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Research Article

Effects of Lecithin/Sorbitol Monostearate-Canola Oil Oleogel as Animal Fat Replacer on the Fatty Acid Composition and Physicochemical Properties of Lamb Sausage

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In the study, the oleogel developed by lecithin/sorbitol monostearate (SMS) with canola oil was prepared and used as lamb fat replacer (0, 25, 50, 75, and 100%) for lamb sausage. Lecithin/SMS-canola oil oleogel decreased the cooking loss, hardness, springiness, chewiness and resilience of sausage, without affecting the cohesiveness. The ratio of unsaturated to saturated fatty acid increased from 1.12 to 3.38 as the replacement increased from 0 to 100%, presenting a health implication. The sensory scores showed no significant difference when the replacement was lower than 50%. The TBARS values of treatment groups were significantly lower than the control after 24 d storage, indicating the retard of lipid oxidation. These findings suggest that 50% replacement of lamb fat with lecithin/SMS-canola oil oleogels may be the optimal for lamb sausages, which provide new information for developing healthy meat products.

1. Introduction

Fat, one of the major nutrients in food, exhibits various functions in food matrix, contributing to food flavor and texture [1]. In meat products, fat greatly contributes to the sensory properties, such as hardness, juiciness, and flavor. However, the animal fat is regarded as less healthy due to the high levels of saturated fatty acids, which are related to diabetes, endothelial dysfunction, inflammation, oxidative stress, metabolic syndrome, etc. [2, 3]. Vegetable oil has high contents of unsaturated fatty acids and is healthier than animal fat [4]. Nieto and Lorenzo [5] reported that olive oil could be used as a fat substitute in meat emulsions to produce healthier meat products. Nevertheless, vegetable oil is different from animal fat in terms of viscosity, color, and flavor, which may lead to negative impacts on the quality of meat products if directly added to replace animal fat [6].

Oleogel, a solid fat formed by gelatinization using vegetable oil and organic gelator (s), has been studied as a promising fat substitute [7]. It is rich in vegetable oils (>97%, wt) and can mimic the properties of fat due to its ability to hold the liquid phase with the three-dimensional network structure *via* hydrogen bonds, van der Waals forces, covalent bonds, or ionic interactions (Dsc, Ak, Abl, & Rpb, 2022; [8]). Several studies have reported that oleogel can partially replace animal fat and improve product quality and fatty acid profile. Da Silva et al. [9] produced a healthier Bologna sausage with reduced fat content, cholesterol, and energy values using an oleogel formed with pork collagen and high oleic sunflower oil (HOSO). Since canola oil contains the highest level of unsaturated fatty acids among vegetable oils, especially the high contents of oleic acid and linoleic acid, it was widely used for preparing oleogel as the animal fat replacer [10]. Gao et al. [11] applied canola oil oleogel with 10% beewax to replace beef fat and found that this oleogel significantly decreased the saturated fatty acid concentration and cooking loss of beef patties. However, the tunability of a single gelator-oil system is relatively low [12], which limits its application to totally imitate the multiple functions of animal fat [13]. Recently, composite gelators were used to

produce the oleogel with higher tunability. Yang et al. [14] mixed emulsified oil with xanthan gum and konjac glucomannan (KGM) to produce a softer and higher elastic oleogel and compared the oleogel with a single gelator. It was found that 5% phytosterol (PS) enhanced the hardness, gel strength, and structural properties of glycerol monoester-(GM-) olive oil oleogel [15].

Lecithin and sorbitan monostearate (SMS) are widely used in organogel systems as emulsifiers and gelators. Lecithin is a surfactant and a dietary supplement with a lot of functions, such as lowering cholesterol level, increasing serum choline level, and enhancing memory [16]. Han et al. [17] studied lecithin/sorbitol stearate (STS) oleogel and found that lecithin formed needle-like or flaky crystals when it was used as a crystal modifier of STS, forming a better gel network. SMS is biocompatible and nonirritating; hence, it is generally applied in the development of cosmetic, medicine, and food as a structural modifier [18]. Peltonen and Yliruusi [19] investigated the interfacial pressure, hysteresis, interfacial tension, and critical micelle concentration of SMS at the water-gas, water-oil, and oil-gas interfaces and found that SMS reduced the interfacial tension, forming a more stable and elastic emulsion. In addition, due to the close packing of SMS molecules, it contributes to a higher stability of gel network. However, to our knowledge, little has been known about the feasibility of the oleogel formed by lecithin/sorbitol monostearate with canola oil as a lamb fat replacer for lamb sausage.

In this study, an oleogel was prepared using lecithin, SMS, and canola oil, and this oleogel was used as lamb fat replacer (0, 25, 50, 75, and 100%) for the production of lamb sausage. Effects of different proportions of oleogel on the components (water, fat, protein, and ash), texture, and fatty acid composition of the cooked sausages before storage, as well as the color, pH, and thiobarbituric acid reactive substances (TBARS) values of sausage during storage were determined. The objectives were to investigate the effect of lecithin/SMS-canola oil oleogel on the fatty acid composition and physicochemical properties, explore the feasibility of this oleogel as a new animal fat replacer, and provide information for developing healthier products in meat industry.

2. Materials and Methods

2.1. Chemicals and Reagents. Canola oil (Kerry Specialty Fats Co., Shanghai, China), salt (National Salt Industry Group Co., Beijing, China), Chinese five spice (Meishijia Food Co., Taizhou, China), fresh Ningxia Tan-sheep lamb (Ning Xia Xin Hai Co., Yinchuan, China), and cooking wine (Haitian Flavoring and Food Co., Foshan, China) were used in this experiment. Span 60 and lecithin were obtained from Xintai Changsheng Biological Co., Ltd. (Yinchuan, China). Methanol, n-heptane, and isooctane were supplied by the Aoyan Experimental Equipment Co., Ltd. (Fuzhou, China) and were chromatographically pure. Other reagents were from Damao Chemical Factory (Tianjin, China) and were of analytical grade.

2.2. Preparation of Oleogel and Lamb Sausage. Oleogel was prepared according to Harris et al. [20] with slight modification. Briefly, canola oil (100 g) was heated to 80°C. Lecithin (5.6 g) and SMS (22.4 g) were added and stirred at 800 rpm for 30 min using a digital thermostatic magnetic stirrer (DF-101S, Weier Experiment Equipment Co., Shenzhen, China). After lecithin and SMS were completely dissolved, the solution was cooled at 25°C for 24 h until it formed a solid oleogel block. The oleogel was stored at 4°C for 2 d for complete stabilisation until further use.

All lamb fat was firstly separated from the lean of fresh lamb hind legs. The lean was cut into small cubes and chopped using a food processor (FP3010, Braun, Kronenberg, Germany). Lean meat was added with 2‰ composite phosphate (sodium tripolyphosphate : sodium pyrophosphate : sodium hexametaphosphate = 2 : 2 : 1, *w*/*w*/*w*) and 10% ice water and chopped at 600 rpm for 5 min, followed by the addition of 2% salt and chopping at 1,400 rpm for 1 min. The mixture was added with 3% sugar, 3% white wine, 0.5% Chinese five spice, 1% soy sauce, and 10% ice water and chopped at 3,000 rpm for 2 min. After the addition of 15% starch and 2‰ transglutaminase (TGase) as well as the chopping at 3,000 rpm for 1 min, lamb fat and oleogel were added according to Table 1 and further mixed at 1,400 rpm for 1 min. Totally, 0, 25, 50, 75, and 100% of lamb fat were replaced by lecithin/SMS-canola oil oleogel. All percentages were based on the weight of meat, and the temperature during whole chopping process was 10–12°C. The meat batter was cured at 4°C for 24 h and then filled into 19 mm collagen casings. The raw sausage was set at 55°C for 30 min, heated at 80°C for 30 min, and steamed for 20 min. After cooling to room temperature, the sausage was stored at 4°C and used within 1 d, except for the storage indicators. For the storage indicators, the sausage was kept at a temperature of 4°C and a humidity of 80% for 24 d. Color, pH, and TBARS values of the samples were tested on days 1, 6, 12, 18, and 24.

2.3. Physicochemical Properties of Canola Oil, and Oleogel. The content of moisture and acid, peroxide, and iodine values of canola oil and oleogel were determined according to ISO 662 (2016) [21], ISO 660 (2020) [22], ISO 3960 (2017) [23], and ISO 3961 (2018) [24], respectively.

2.4. Proximate Composition of Lamb Sausage. The contents of moisture, protein, fat, and ash were determined according to ISO 1442 (1997) [25], ISO 5983-1 (2005) [26], ISO 1443 (1973) [27], and ISO 936 (1998) [28], respectively.

2.5. Fatty Acid Analysis. Fatty acids of canola oil, oleogel, and lamb sausage were extracted and determined according to ISO 18363-1 (2015) [29]. After methyl esterification, samples were analysed by GC-MS (GCMS-QP2010, Shimadzu, Kyoto, Japan) equipped with a BPX-70 capillary column (60 m × 0.25 mm (id), 0.2 μ film thickness). The temperature of FID detector (Shimadzu, Kyoto, Japan) was 280°C, the split ratio was 100 : 1, and the injection volume was 1 μL. The oven (YXD-Z303, Lechuang Network Technology Co., Foshan, China) was held at 100°C for 13 min, heated to 180°C at 2°C/min and kept for 6 min, then heated to 200°C

Table 1: Experiment grouping.

Group		Lamb addition amount (%)	Fat added (%)	Addition of oleogel (%)	Replacement ratio (%)
Control group	T_0	60	40	0	0
Treatment group	T_1	60	30	10	25
Treatment group	T_2	60	20	20	50
Treatment group	T_3	60	10	30	75
Treatment group	T_4	60	0	40	100

at 1°C/min and kept for 20 min, and finally heated to 230°C at 4°C/min and kept for 10.5 min. Fatty acids were identified based on the mass spectra databases and standard solutions. The relative quantification was performed according to the area of each fatty acid peak.

2.6. Cooking Loss. The sausages were weighed before heating and after cooling. The cooking loss was calculated according to Chen et al. [30] with the following formula:

$$\text{Cooking loss}\,(\%) = \frac{m_1 - m_2}{m_1} \times 100, \quad (1)$$

where m_1 is the weight of sausage before heating, and m_2 is the weight of sausage after cooling.

2.7. Texture Profile Analysis (TPA). Sausage texture was analysed according to Kim et al. [31] with slight modification. Briefly, samples were cut into cylinders (with a height of 2 cm and a diameter of 1.5 cm) and analysed using a texture analyser (TA-XT Plus, Stable Micro System Haslemere, Godalmin, UK) with a P/50 probe. The parameters were pretest speed of 2 mm/s, midtest speed of 1 mm/s, posttest speed of 1 mm/s, and trigger force of 5 g. Each sample was axially compressed to 50% of its initial height. Data of hardness, springiness, cohesiveness, chewiness, and resilience were recorded.

2.8. Color, pH, and TBARS Values. The color value of sausage cross-section was determined using a portable colorimeter (CR400, Konica-Minolta, Kyoto, Japan) calibrated with a standard white board. L^* (lightness), a^* (redness), and b^* (yellowness) values of each point on the central part of sausage cross-section were measured.

Five grams of sausage were homogenised with 50 mL of deionized water at 10,000 rpm for 1 min using a homogeniser (PT45-80-GT, Kinematica, Luzern, Switzerland). The pH value of homogenate was measured using a pH meter (FE28, Mettler Toledo, Zurich, Swiss).

TBARS value was determined with a method modified from Wang et al. [32]. Five grams of sample were mixed with 25 mL of 7.5% trichloroacetic acid (containing 0.1 EDTA), shaken for 30 min, and filtered through a Whatman filter paper. Five milliliters of filtrate were mixed with 5 mL of 0.02 M thiobarbituric acid (TCA) and heated in a boiling water bath for 40 min. After cooling to room temperature, the absorbance value was measured at 532 nm and 600 nm using an UV-VIS spectrophotometer (T6, Sizhuo Medical Devices Co., Jinan, China). According to Shibata et al. [33], 2 wavelengths were used in order to enhance the accuracy and sensitivity of results. The TBARS value was expressed as the content of malondialdehyde (MDA) per kg of sausage (mg MDA/kg) and calculated according to the following formula:

$$\text{TBARS value} = \frac{(A_{532} - A_{600}) \times 4.69 \times 10}{m \times 10}, \quad (2)$$

where A532 and A600 are the absorbance values at 532 nm and 600 nm, respectively; m is the weight of sample.

Color, pH, and TBARS values were measured on days 1, 6, 12, 18, and 24 and were done in triplicate independently. TBARS value was expressed as mg MDA/kg lamb sausage.

2.9. Sensory Evaluation. Sensory descriptive analysis was conducted by thirty experienced and trained sensory panelists (15 females and 15 males, at the ages of 30–45). All of the panelists were trained through three preliminary sessions for sample familiarization by an expert in the meat science laboratory in Ningxia University. Panelists were provided a description table with the definition and the intensity scale for each sensory attribute as the reference for scoring. They were trained for the definitions to ensure that each panelist applied the same evaluation criteria during sensory evaluation. All participants received hard copies of the information of this study and signed the informed consent.

Sensory evaluation was performed according to Chen et al. [30] with slight modification. The sensory panels were carried out in a sensory test laboratory with partitioned cabinets (ISO 8589, 2007) [34]. The tests consisted of three sessions that were conducted on different days with the same panelists. For every session, each panelist evaluated all treatments (T0-T4). After heating in a microwave oven for 15 s, lamb sausage from each group was cut into pieces (2 to 3 cm long) and placed on white plates coded with a 3-digit random number. Then, all the samples were immediately served to panelists. Mineral water and unsalted crackers were provided between samples to clean the palate. The panelists evaluated samples in terms of each sensory attribute (appearance, color, odour, tenderness, or overall acceptance) according to Table 2 with the definition and the intensity scale.

2.10. Statistical Analysis. All assays were done in triplicate independently. Data were analysed by one-way ANOVA (Duncan's Multiple Range Test) with least significant difference (LSD) test using SPSS 17.0 (International Business Machines Co., Armonk, USA). The significance of difference was set as $P < 0.05$.

Table 2: Sensory descriptors with definitions and intensity range.

Descriptive vocabulary	Definition	Intensity range
Appearance	The casing is dry and complete and close to the meat filling, and the intestine is full without mold	8–10
	The casing is slightly moist or sticky, easy to separate from the meat but not easy to break, with mildew on the surface	5–8
	The casing is moist and sticky and easily separated from the meat, and easy to tear, with serious mildew on the surface	1–5
Color	The cut surface is shiny, the muscles are grayish red to rose red, and the fat is white or reddish	8–10
	Part of the meat is shiny, the muscles are dark gray or brown, and the fat is yellow	5–8
	The whole meat is dull, the muscle is dull, and the fat is yellow	1–5
Odour	The fat has no sour taste, no bad smell, and has the unique flavor of sausage	8–10
	Fat has a mildly rancid taste, and sometimes the meat filling has a sour taste	5–8
	Fat has a heavier rancid taste	1–5
Tenderness	The meat is tender, tough, and chewy	8–10
	The meat is average, with a certain degree of toughness	5–8
	Poor meat quality, no chewing	1–5
Overall acceptance	Overall happy to accept	8–10
	Acceptable	5–8
	Not very acceptable	1–5

3. Results and Discussion

3.1. Physicochemical Properties and Fatty Acid Composition of Canola Oil and Lecithin/SMS-Canola Oil Oleogel. As shown in Table 3, the acid, peroxide, and iodine values of both canola oil and oleogel met the regulations of oil [35]. The moisture content of oleogel was slightly higher than that of canola oil since lecithin and SMS contained water. Acid and peroxide values represent the degree of deterioration and oxidation of the oil, respectively [36]. These values of oleogel were higher than those of canola oil, because the oleogel was heated during preparation and the oxidation was accelerated. Iodine value reflects the number of double bonds in the oil, which means the higher the iodine value, the higher the content of unsaturated fatty acid [36]. During heating, a series of reactions, such as oxidation, occurred in canola oil, reducing the number of double bonds in the oleogel. In addition, the low iodine value demonstrated the solid state of oleogel [37].

Canola oil was rich in unsaturated fatty acids (UFA, 88.11%), among which oleic acid (55.13%) and linoleic acid (19.71%) showed the highest percentages (Table 3). The content of saturated fatty acid (SFA) of canola oil was 10.27%, mainly palmitic acid and stearic acid, which was consistent with the results of Gao et al. [11]. The content of trans fatty acid (TFA) in the organic oleogel was lower than that in canola oil ($P < 0.05$) due to the oxidation reaction during heating and the low fat content of the oleogel itself. The SFA of the oleogel (21.41%) was lower than that of animal fat [38], indicating that oleogel had the potential to be used as a substitute of lamb fat to improve the fatty acid composition in sausage.

Table 3: Basic physicochemical indexes and fatty acid composition of canola oil and oleogel.

	Canola oil	Oleogel
Moisture (%)	0.07 ± 0.01^{a}	0.26 ± 0.03^{b}
Acid value (mg/g)	0.22 ± 0.04^{a}	1.46 ± 0.10^{b}
Peroxide value (mmol/kg)	1.35 ± 0.10^{a}	2.50 ± 0.10^{b}
Iodine value (g/100 g)	125.90 ± 2.55^{a}	35.33 ± 0.49^{b}
C16:0	4.51 ± 0.13^{a}	11.38 ± 0.89^{b}
C18:0	2.03 ± 0.02^{a}	7.90 ± 0.66^{b}
C18:1	55.13 ± 0.64^{a}	44.39 ± 1.07^{b}
C18:2	19.71 ± 0.27^{a}	16.92 ± 0.49^{b}
C18:3	3.25 ± 0.05^{a}	2.98 ± 0.19^{a}
TFA	3.07 ± 0.03^{a}	2.74 ± 0.22^{b}
ΣSFA	10.27 ± 0.29^{a}	21.41 ± 0.50^{b}
ΣMUFA	56.03 ± 0.61^{a}	44.91 ± 1.02^{b}
ΣPUFA	32.07 ± 0.45^{a}	27.03 ± 0.04^{b}
ΣUFA	88.11 ± 1.05^{a}	71.94 ± 1.06^{b}

Note: (1) results are expressed as means ± standard deviation. Values with a different letter (a and b) within a row are significantly different ($P < 0.05$); (2) TFA: trans fatty acids; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; UFA: unsaturated fatty acids.

3.2. Effect of Lecithin/SMS-Canola Oil Oleogel on the Proximate Composition and Texture of Lamb Sausage. As shown in Table 4, when the lamb fat was replaced by lecithin/SMS-canola oil oleogel from 0% to 100%, there were no significant changes of water, protein, and ash contents in sausages, while the fat content was significantly reduced ($P < 0.05$). Compared to T_0, the fat contents of T_1, T_2, T_3, and T_4 decreased by 5.62, 7.20, 14.55, and 24.42%, respectively.

Table 4: Physicochemical index, cooking loss, and texture characteristics of sausage in different treatment groups.

	T_0	T_1	T_2	T_3	T_4	P value
Moisture (%)	46.96 ± 0.89^{a}	48.08 ± 0.26^{a}	48.68 ± 0.26^{a}	49.05 ± 1.17^{a}	51.16 ± 0.71^{a}	n.s.
Fat (%)	20.27 ± 0.91^{a}	19.13 ± 0.92^{ab}	18.81 ± 0.81^{ab}	17.32 ± 0.46^{b}	15.32 ± 0.42^{c}	*
Protein (%)	11.99 ± 0.77^{a}	12.89 ± 1.62^{a}	12.93 ± 2.27^{a}	11.05 ± 0.40^{a}	11.28 ± 1.03^{a}	n.s.
Ash (%)	3.82 ± 0.10^{a}	3.83 ± 0.06^{a}	3.94 ± 0.18^{a}	3.89 ± 0.02^{a}	3.75 ± 0.14^{a}	n.s.
Cooking loss (%)	48.82 ± 1.32^{a}	41.49 ± 0.14^{c}	41.96 ± 0.75^{c}	43.95 ± 1.74^{bc}	46.06 ± 0.17^{b}	**
Hardness (g)	2877.07 ± 9.23^{a}	2632.94 ± 12.05^{b}	1918.71 ± 80.92^{c}	1811.61 ± 88.53^{c}	1350.03 ± 63.26^{d}	***
Springiness (%)	74.62 ± 2.23^{a}	60.89 ± 0.10^{b}	55.67 ± 2.28^{c}	54.35 ± 1.45^{c}	54.53 ± 0.87^{c}	***
Cohesiveness	0.53 ± 0.02^{a}	0.34 ± 0.08^{a}	0.36 ± 0.14^{a}	0.42 ± 0.01^{a}	0.45 ± 0.04^{a}	n.s.
Chewiness	712.22 ± 13.34^{a}	694.32 ± 33.52^{b}	569.80 ± 18.91^{c}	462.31 ± 5.38^{d}	388.93 ± 18.14^{e}	***
Resilience (%)	13.92 ± 0.87^{a}	11.09 ± 0.62^{c}	11.82 ± 1.33^{c}	12.59 ± 0.14^{c}	14.66 ± 0.73^{b}	***

Note: (1) results are expressed as means ± standard deviation. Values with a different letter (a–c) within a row are significantly different ($P < 0.05$); (2) P value: $^{***}(P < 0.001)$, $^{**}(P < 0.01)$, $^{*}(P < 0.05)$, n.s.: not significant. (The same below).

Cooking loss is a key factor to reflect the juiciness of sausage and is related to the water or fat holding capacity during heating [30]. The cooking loss greater than 40% might be due to the low concentration of salt during sample preparation [39], high cooking temperature, and long cooking time [40]. The cooking losses of T_1, T_2, T_3, and T_4 were all lower than that of T_0, with the decrements of 15.01, 14.05, 9.98, and 5.65%, respectively (Table 4). As the increase of oleogel, more fat globules were dispersed in the 3D cross-linked network structure, trapping water globules, thus reducing the content of water evaporation during heating [36]. However, the cooking loss increased as the oleogel replacement increased from 25 to 100% (T1 to T4), which was contrary to the results of a previous study of da Silva et al. [9]. This may be because the melting point of lecithin/SMS-canola oil oleogel was relatively low, and its structure was destroyed when the sausages were cooked, so that its affinity for water and the interaction with protein became weak. This result was similar to Kim et al. [31], who found that the cooking loss of meat emulsions increased when the replacement of grape seed oil and gelatin/alginate increased and assumed that this was due to the melting of gelatin.

TPA is important for evaluating the acceptability of meat products, including hardness, springiness, cohesiveness, chewiness, and resilience. Compared to T_0, oleogel significantly decreased the hardness, springiness, chewiness, and resilience of products ($P < 0.05$), but did not affect the cohesiveness. Salcedo-Sandoval et al. [41] reported that when various fats or fat replacers were applied, the differences of TPA parameters may be related to the proximate components of the product, especially moisture and fat contents. The size of fat globules in the oleogel prepared using vegetable oil was different from that of animal fat; thus, the interaction between proteins and fat globules was changed when the lamb fat was replaced by the oleogel [42]. As the replacement proportion of oleogel increased, the fat content of sausages decreased, and the amount of relatively large fat globules increased. Relatively large fat globules were regarded to be unstable, resulting in the instability of fat-protein structure [43].

3.3. Effect of Lecithin/SMS-Canola Oil Oleogel on the Fatty Acid Composition of Lamb Sausage. Table 5 shows the fatty acid composition of sausages made with lecithin/SMS-canola oil oleogel as fat replacer in different proportions. It can be seen that most fatty acids in treatment groups were significantly different from the control ($P < 0.05$). Among the whole fatty acids, oleic acid accounted for the most (8.26–11.73%), followed by palmitic acid (3.18–5.58%), linoleic acid (1.41–4.67%), and stearic acid (1.88–3.87%). In all groups, the content of SFA of T_0 was the highest, mainly including palmitic acid (C16:0) and stearic acid (C18:0). When lecithin/SMS-canola oil oleogel was used for 25, 50, 75, and 100% replacement, SFA contents of lamb sausages significantly were reduced by 34.01, 23.75, 59.38, and 55.30%, respectively. This was consistent with Asuming-Bediako et al. [44], who replaced pork back fat with HOSO and found that SFA content of sausage was only 8.34%.

Oleic acid (C18:1) was the most abundant monounsaturated fatty acid (MUFA) of lamb sausage. The content of oleic acid increased significantly as the replacement proportion of oleogel increased from 0 to 100%. T_3 and T_4 showed the highest levels of oleic acid, indicating that reformulation of sausage with oleogel increased the nutritional and health characteristics of sausage, because oleic acid could reduce the risks related to cardiovascular disease, such as obesity, high blood pressure, and cholesterol [45, 46].

The most abundant polyunsaturated fatty acid (PUFA) of lamb sausage was linoleic acid (C18:2). As the oleogel substitution increased from 25 to 100%, the contents of linoleic acid in sausages were increased by 1.62- to 3.31-fold. As an essential fatty acid in the human body, linoleic acid can lower blood cholesterol and prevent atherosclerosis [8]. Therefore, the reformulation improved the health characteristic of products.

Several studies reported that after the addition of vegetable oil, the UFA/SFA ratio increased, indicating the improvement of nutrient composition [5]. The UFA/SFA ratio gradually increased from 1.12 to 3.38 as the amount of oleogel replacement increased (Table 5). This result was consistent with a previous study [47], showing that UFA

Table 5: Fatty acid composition of sausages in different treatment groups.

	T_0	T_1	T_2	T_3	T_4	P value
C14:0	0.90 ± 0.16^{a}	0.46 ± 0.04^{b}	0.39 ± 0.02^{b}	0.13 ± 0.03^{c}	0.05 ± 0.00^{c}	***
C14:1	0.03 ± 0.01^{a}	0.02 ± 0.00^{b}	0.02 ± 0.00^{b}	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}	**
C15:0	0.32 ± 0.06^{a}	0.15 ± 0.05^{b}	0.15 ± 0.02^{b}	0.04 ± 0.01^{c}	0.02 ± 0.00^{c}	**
C15:1	0.01 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	n.s.
C16:0	5.58 ± 0.25^{a}	4.13 ± 0.61^{bc}	4.51 ± 0.58^{ab}	2.65 ± 0.54^{d}	3.18 ± 0.35^{cd}	*
C16:1	0.45 ± 0.08^{a}	0.24 ± 0.06^{b}	0.23 ± 0.03^{b}	0.09 ± 0.01^{c}	0.07 ± 0.00^{c}	**
C17:0	0.97 ± 0.18^{a}	0.47 ± 0.16^{b}	0.45 ± 0.06^{b}	0.12 ± 0.03^{c}	0.05 ± 0.01^{c}	**
C18:0	3.87 ± 0.57^{a}	2.39 ± 0.72^{b}	2.84 ± 0.44^{ab}	1.60 ± 0.35^{b}	1.88 ± 0.20^{b}	*
C18:1	10.96 ± 0.91^{a}	8.26 ± 0.00^{b}	8.87 ± 0.47^{b}	11.14 ± 0.27^{a}	11.73 ± 0.24^{a}	**
C18:2	1.41 ± 0.13^{d}	2.28 ± 0.11^{c}	3.47 ± 0.26^{b}	3.44 ± 0.17^{b}	4.67 ± 0.44^{a}	***
C18:3	0.04 ± 0.00^{c}	0.16 ± 0.09^{c}	0.39 ± 0.03^{b}	0.44 ± 0.11^{b}	0.66 ± 0.12^{a}	**
C20:1	0.16 ± 0.02^{a}	0.14 ± 0.04^{a}	0.10 ± 0.01^{ab}	0.05 ± 0.01^{b}	0.05 ± 0.01^{b}	*
C20:2	0.01 ± 0.00^{c}	0.01 ± 0.00^{c}	0.03 ± 0.01^{b}	0.02 ± 0.00^{bc}	0.06 ± 0.01^{a}	**
C20:3	0.01 ± 0.00^{c}	0.27 ± 0.17^{c}	0.68 ± 0.05^{b}	0.76 ± 0.21^{b}	1.19 ± 0.22^{a}	**
C20:4	0.07 ± 0.01^{a}	0.06 ± 0.01^{ab}	0.06 ± 0.01^{b}	0.05 ± 0.00^{b}	0.05 ± 0.00^{b}	*
C22:0	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}	0.04 ± 0.00^{b}	0.02 ± 0.03^{bc}	0.08 ± 0.01^{a}	**
ΣSFA	12.26 ± 1.19^{a}	8.09 ± 1.52^{bc}	8.98 ± 1.24^{b}	4.98 ± 0.93^{d}	5.48 ± 0.60^{cd}	**
ΣMUFA	12.15 ± 1.12^{a}	8.93 ± 0.10^{b}	9.53 ± 0.38^{b}	11.39 ± 0.34^{a}	11.89 ± 0.23^{a}	**
ΣPUFA	1.57 ± 0.13^{c}	2.78 ± 0.37^{c}	4.65 ± 0.38^{b}	4.72 ± 0.50^{b}	6.66 ± 0.76^{a}	**
UFA	13.72 ± 1.24^{c}	11.71 ± 0.48^{d}	14.18 ± 0.00^{c}	16.11 ± 0.85^{b}	18.55 ± 0.52^{a}	**
UFA/SFA	1.12 ± 0.01^{b}	1.47 ± 0.22^{b}	1.59 ± 0.22^{b}	3.28 ± 0.44^{a}	3.38 ± 0.25^{a}	**
$n-6/n-3$	40.70 ± 6.63^{a}	19.23 ± 9.07^{b}	10.58 ± 0.45^{b}	9.97 ± 2.04^{b}	8.51 ± 0.36^{b}	**

Note: (1) results are expressed as means ± standard deviation. Values with a different letter (a–c) within a row are significantly different ($P < 0.05$); (2) SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; UFA: unsaturated fatty acids.

content in sausage increased while SFA content decreased when pork fat was replaced by light and semiheavy spent laying hens and soybean oil, compared with traditional sausage. It is worth noting that lowering the $n-6/n-3$ ratio is important for improving the nutrition of meat products [48]. Table 5 shows that the $n-6/n-3$ ratio in lamb sausages was significantly reduced from 40.70 to 8.51 when the animal fat was replaced with oleogel, which was consistent with Câmara et al. [49].

3.4. Effect of Lecithin/SMS-Canola Oil Oleogel on the Color of Lamb Sausage during Storage. The color change is closely related to the sausage recipe, especially the type and amount of fat or oil used [50]. As shown in Table 6, L^* and b^* values of $T_1 - T_4$ were significantly higher than T_0 ($P < 0.05$), while a^* value was lower ($P < 0.05$). This was in line with Wang et al. [32], who developed Harbin sausage with camellia oil oleogel as the partial replacement of pork back fat. Camila et al. [51] reported that the increase of L^* value may be due to the smaller oil droplets size of oleogel, compared to animal fat, resulting in the greater degree of light reflection. The decrease of a^* value may be because the emulsion formed with oil, protein, and water during the chopping induced the scattering of light [52]. In addition, the increase of b^* value may be related to the yellow color of canola oil, which was previously reported by Morales-Irigoyen et al. [53].

In the same treatment group during 24 d storage, a^* value significantly decreased ($P < 0.05$), while b^* value significantly increased ($P < 0.05$). There was no significant change of L^* value in the same group during storage. Similar changes were also observed by da Silva et al. [9] in the Bologna sausage using sunflower seed oil oleogel during 35 d storage. Lorenzo et al. [54] reported that a^* value of sausage decreased during ripening, due to the partial or complete denaturation of nitrosomyoglobin resulting from accumulated lactic acid. Shan et al. [55] found that the increase of b^* value was related to lipid oxidation. In the study, compared to the control, the replacement of oleogel showed a lower redness and a higher yellowness during storage.

3.5. Effect of Lecithin/SMS-Canola Oil Oleogel on pH and TBARS Values of Lamb Sausage during Storage. As shown in Figure 1(a), during 18 d storage, pH value of T_0 dropped rapidly (from 5.73 to 4.96, $P < 0.05$), while pH values of $T_1 - T_4$ showed milder decreases than T_0. During the storage of 18–24 d, pH values of all groups significantly increased ($P < 0.05$), which may be due to the

Table 6: The color of sausages in different treatment groups.

	Time (d)	T_0	T_1	T_2	T_3	T_4	P value
L^*	0	51.73 ± 1.15^{bA}	55.29 ± 1.74^{aA}	56.52 ± 2.47^{aA}	57.16 ± 1.28^{aA}	58.96 ± 0.68^{aA}	*
	6	51.68 ± 1.78^{cA}	54.01 ± 0.71^{bA}	56.48 ± 1.21^{aA}	56.76 ± 1.52^{aA}	58.86 ± 1.70^{bA}	***
	12	52.50 ± 1.14^{bA}	55.01 ± 2.03^{bA}	55.28 ± 1.14^{abA}	56.90 ± 0.71^{aA}	57.80 ± 1.88^{bA}	*
	18	51.25 ± 1.05^{bA}	55.94 ± 1.08^{aA}	56.00 ± 2.37^{aA}	57.63 ± 1.87^{aA}	58.08 ± 1.27^{aA}	***
	24	51.98 ± 0.28^{cA}	56.38 ± 2.42^{abA}	56.73 ± 2.38^{aA}	57.06 ± 1.40^{aA}	57.49 ± 1.41^{bA}	**
	P value	n.s.	n.s.	n.s.	n.s.	n.s.	
a^*	0	10.05 ± 0.27^{aA}	10.00 ± 0.62^{aA}	8.75 ± 0.74^{bA}	8.45 ± 0.88^{bA}	8.39 ± 0.54^{abAB}	*
	6	9.34 ± 0.62^{aAB}	9.62 ± 0.09^{aA}	8.77 ± 0.38^{aA}	8.75 ± 0.60^{aA}	8.74 ± 0.87^{aA}	n.s
	12	9.98 ± 1.27^{bC}	9.92 ± 0.20^{aA}	8.77 ± 0.92^{abA}	8.13 ± 0.73^{bA}	7.65 ± 0.34^{aAB}	*
	18	8.86 ± 0.34^{aABC}	8.92 ± 0.46^{aB}	8.51 ± 0.27^{aA}	7.94 ± 0.06^{bB}	7.27 ± 0.62^{bC}	***
	24	8.38 ± 0.41^{abBC}	8.78 ± 0.26^{aB}	7.88 ± 0.88^{cB}	7.56 ± 0.50^{bcAB}	7.35 ± 0.75^{abBC}	*
	P value	*	**	*	*	s	
b^*	0	13.20 ± 1.24^{bA}	14.39 ± 1.34^{abAB}	14.58 ± 1.02^{bB}	15.02 ± 1.52^{bB}	15.33 ± 1.25^{aA}	*
	6	13.54 ± 1.09^{cAB}	14.11 ± 0.46^{bB}	14.63 ± 0.50^{bB}	15.38 ± 0.60^{bB}	16.80 ± 0.77^{aA}	***
	12	13.85 ± 2.32^{aAB}	14.17 ± 2.42^{aB}	14.85 ± 1.38^{aB}	16.13 ± 1.90^{aAB}	16.54 ± 1.98^{aB}	*
	18	14.25 ± 1.19^{cAB}	15.49 ± 0.97^{aA}	15.86 ± 0.66^{abA}	16.43 ± 1.37^{bcA}	16.51 ± 0.43^{aAB}	**
	24	14.71 ± 1.30^{cB}	15.49 ± 0.57^{abcA}	15.58 ± 2.96^{abA}	16.33 ± 1.75^{bcA}	17.15 ± 1.13^{aA}	*
	P value	*	*	*	*	*	

Note: results are expressed as means ± standard deviation. Averages within the same line followed by the different lowercase letters show significant difference ($P < 0.05$), and averages within the same column followed by the different upper case show significant difference ($P < 0.05$).

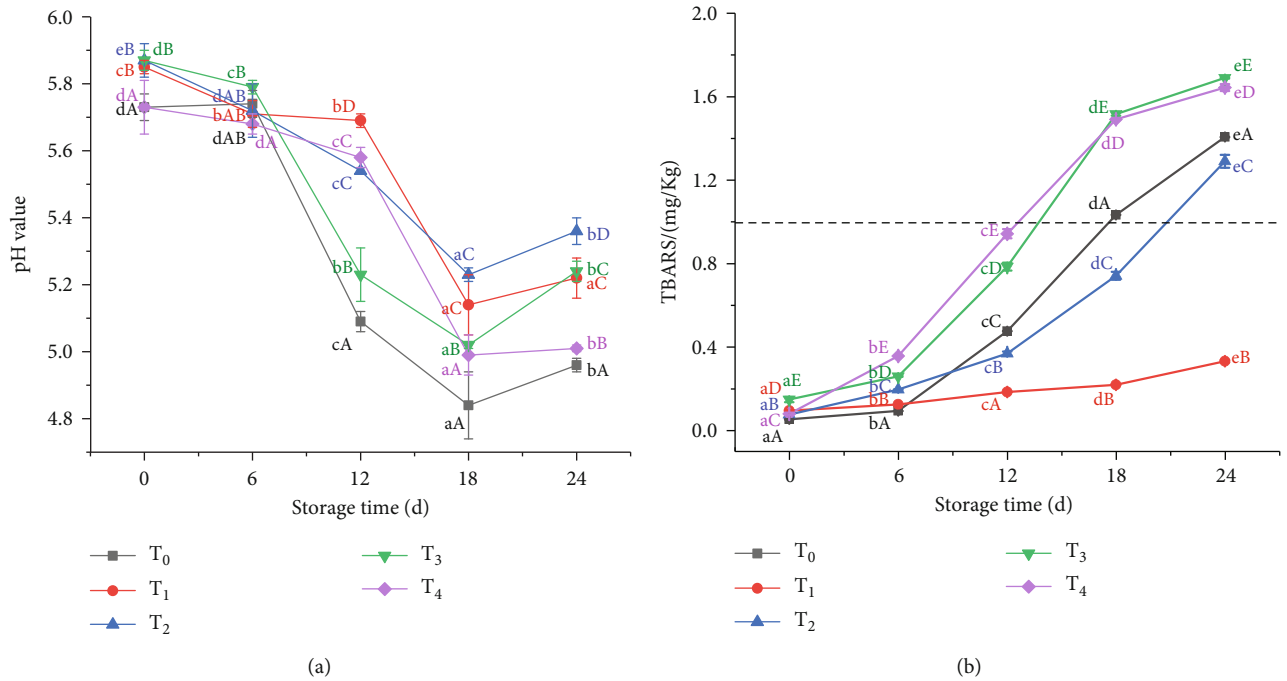

Figure 1: Changes of pH value and TBARS of sausages in different treatment groups at 4 °C. Note: lowercase letters indicate that there are significant differences between the same set of samples ($P < 0.05$), and capital letters indicate that there is a significant difference between different groups for the same storage days ($P < 0.05$).

increase of nitrogen-containing compounds from protein hydrolysis. The results were in line with da Silva et al. [9], who used oleogel rich in oleic acid to replace pork back fat in Bologna-type sausages. The final pH values of four treatment groups were higher than that of the control, which may be related to the effect of oleogel on the proteolysis of lamb sausage. These results were in line with de Carvalho et al. [56], who reported that tiger nut oil enhanced the pH of lamb sausage during storage.

During storage, the oxidation of fatty acids and other lipids led to quality deterioration, which not only reduced the shelf life and impaired sensory acceptance but also produced toxic compounds [32]. TBARS values of all samples increased during storage ($P < 0.05$, Figure 1(b)), indicating that lipid oxidation occurred. After 24 days of storage, the TBARS values of T_1 and T_2 were significantly lower than that of T_0, while the TBARS values of T_3 and T_4 were higher than that of T_0 ($P < 0.05$), which was consistent with Moghtadaei et al. [36]. The difference in oxidation stability was related to the composition of oleogel and the production method. The reason why T_3 and T_4 showed higher TBARS values may be due to higher content of polyunsaturated fatty acids and greater oxidation degrees with high replacement proportion of lecithin/SMS-canola oil oleogel [48]. After storage, T_1 showed the lowest increment of TBARS among all groups, which was in agreement with Öztürk-Kerimoğlu et al. [57]. This positive result showed that the lecithin/SMS-canola oil oleogel could act as a natural barrier, so that the addition of an appropriate amount of oleogel could retard the lipid oxidation of sausages. Our results indicated that 50% replacement of lamb fat with lecithin/SMS-canola oil oleogels could effectively alleviate the rancidity and lipid oxidation of lamb sausage.

3.6. Effect of Lecithin/SMS-Canola Oil Oleogel on the Sensory Evaluation of Lamb Sausage. As shown in Figure 2, the color scores of T_3 and T_4 were significantly lower than that of T_0 ($P < 0.05$), which may be because the a^* values of T_3 and T_4 were lower and the b^* values were higher than T_0. The scores of appearance, tenderness, and overall acceptability of T_3 and T_4 were also affected by high proportions of lecithin/SMS-canola oil oleogel substitution. On the other hand, there were no significant differences in appearance, odour, tenderness, and overall acceptability among T_1, T_2, and T_0 ($P > 0.05$), but there were significant differences in color ($P < 0.05$). The results of the sensory evaluation were consistent with those of TPA. The scores of sensory evaluation decreased when the substitution proportion was higher than 50%. Thus, 50% replacement of lamb fat with lecithin/SMS-canola oil oleogel in lamb sausage could reduce the adverse effects on sensory attributes of lamb sausage to the greatest extent.

Meat product is a complex system in which the fat contributes to the emulsification and flavor. When the oleogel was used to replace lamb fat, the characteristic flavor of lamb sausage would be inevitably affected. Therefore, lecithin/SMS-canola oil oleogel should be used with a reasonable proportion in other meat products. In short, lecithin/SMS-canola oil oleogel showed considerable prospects for the development of food products with low SFAs and TFAs.

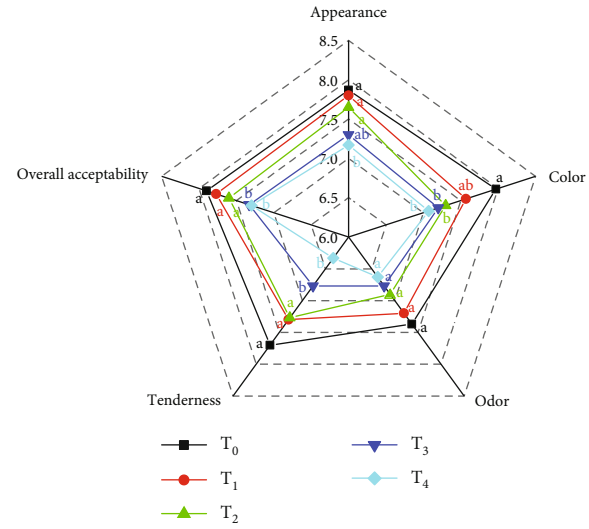

Figure 2: Sausage sensory rating radar map. Note: letters indicate significant differences between samples ($P < 0.05$).

4. Conclusions

In conclusion, the replacement of lamb fat with lecithin/SMS-canola oil oleogel in lamb sausage decreased SFA content, increased UFA content, and retarded lipid oxidation during storage, which improved the fatty acid composition and extended the shelf life. To reach the accepted organoleptic attributes, replacement proportion of oleogel should be within 50%.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Additional Points

Practical Applications. Oleogel has been a promising animal fat replacer due to its health and nutritional benefits. The present work offered some new information about the use of lecithin, SMS, and canola oil to prepare the oleogel, exploring the feasibility of using this oleogel as a lamb fat substitute (0, 25%, 50%, 75%, and 100%). Based on the results, 50% replacement of lamb fat with lecithin/SMS-canola oil oleogels may be optimal for the production of lamb sausage.

Ethical Approval

This article does not contain any studies with human or animal subjects.

Conflicts of Interest

No potential conflict of interest was reported by the authors.

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References

[1] N. Milievi, M. Saka, M. Hadnaev, D. Krobot, and L. Pezo, "Physico-chemical properties of low-fat cookies containing wheat and oat bran gels as fat replacers," *Journal of Cereal Science*, vol. 95, no. 1, article 103056, 2020.

[2] D. Mozaffarian and R. Clarke, "Quantitative effects on cardiovascular risk factors and coronary heart disease risk of replacing partially hydrogenated vegetable oils with other fats and oils," *European Journal of Clinical Nutrition*, vol. 63, no. S2, pp. S22–S33, 2009.

[3] H. M. Roche, "Fatty acids and the metabolic syndrome," *Proceedings of the Nutrition Society*, vol. 64, no. 1, pp. 23–29, 2005.

[4] J. C. Barros, P. E. Munekata, F. A. L. de Carvalho et al., "Healthy beef burgers: effect of animal fat replacement by algal and wheat germ oil emulsions," *Meat Science*, vol. 173, article 108396, 2021.

[5] G. Nieto and J. M. Lorenzo, "Use of olive oil as fat replacer in meat emulsions," *Current Opinion in Food Science*, vol. 40, pp. 179–186, 2021.

[6] L. Shao, J. Bi, R. Dai, and X. Li, "Effects of fat/oil type and ethylcellulose on the gel characteristic of pork batter," *Food Research International*, vol. 138, article 109788, 2020.

[7] I. Oh, J. Lee, H. G. Lee, and S. Lee, "Feasibility of hydroxypropyl methylcellulose oleogel as an animal fat replacer for meat patties," *Food Research International*, vol. 122, pp. 566–572, 2019.

[8] E. Panagiotopoulou, T. Moschakis, and E. Katsanidis, "Sunflower oil organogels and organogel-in-water emulsions (part II): implementation in frankfurter sausages," *LWT-Food Science and Technology*, vol. 73, pp. 351–356, 2016.

[9] S. L. da Silva, J. T. Amaral, M. Ribeiro et al., "Fat replacement by oleogel rich in oleic acid and its impact on the technological, nutritional, oxidative, and sensory properties of Bologna-type sausages," *Meat Science*, vol. 149, pp. 141–148, 2019.

[10] A. K. Zetzl, A. G. Marangoni, and S. Barbut, "Mechanical properties of ethylcellulose oleogels and their potential for saturated fat reduction in frankfurters," *Food & Function*, vol. 3, no. 3, pp. 327–337, 2012.

[11] Y. Gao, M. Li, L. Zhang, Z. Wang, Q. Yu, and L. Han, "Preparation of rapeseed oil oleogels based on beeswax and its application in beef heart patties to replace animal fat," *LWT-Food Science and Technology*, vol. 149, article 111986, 2021.

[12] S. Guo, M. Song, X. Gao, L. Dong, and Y. Lan, "Assembly pattern of multicomponent supramolecular oleogel composed of ceramide and lecithin in sunflower oil: self-assembly or self-sorting?," *Food & Function*, vol. 11, no. 9, pp. 7651–7660, 2020.

[13] M. Kim, H. S. Hwang, S. Jeong, and S. Lee, "Utilization of oleogels with binary oleogelator blends for filling creams low in saturated fat - ScienceDirect," *LWT-Food Science and Technology*, vol. 155, article 112972, 2022.

[14] X. Yang, T. Gong, D. Li, A. Li, and Y. Guo, "Preparation of high viscoelastic emulsion gels based on the synergistic gelation mechanism of xanthan and konjac glucomannan," *Carbohydrate Polymers*, vol. 226, article 115278, 2019.

[15] K. Zampouni, A. Soniadis, T. Moschakis, C. G. Biliaderis, A. Lazaridou, and E. Katsanidis, "Crystalline microstructure and physicochemical properties of olive oil oleogels formulated with monoglycerides and phytosterols," *LWT-Food Science and Technology*, vol. 154, article 112815, 2022.

[16] X. Zhou, H. Lin, S. Zhu, X. Xu, F. Lyu, and Y. Ding, "Textural, rheological and chemical properties of surimi nutritionally-enhanced with lecithin," *LWT-Food Science and Technology*, vol. 122, article 108984, 2020.

[17] L. Han, L. Li, B. Li et al., "Structure and physical properties of organogels developed by sitosterol and lecithin with sunflower oil," *Journal of the American Oil Chemists' Society*, vol. 91, no. 10, pp. 1783–1792, 2014.

[18] M. T. H. Swe and P. Asavapichayont, "Effect of silicone oil on the microstructure, gelation and rheological properties of sorbitan monostearate-sesame oil oleogels," *Asian Journal of Pharmaceutical Sciences*, vol. 13, no. 5, pp. 485–497, 2018.

[19] L. J. Peltonen and J. Yliruusi, "Surface pressure, hysteresis, interfacial tension, and CMC of four sorbitan monoesters at water-air, water-hexane, and hexane-air interfaces," *Journal of Colloid and Interface Science*, vol. 227, no. 1, pp. 1–6, 2000.

[20] L. Harris, J. Rosen-Kligvasser, and M. Davidovich-Pinhas, "Gelation of oil using combination of different free fatty acids," *Food Structure*, vol. 21, article 100121, 2019.

[21] ISO, *ISO Paper 662: Animal and Vegetable Fats and Oils - Determination of Moisture and Volatile Matter Content*, ISO, Geneva, Switzerland, 2016.

[22] ISO, *ISO Paper 660: Animal and Vegetable Fats and Oils - Determination of Acid Value and Acidity*, ISO, Geneva, Switzerland, 2020.

[23] ISO, *ISO Paper 3960: Animal and Vegetable Fats and Oils - Determination of Peroxide Value - Iodometric (Visual) Endpoint Determination*, ISO, Geneva, Switzerland, 2017.

[24] ISO, *ISO Paper 3961: Animal and Vegetable Fats and Oils - Determination of Iodine Value*, ISO, Geneva, Switzerland, 2018.

[25] ISO, *ISO Paper 1442: Meat and Meat Products - Determination of Moisture Content (Reference Method)*, ISO, Geneva, Switzerland, 1997.

[26] ISO, *ISO Paper 5983-1: Animal Feeding Stuffs - Determination of Nitrogen Content and Calculation of Crude Protein Content - Part 1: Kjeldahl Method*, ISO, Geneva, Switzerland, 2005.

[27] ISO, *ISO Paper 1443: Meat and Meat Products - Determination of Total Fat Content (Reference Method)*, ISO, Geneva, Switzerland, 1973.

[28] ISO, *ISO Paper 936: Meat and Meat Products - Determination of Total Ash*, ISO, Geneva, Switzerland, 1998.

[29] ISO, *ISO Paper 18363-1: Animal and Vegetable Fats and Oils - Determination of Fatty-Acid-Bound Chloropropanediols (MCPDs) and Glycidol by GC/MS*, ISO, Geneva, Switzerland, 2015.

[30] Y. Chen, X. Jia, F. Sun et al., "Using a stable pre-emulsified canola oil system that includes porcine plasma protein hydrolysates and oxidized tannic acid to partially replace pork fat in frankfurters," *Meat Science*, vol. 160, article 107968, 2020.

[31] T.-K. Kim, H.-I. Yong, S. Jung, Y.-B. Kim, and Y.-S. Choi, "Effects of replacing pork fat with grape seed oil and

gelatine/alginate for meat emulsions," *Meat Science*, vol. 163, article 108079, 2020.

[32] X. Wang, Y. Xie, X. Li, Y. Liu, and W. Yan, "Effects of partial replacement of pork back fat by a camellia oil gel on certain quality characteristics of a cooked style Harbin sausage," *Meat Science*, vol. 146, pp. 154–159, 2018.

[33] S. Shibata, M. Furukawa, and K. Goto, "Dual-wavelength spectrophotometry: general method," *Analytica Chimica Acta*, vol. 46, no. 2, pp. 271–279, 1969.

[34] ISO, *ISO Paper 8589: Sensory Analysis-General Guidance for the Design of Test Rooms*, ISO, Geneva, Switzerland, 2007.

[35] C. Alimentarius, "Codex standard for named vegetable oils," *Codex stan*, vol. 210, pp. 1–3, 1999.

[36] M. Moghtadaei, N. Soltanizadeh, and S. A. H. Goli, "Production of sesame oil oleogels based on beeswax and application as partial substitutes of animal fat in beef burger," *Food Research International*, vol. 108, pp. 368–377, 2018.

[37] M. D. Guillén and P. S. Uriarte, "Simultaneous control of the evolution of the percentage in weight of polar compounds, iodine value, acyl groups proportions and aldehydes concentrations in sunflower oil submitted to frying temperature in an industrial fryer," *Food Control*, vol. 24, no. 1-2, pp. 50–56, 2012.

[38] S. C. Chew, "Cold-pressed rapeseed (_Brassica napus_) oil: chemistry and functionality," *Food Research International*, vol. 131, article 108997, 2020.

[39] H. Yang, M. Han, X. Wang et al., "Effect of high pressure on cooking losses and functional properties of reduced-fat and reduced-salt pork sausage emulsions," *Innovative Food Science & Emerging Technologies*, vol. 29, pp. 125–133, 2015.

[40] G. Vu, H. Zhou, and D. J. McClements, "Impact of cooking method on properties of beef and plant-based burgers: appearance, texture, thermal properties, and shrinkage," *Journal of Agriculture and Food Research*, vol. 9, article 100355, 2022.

[41] L. Salcedo-Sandoval, S. Cofrades, C. R.-C. Pérez, M. T. Solas, and F. Jiménez-Colmenero, "Healthier oils stabilized in konjac matrix as fat replacers in n – 3 PUFA enriched frankfurters," *Meat Science*, vol. 93, no. 3, pp. 757–766, 2013.

[42] V. O. de Souto, M. M. F. Santos, D. A. S. Lima et al., "Olive oil-in-water emulsion as a source of desirable fatty acids in free-range "Caipira" chicken ham," *LWT-Food Science and Technology*, vol. 144, article 111216, 2021.

[43] S. Barbut, B. E. Tiensa, and A. G. Marangoni, "Partial fat replacement in liver pate using canola oil organogel," *LWT-Food Science and Technology*, vol. 139, article 110428, 2021.

[44] N. Asuming-Bediako, M. Jaspal, K. Hallett, J. Bayntun, A. Baker, and P. Sheard, "Effects of replacing pork backfat with emulsified vegetable oil on fatty acid composition and quality of UK-style sausages," *Meat Science*, vol. 96, no. 1, pp. 187–194, 2014.

[45] E. Lopez-Huertas, "Health effects of oleic acid and long chain omega-3 fatty acids (EPA and DHA) enriched milks. A review of intervention studies," *Pharmacological Research*, vol. 61, no. 3, pp. 200–207, 2010.

[46] J. López-Miranda, F. Pérez-Jiménez, E. Ros et al., "Olive oil and health: summary of the II international conference on olive oil and health consensus report, Jaen and Cordoba (Spain) 2008," *Nutrition, metabolism and cardiovascular diseases*, vol. 20, no. 4, pp. 284–294, 2010.

[47] K. de Souza, R. Araujo, A. Dos Santos, C. Rodrigues, D. De Faria, and M. Trindade, "Adding value to the meat of spent laying hens manufacturing sausages with a healthy appeal," *Brazilian Journal of Poultry Science*, vol. 13, no. 1, pp. 57–63, 2011.

[48] B. Nacak, B. Öztürk-Kerimoğlu, D. Yıldız, Ö. Çağındı, and M. Serdaroğlu, "Peanut and linseed oil emulsion gels as potential fat replacer in emulsified sausages," *Meat Science*, vol. 176, article 108464, 2021.

[49] A. K. F. I. Câmara, M. M. Ozaki, M. Santos et al., "*Olive oil-based emulsion gels containing chia (_Salvia hispanica_ L.) mucilage delivering healthy claims to low-saturated fat Bologna sausages*," *Structure*, vol. 28, article 100187, 2021.

[50] M. Youssef and S. Barbut, "Fat reduction in comminuted meat products-effects of beef fat, regular and pre-emulsified canola oil," *Meat Science*, vol. 87, no. 4, pp. 356–360, 2011.

[51] D. Camila, D. Guilherme, A. Honório et al., "Functional emulsion gels as pork back fat replacers in Bologna sausage," *Food Structure*, vol. 20, article 100105, 2019.

[52] M. Pérez-Mateos, L. Boyd, and T. Lanier, "Stability of omega-3 fatty acids in fortified surimi seafoods during chilled storage," *Journal of Agricultural and Food Chemistry*, vol. 52, no. 26, pp. 7944–7949, 2004.

[53] E. Morales-Irigoyen, P. Severiano-Pérez, M. Rodriguez-Huezo, and A. Totosaus, "Textural, physicochemical and sensory properties compensation of fat replacing in pork liver pâté incorporating emulsified canola oil," *Food Science and Technology International*, vol. 18, no. 4, pp. 413–421, 2012.

[54] J. M. Lorenzo and D. Franco, "Fat effect on physico-chemical, microbial and textural changes through the manufactured of dry-cured foal sausage lipolysis, proteolysis and sensory properties," *Meat Science*, vol. 92, no. 4, pp. 704–714, 2012.

[55] B. Shan, Y. Z. Cai, J. D. Brooks, and H. Corke, "Antibacterial and antioxidant effects of five spice and herb extracts as natural preservatives of raw pork," *Journal of the Science of Food and Agriculture*, vol. 89, no. 11, pp. 1879–1885, 2009.

[56] F. A. L. de Carvalho, P. E. S. Munekata, A. Lopes de Oliveira et al., "Turmeric (_Curcuma longa_ L.) extract on oxidative stability, physicochemical and sensory properties of fresh lamb sausage with fat replacement by tiger nut (_Cyperus esculentus_ L.) oil," *Food Research International*, vol. 136, article 109487, 2020.

[57] B. Öztürk-Kerimoğlu, H. S. Kavuşan, D. B. Gürel, Ö. Çağındı, and M. Serdaroğlu, "Cold-set or hot-set emulsion gels consisted of a healthy oil blend to replace beef fat in heat-treated fermented sausages," *Meat Science*, vol. 176, article 108461, 2021.