of the samples. On the other hand, the replacement of beef fat with hazelnut oil led to a lower hardness value – 26.72 N compared to 29.65 N (beef fat) – but the formulation with 50% animal fat and 50% oil increased the hardness to 33.31 N (Urgu-Ozturk et al., 2020).

CONCLUSIONS

The present study contributes to existing research on the formulation of meat products with alternative fat sources. Considering the fact that meat products are frequently consumed, it is essential to develop healthier alternatives while maintaining their quality and physicochemical characteristics. The present study offered an approach to understanding the physical and textural properties relevant to the processing of Vienna sausages, as well as developing a nutritionally improved product due to the high content of unsaturated fatty acids contained in the sunflower oil that was used to completely replace pork backfat. Reducing the saturated fat content with sunflower oil did not lead to significant differences in the textural characteristics of meat batters (hardness, cohesiveness and gumminess) and finished products cooked without casings (the most common form of consumption). Since the only difference between the samples is the type of added fat, the changes that appear during the process are due to the bonds created between the meat proteins and the fat source, which also depend on temperature. The hardness and gumminess were slightly lower in the meat pastes obtained from sausages formulated with sunflower oil than in the control with pork backfat. The good emulsion stability exhibited by sausages reformulated with vegetable oil may contribute to the improved texture and stability of the finished products. The rheological properties of the meat pastes produced using sunflower oil exhibited similarities to those produced with pork backfat in terms of hardness and gumminess. Nevertheless, the pork backfat samples had higher values, attributable to the interaction of liquid oil with the meat proteins. The results of our study, together with the studies of other authors, indicate that it is possible to replace animal fats in meat products while maintaining their physicochemical properties. The improved formulation resulted in the manufacture of a meat product that exhibited reduced saturated fat content while maintaining similar properties to the conventional type, but with a better nutritional quality due to the replacement of pork fat with sunflower oil. It is technologically feasible to develop Vienna sausages with sunflower oil since a major advantage is the capacity to use the current manufacturing process and equipment used to produce conventional products, and this offers an attractive possibility for the development of healthier formulations by the meat processing industry.

DECLARATIONS

Data statement

All data supporting this study has been included in this manuscript.

Ethical Approval

Not applicable.

Competing Interests

The authors declare that they have no conflicts of interest.

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