

Article

A Pumpkin Seed Oil and Orange Peel Flour Gelled Emulsion as a Novel Fat Replacer in English Breakfast Sausages: Effects on Composition, Quality, and Sensory Acceptance

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Abstract

The excessive intake of saturated and trans fats is associated with several chronic disorders. Reformulating foods to reduce total and saturated fats has therefore become a global health priority. However, the structural and sensory roles of saturated fats often hinder direct reduction. Oil structuring technologies, such as gelled emulsions, have emerged as effective strategies to replace solid fats with liquid vegetable oils, improving nutritional quality. This study evaluated the effects of partially replacing pork backfat (33% and 66%) with oil-in-water gelled emulsions prepared using pumpkin seed oil and orange peel flour (PS-GE) in English breakfast sausages. Reformulated samples exhibited higher moisture contents, whereas fat and protein levels were reduced compared with the control. Increasing the proportion of PS-GE substitution led to a progressive rise in total unsaturated fatty acids accompanied by a decrease in total saturated fatty acids. Lipid oxidation was not affected by the reformulation in raw sausages. Sensory evaluation confirmed comparable acceptability among all samples, indicating that fat replacement did not negatively influence product quality. Overall, the use of orange peel flour and pumpkin seed oil as a gelled emulsion presents a promising strategy for producing healthier English breakfast sausages with enhanced nutritional profiles and maintained technological and sensory properties.

Keywords: meat product; oil structuring; polyunsaturated fatty acid; functional food; lipid oxidation



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1. Introduction

Several studies have demonstrated the adverse health outcomes associated with saturated and trans fats, linking them to increased concentrations of low-density lipoprotein (LDL) cholesterol, a widely well-known and recognized risk factor for the progression of cardiovascular disease (CVD) development [1] and elevated total serum cholesterol, associated with coronary artery disease risk [2]. Excessive fat consumption has therefore been correlated with a higher incidence of CVD, obesity, hypercholesterolemia, hypertension, coronary heart disease, and other chronic conditions [3,4]. In accordance with guidelines issued by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), the total consumption of dietary fat should be restricted to a maximum of 30% of the overall energy intake in adults, with saturated fatty acids limited to 10%, ideally

replaced by polyunsaturated fatty acids [5]. One of the main problems with a high-calorie intake is overweight and obesity. Obesity has become one of the most pressing global health challenges. The WHO [6] reported that in 2022, 1 in 8 individuals worldwide was obese, and by 2024, approximately 35 million children under five years old presented as overweight. In the European Union, the prevalence of overweight and obesity continues to rise. In 2022, 50.6% of individuals over 16 years were classified as overweight. In Spain, in the same year, 50.4% of adults were overweight, with obesity affecting 16.1% of men and 13.4% of women [7]. These figures emphasize obesity as a leading modifiable risk factor for non-communicable diseases including diabetes, cardiovascular disease, cancer, and neurodegenerative disorders [6]. Reformulating foods to reduce total, trans, and saturated fat content represents a key public health strategy for preventing obesity and diet-related non-communicable diseases [1,5]. However, saturated fatty acids play a critical techno-functional role in food matrices, like meat products. In these types of products, animal fat contributes to flavor, texture, palatability, and mouthfeel. For these reasons, their reduction or removal often compromises product quality and consumer acceptance [4].

Oil structuring has attracted considerable interest as a strategy to replace solid fats with liquid oils, enabling the development of healthier food formulations while addressing the techno-functional limitations associated with saturated fatty acids [4,8]. Among these strategies, the use of gelled emulsions (GEs) represents a promising approach to overcoming challenges such as altered flavor, texture, appearance, and oxidative stability. GEs are valued for their desirable solid-like mechanical properties, high physico-chemical stability, and safety, allowing them to effectively mimic the textural attributes and oral sensory properties of animal fats [9]. Structurally, GEs consist of oil droplets dispersed within a three-dimensional network formed by hydrocolloids such as polysaccharides or proteins, which act as emulsifiers or matrices for the lipid phase. This hybrid structure provides a stable, fat-like system that can reduce total fat and caloric content, contributing to lower saturated fatty acid intake and improved nutritional quality [9,10]. The selection of structuring agents is based on their gelling, emulsifying, and water- and fat-binding capacities, as well as their nutritional value [10].

Fruit-derived ingredients are rich in dietary fiber and function as effective gelling and emulsifying agents [11]. From a sustainability perspective, agro-industrial coproducts represent abundant sources of hydrocolloids with functional properties that can be enhanced by physical treatments [9]. Considering this, Spain is one of the leading orange producers in Europe. A percentage of the harvest is intended for juice production, which results in a significant number of byproducts, predominantly consisting of skin. The skin of the orange is a significant source of dietary fiber, especially cellulose, hemicellulose, and pectin, among other components [12]. Due to this composition, orange peel represents a promising ingredient to be used as an emulsifier agent, which can be obtained quickly, efficiently, and through environmentally friendly processes.

On the other hand, vegetable oils are widely used in GE formulations as healthier alternatives to animal fats, offering improved lipid profiles and additional health benefits [9,13,14]. However, oil type strongly influences oxidative stability and sensory characteristics [4]. Pumpkin seed oil is abundant in unsaturated fatty acids and valuable bioactive compounds, including phytosterols, squalene, carotenoids, and tocopherols, contributing to anti-inflammatory, antioxidant, and cytoprotective effects [15,16]. Overall, the use of GEs formulated with functional structuring agents and bioactive-rich vegetable oils represents a promising strategy to reduce saturated fat content and develop functional foods with potential health-promoting effects [17]. Therefore, the aim of the present study was to evaluate the effect on the chemical composition, fatty acid profile, physico-chemical properties, lipid oxidation, and sensory attributes of English breakfast sausages where the

animal fat was incompletely replaced using a gelled emulsion made of pumpkin seed oil in combination with orange peel flour.

2. Materials and Methods

2.1. Materials

The following ingredients were used in the gelled emulsions: Pumpkin seed oil (51.96% linoleic acid, 28.83% oleic acid, 12.32% palmitic acid, 5.50% stearic acid, and 1.39% others) distributed by Martinez-Lozano S.L. (Murcia, Spain) was used; lyophilized orange peel flour obtained from orange (*Citrus x sinensis* cultivar 'Navel Lane Late') fruits were procured at the commercial maturity stage from the experimental field facility belonging to Miguel Hernandez University, located in Orihuela, Spain. Gelatin derived from porcine source (240 Bloom strength) was obtained from Mondelez S.L. (Madrid, Spain).

The required meat components (pork backfat and pork meat) were purchased from a local butchery in Orihuela (Spain), and spices and additives were provided by Suministros River S.L.U. (Orihuela, Spain).

2.2. Gelled Emulsion Elaboration

The gelled emulsion (PS-GE) was prepared using the following ingredients: water (48%), pumpkin seed oil (40%), gelatin (6.5%), orange peel flour (5%), and salt (0.5%). The preparation method used for the gelled emulsion elaboration was conducted according to the process described below. Briefly, 80% of the total water required was heated to 60 °C to dissolve the amount of gelatin needed to produce PS-GE. Therefore, the other 20% of water was used to dissolve the amount of salt required. Once both substances were dissolved and mixed into the water, the mixture was poured over orange peel flour and homogenized by blending. Pumpkin seed oil was gradually added to the homogeneous mixture. PS-GE with the following properties was obtained: The pH of the system was 4.9 ± 0.06 , while emulsion stability reached $97.01 \pm 1.27\%$. Regarding color properties, the L^* , a^* , b^* , C^* , and h^* values were 67.23 ± 3.09 , -1.60 ± 0.62 , 28.94 ± 3.13 , 14.66 ± 1.23 , and 72.18 ± 2.23 , respectively. Once PS-GE was obtained, it was refrigerated and stored at 4 °C until its use.

2.3. Elaboration of English Breakfast Sausages

English breakfast sausages were formulated using a conventional recipe, incorporating 588.00 g/kg of pork meat (70.18% moisture, 25.78% protein, 3.34% lipids, and 0.70% ash), 205.00 g/kg of pork backfat (85.60% lipids, 3.01% proteins, 11.08% moisture, and 0.31% ash), ice (134.50 g/kg), breadcrumbs (57.50 g/kg), salt (7.16 g/kg), yeast extract (1.35 g/kg), spices (5.18 g/kg), tripolyphosphate (0.50 g/kg), potassium metabisulphite (0.63 g/kg), and sodium ascorbate (0.19 g/kg). This original mixture was used as a control sample, while to evaluate the influence of pork backfat replacement, 2 formulations were developed (Table 1), with 33% (ESGE33) and 66% (ESGE66) pork backfat substitution by PS-GE.

Table 1. Formulations of control English breakfast sausage and sausages with partial replacement of pork backfat with gelled emulsion elaborated with pumpkin seed oil and orange peel flour.

	CT	ESGE33	ESGE66
Pork meat	588.00	588.00	588.00
Pork backfat	205.00	136.70	68.30
PS-GE	0	68.30	136.70
Ice	134.50	134.50	134.50
Breadcrumbs	57.50	57.50	57.50
Tripolyphosphate	0.50	0.50	0.5
Salt	7.16	7.16	7.16

Table 1. *Cont.*

	CT	ESGE33	ESGE66
Yeast extract	1.35	1.35	1.35
White pepper	1.04	1.04	1.04
Mace	0.94	0.94	0.94
Nutmeg	0.85	0.85	0.85
Dill	0.75	0.75	0.75
Oregano	0.75	0.75	0.75
Potassium metabisulphite	0.63	0.63	0.63
Sweet paprika	0.47	0.47	0.47
Ginger	0.38	0.38	0.38
Sodium ascorbate	0.19	0.19	0.19

PS-GE: pumpkin seed oil and orange peel flour gelled emulsion; CT: control English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. Amounts expressed as g/kg of product.

The English breakfast sausages were elaborated in the food pilot plant of Miguel Hernández University in the Polytechnic School of Orihuela (Orihuela, Alicante, Spain). For this process, the meat materials and gelled emulsion required for each formulation were weighed and mixed with salt. After that, ice and breadcrumbs were added, and the mixture was stirred again. Finally, sodium tripolyphosphate and spices were added. The mixture was placed into a sausage stuffer to fill an artificial collagen casing 22 mm in diameter. The resultant sausage batches were stored under refrigerated conditions (4 °C) until their subsequent testing. For the analyses carried out in the cooked samples, the English breakfast sausages were baked at 180 °C for 10 min.

2.4. Chemical Composition

The content of ash, fat, moisture, and protein was quantified in both raw and cooked samples according to the established AOAC official methods [18]. All assays were taken on three samples of each formulation. Chemical composition parameters were determined based on three sample replicates.

2.5. Fatty Acid Composition, Health Indices, and Nutritional Parameters

Lipid extraction was performed based on Folch et al. [19] using raw and cooked English breakfast sausage batches. Subsequently, the extracted fatty acids were transesterified following the method reported by Pellegrini et al. [20]. The results regarding fatty acid methyl ester (FAME) composition were expressed as g/100 g of total fat. The nutritional indices refer to the sum of total saturated fatty acids (SFAs), polyunsaturated fatty acids (PUFAs), monounsaturated fatty acids (MUFAs), and the specific quantities of omega 3 (n-3) and omega 6 (n-6) fatty acids. The PUFA-SFA content and n-6/n-3 ratios were determined, as well as the atherogenicity index (AI) (Equation (1)) and the index of thrombogenicity (TI) (Equation (2)). The hypocholesterolemic/hypercholesterolemic ratio (h/H) (Equation (3)) was calculated as described by Chen and Liu [21].

$$AI = \frac{C12 : 0 + (4x C14 : 0) + C16 : 0}{\sum MUFA + \sum n-6 + \sum n-3} \quad (1)$$

$$TI = \frac{C14 : 0 + C16 : 0 + C18 : 0}{(\frac{1}{2}x \sum MUFA) + (\frac{1}{2}x \sum n-6) + (3x \sum n-3) + \frac{\sum n-3}{\sum n-6}} \quad (2)$$

$$\frac{h}{H} = \frac{C18 : 1n9 + C18 : 1n7 + \sum PUFA}{(C14 : 0 + C16 : 0)} \quad (3)$$

2.6. Physico-Chemical Analysis

The pH of English breakfast sausages was measured with a Crison micro pH-meter model GLP 21 (Crison Instrument S.A., Barcelona, Spain) using a penetrating electrode. Water activity was determined using a Novasina TH-500 analyzer (Novasina, Axair LTD., Pfaeffikon, Switzerland) at 25 °C. Color was assessed on both surface and interior areas with a Minolta spectrophotometer model CM-700 (Konica Minolta Sensing, Inc., Tokyo, Japan) under D65 illumination and a 10° observer angle. CIEL*a*b* coordinates (L^* , a^* , b^*) were recorded, from which chroma (C^*) and hue angle (h^*) were calculated with Equations (4) and (5). Total color differences (ΔE) relative to the control were determined using Equation (6).

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}. \quad (4)$$

$$h^* = \tan^{-1} b^* / a^*. \quad (5)$$

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}. \quad (6)$$

2.7. Cooking Loss

For each formulation of English breakfast sausage, the sample weights were determined at room temperature prior to and following the cooking process. After preparation, the samples were maintained at room temperature for 15 min to ensure thermal equilibration prior to analysis. Cooking loss was quantified using Equation (7). All analyses were conducted in triplicate for every formulation.

$$\% \text{ Cooking loss} = \frac{\text{raw weight} - \text{cooked weight}}{\text{raw weight}} \times 100. \quad (7)$$

2.8. Texture Analysis

The texture of each sample was evaluated using a TA-XT2i texture analyzer (Stable Micro Systems, Surrey, UK). To carry out this evaluation, five 1 cm thick sections of each sample were subjected to dual compression cycles at 75% deformation at a speed of 1 mm/s with a 10 g trigger force. A recovery interval of 5 s was introduced between the two compressions to allow for the restoration of the sample structure. The entire assessment was performed under controlled conditions at a temperature of 18 ± 2 °C. From the yielded force–time deformation curves obtained, six parameters were calculated: hardness, adhesiveness, elasticity, cohesiveness, chewiness, and resilience [22]. Texture parameters were determined from five sample replicates per formulation.

2.9. Lipid Oxidation

Lipid oxidation in English breakfast sausage samples was assessed using the thiobarbituric acid reactive (TBARS) assay, with malondialdehyde (MDA) extraction performed according to the procedure described by Rosmini et al. [23]. The results were expressed as milligrams of MDA per kilogram of sample. Each batch was analyzed in triplicate.

2.10. Sensory Assessment

The sensory evaluation of the English breakfast sausage samples was conducted using a hedonic test the day after processing each batch. For this, seventy-five panelists (20–65 years old) were recruited from staff and students at the Polytechnic School of Orihuela (Miguel Hernández University). Prior to the assessment, every participant was fully briefed on the attributes of the product and the specific evaluation procedure. Participation was voluntary, and written consent was secured from all subjects. Ethical clearance for this study was granted by the Responsible Research Office (OIR) of Miguel Hernández

University (Reference: PRL.DTA.MVM.02.22; Registration: OIR-Reg. 221028120554, UMH, Elche, Alicante, Spain). The sensory test was conducted within the designated tasting laboratory at the Miguel Hernández University. The breakfast sausages were cooked in a convection oven (Balay Activa 505, BSH Electrodomésticos España SA, Pamplona, Spain) at 180 ± 2 °C until a final internal temperature of 72 ± 2 °C was reached. Each evaluator received three 2 cm slices (one representing each experimental treatment). These samples were presented in a randomized sequence and identified using three-digit random codes. Water was provided and consumed between samples to rinse the palate. Panelists rated color, odor, hardness, juiciness, oily sensation, and general overall acceptance using a 9-point hedonic scale (ranging from 1 = dislike extremely to 9 = like extremely).

2.11. Statistical Analysis

The process, the development of the pumpkin seed oil emulsion (PS-GE), and the preparation of English breakfast sausages were repeated on three separate occasions (three distinct batches). Each of these batches was processed on a different day to account for day-to-day variability. Furthermore, all chemical and analytical measurements were executed in triplicate. Data processing was conducted using SPSS software (version 27.0, SPSS Inc., Chicago, IL, USA), selecting a one-way analysis of variance (ANOVA) for physico-chemical and sensory analyses and a two-way analysis of variance (ANOVA) for chemical composition, lipid profile, and lipid oxidation analyses. Mean differences were further investigated using the Tukey-b post hoc test, with statistical significance set at a 5% level ($p < 0.05$).

3. Results and Discussion

3.1. Proximal Composition of English Breakfast Sausages

The results of the assessment of the chemical composition of the control and the reformulated English breakfast sausages with a pumpkin seed oil and orange peel flour gelled emulsion as an incomplete animal fat replacer are shown in Table 2. In raw samples, English breakfast sausage with 66% PS-GE (ESGE66) had the highest values ($p < 0.05$) for moisture compared to the English breakfast sausage control sample (CT) and English breakfast sausage with 33% PS-GE (ESGE33). The moisture values varied between 66.73 and 64.36 g/100 g of sample. This increase in moisture may be due to the addition of water in the process of elaborating the gelled emulsion. Nevertheless, in cooked samples, the moisture results showed no differences ($p > 0.05$). This trend for cooked sausages could be due to water redistribution and structural stabilization during cooking. Protein denaturation and gelation in both the meat matrix and the PS-GE system promote the formation of a cohesive network capable of retaining structural water across all formulations [24,25]. In addition, orange peel flour, due to the content of pectin that showed a high water retention capacity, as well as denatured proteins could contribute to the balance between water released from meat and fat tissues and its subsequent absorption by the matrix [26,27]. In raw English breakfast sausage, the increase in moisture content was not accompanied by a significant reduction ($p > 0.05$) in fat content when PS-GE was used, as could be expected. In contrast to other studies in which fat replacement in meat products using gelled emulsions has been reported, such as those by Botella-Martínez et al. [12] and Zampouni et al. [28], a decrease in fat content was observed as the level of replacement increased. On the other hand, in cooked samples, fat reduction reached approximately 18.7% and 36.38% in ESGE33 and ESGE66, respectively, compared to the CT sample. These findings agree with those reported by Badar et al. [29], Ren et al. [10], and Botella-Martínez et al. [30], who also observed reduced fat contents in meat products where pork backfat was partially or totally replaced with gelled emulsions formulated with several vegetable oils. Regarding

protein content, in cooked English breakfast sausages, it decreased with an increase in fat replacement by PS-GE, showing significant differences ($p < 0.05$) between reformulated samples and the control sample. The protein values obtained were comparable to those stated by Thangavelu et al. [31], Lee et al. [32], and Morin et al. [33], showing the wide variability in fresh sausage formulations available on the market. The differences in protein content among the cooked samples may result from heat-induced modifications in the meat protein matrix and the variable retention of water and fat during cooking. In formulations where fat was partially replaced with a gelled emulsion, this altered structure can modify water- and fat-binding capacities [32,34]. Consequently, although the total protein content in the raw mixtures was similar ($p > 0.05$), the extent of moisture loss and matrix contraction after heating likely caused apparent differences in protein concentration, reflecting the distinct thermophysical behaviors of each formulation [35,36]. Regarding the ash content of raw and cooked English breakfast sausages, no statistically significant differences ($p > 0.05$) were found between the samples analyzed. In this study, heat treatment affected the overall composition of the samples. As observed for moisture, fat content decreased ($p > 0.05$) compared with the corresponding raw samples. In contrast, protein and ash contents increased ($p > 0.05$) after cooking, likely due to concentration effects associated with moisture loss (Table 2).

Table 2. Chemical composition of raw and cooked control English breakfast sausages and sausages with partial replacement of pork backfat with gelled emulsion elaborated with pumpkin seed oil and orange peel flour.

Sample	RAW			COOKED		
	CT	ESGE33	ESGE66	CT	ESGE33	ESGE66
Fat	13.44 ± 1.04 ^{aA}	13.99 ± 1.47 ^{aA}	12.49 ± 0.99 ^{aA}	10.80 ± 1.00 ^{xB}	8.78 ± 0.50 ^{xyB}	6.87 ± 0.87 ^{yB}
Protein	16.91 ± 0.14 ^{aB}	16.08 ± 1.76 ^{aB}	17.09 ± 1.02 ^{aB}	26.60 ± 0.16 ^{xA}	22.78 ± 0.74 ^{yA}	23.17 ± 0.28 ^{yA}
Ash	1.11 ± 0.58 ^{aB}	0.79 ± 0.18 ^{aB}	0.75 ± 0.11 ^{aB}	2.04 ± 0.07 ^{xA}	2.09 ± 0.09 ^{xA}	2.22 ± 0.08 ^{xA}
Moisture	64.36 ± 0.66 ^{bA}	64.68 ± 0.28 ^{bA}	66.73 ± 0.69 ^{aA}	54.78 ± 0.19 ^{xB}	55.83 ± 0.12 ^{xB}	54.93 ± 1.13 ^{xB}

Values are expressed as g/100 g of sample. CT: control English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. For each group, values followed by same lowercase letter within same row (raw: a, b; cooked: x, y) are not significantly different ($p > 0.05$), and uppercase letters in same row (A, B) compare same property for same sample but with different treatments (raw or cooked) according to Tukey's multiple range test.

3.2. Lipid Profile and Nutritional Indices of English Breakfast Sausages

The major fatty acids and calculated health indices of both raw and cooked English breakfast sausages (CT, ESGE33, and ESGE66) are presented in Table 3. The reformulation of the sausages markedly improved their fatty acid composition. In raw samples, the control formulation (CT) exhibited significantly higher ($p < 0.05$) levels of saturated fatty acids, particularly palmitic (C16:0) and stearic acids (C18:0), as well as greater concentrations of the monounsaturated fatty acid oleic acid (C18:1 n9). As pumpkin seed oil was incorporated into the gelled emulsion, its lipid profile was reflected in the ESGE33 and ESGE66 formulations, leading to a pronounced increase in linoleic acid (C18:2 n6) from 11.07 g/100 g of fat in the control sample to 34.95 g/100 g of fat in the ESGE66 sample. Reformulation significantly reduced ($p < 0.05$) the total saturated fatty acid content from 38.15 g/100 g of fat in CT to 25.68 g/100 g of fat in ESGE66, mainly due to the lower proportions of palmitic and stearic acids. Similarly, monounsaturated fatty acids decreased ($p < 0.05$) from 48.74 to 38.34 g/100 g of fat, reflecting the reduction in oleic acid in the reformulated samples. Conversely, the polyunsaturated fatty acid fraction increased substantially ($p < 0.05$), rising from 12.74 to 36.04 g/100 g of fat between CT and ESGE66. This pattern aligns with previous studies reporting that the substitution of animal fat with gelled emulsions containing healthy oils results in a marked decrease in saturated and monounsaturated fatty acids,

accompanied by a notable increase in polyunsaturated fatty acids. A similar trend was observed in the cooked sausages, where the proportions of saturated and monounsaturated fatty acids declined significantly ($p < 0.05$) from 36.13 and 49.19 g/100 g of fat in CT to 31.31 and 42.67 g/100 g of fat in ESGE66, respectively. In contrast, the polyunsaturated fatty acid content rose ($p < 0.05$) from 14.32 to 26.06 g/100 g of fat as the level of PS-GE substitution increased. These results agree with previous studies reporting that replacing animal fat in meat products with gelled emulsions containing healthy oils improves the nutritional index. Thus, Cîrstea et al. [37] reported that pork patties, where the animal fat was substituted with an emulsion composed of olive, chia, and algal oils, were stabilized by soy protein isolate and either gelatin or chitosan. These improvements included a reduced saturated fatty acid (SFA) content and n-6/n-3 ratios, alongside an increased long-chain polyunsaturated fatty acid (PUFA) content, when compared to control samples. In a similar study, de Brito sodré et al. [38] made modifications to the fatty acid profile where an açai oil and guar gum-based emulsion gel was incorporated at different levels (25%, 50%, 75%, and 100%) in goat meat burgers. This replacement led to an SFA decrease ranging from 17.80% to 58.71%, while the PUFA content increased between 4.16% and 50%.

Table 3. Fatty acid profile and health indices of raw and cooked control English breakfast sausages and sausages with partial replacement of pork backfat with gelled emulsion elaborated with pumpkin seed oil and orange peel flour.

Fatty Acid	RAW			COOKED		
	CT	ESGE33	ESGE66	CT	ESGE33	ESGE66
C16:0	23.33 ± 0.33 ^{aA}	19.32 ± 0.95 ^{bA}	16.44 ± 0.26 ^{cB}	22.43 ± 0.89 ^{xA}	20.78 ± 0.29 ^{xyA}	18.96 ± 0.05 ^{yA}
C16:1	2.38 ± 0.13 ^{aA}	1.58 ± 0.21 ^{bB}	0.97 ± 0.07 ^{aB}	2.30 ± 0.15 ^{xA}	1.89 ± 0.04 ^{xyA}	1.54 ± 0.00 ^{yA}
C18:0	12.23 ± 0.13 ^{aA}	9.81 ± 0.98 ^{bA}	7.91 ± 0.35 ^{cB}	11.66 ± 0.33 ^{xA}	10.31 ± 0.06 ^{yA}	9.35 ± 0.01 ^{zA}
C18:1	45.56 ± 0.03 ^{aA}	40.50 ± 1.73 ^{bA}	36.75 ± 1.62 ^{cB}	45.95 ± 0.50 ^{xA}	42.64 ± 0.56 ^{yA}	41.56 ± 0.20 ^{zA}
C18:2 (n6,9)	11.07 ± 0.36 ^{cA}	24.62 ± 2.80 ^{bA}	34.95 ± 1.82 ^{aA}	12.66 ± 1.37 ^{zA}	19.96 ± 0.11 ^{yA}	24.58 ± 0.04 ^{xB}
ΣSFA	38.15 ± 0.31 ^{aA}	30.97 ± 1.50 ^{bB}	25.68 ± 0.49 ^{cB}	36.13 ± 0.95 ^{xB}	34.66 ± 0.31 ^{yA}	31.31 ± 0.04 ^{zA}
ΣUFA	61.85 ± 0.31 ^{cB}	68.84 ± 1.31 ^{bA}	74.30 ± 0.51 ^{aA}	63.70 ± 0.76 ^{zA}	65.34 ± 0.31 ^{yB}	68.68 ± 0.05 ^{xB}
ΣMUFA	48.74 ± 0.25 ^{aA}	42.98 ± 1.28 ^{bA}	38.34 ± 1.10 ^{cB}	49.19 ± 0.64 ^{xA}	43.94 ± 0.35 ^{yA}	42.67 ± 0.20 ^{zA}
ΣPUFA	12.74 ± 0.37 ^{cB}	25.97 ± 2.77 ^{bA}	36.04 ± 1.75 ^{aA}	14.32 ± 1.29 ^{zA}	21.46 ± 0.09 ^{yB}	26.06 ± 0.11 ^{xB}
Σn-3	0.64 ± 0.02 ^{aA}	0.54 ± 0.01 ^{bA}	0.44 ± 0.01 ^{cA}	0.62 ± 0.02 ^{xA}	0.58 ± 0.00 ^{yB}	0.60 ± 0.05 ^{xyB}
Σn-6	11.07 ± 0.36 ^{cA}	24.62 ± 2.80 ^{bA}	34.95 ± 1.82 ^{aA}	12.66 ± 1.37 ^{zA}	19.96 ± 0.11 ^{yB}	24.58 ± 0.04 ^{xB}
Health indices						
Σn-3/Σn-6	0.06 ± 0.01 ^{aA}	0.02 ± 0.00 ^{bA}	0.01 ± 0.00 ^{cB}	0.05 ± 0.01 ^{xA}	0.03 ± 0.00 ^{yB}	0.02 ± 0.00 ^{zA}
ΣPUFA/ΣSFA	0.33 ± 0.09 ^{cA}	0.83 ± 0.10 ^{bA}	1.40 ± 0.05 ^{aA}	0.39 ± 0.09 ^{zB}	0.62 ± 0.03 ^{yB}	0.83 ± 0.07 ^{xB}
AI	0.49 ± 0.01 ^{aA}	0.35 ± 0.02 ^{bB}	0.26 ± 0.01 ^{cB}	0.45 ± 0.02 ^{xB}	0.40 ± 0.01 ^{yA}	0.34 ± 0.00 ^{zA}
TI	1.17 ± 0.02 ^{aA}	0.85 ± 0.06 ^{bB}	0.66 ± 0.02 ^{cB}	1.09 ± 0.04 ^{xB}	0.96 ± 0.01 ^{yA}	0.83 ± 0.00 ^{zA}
h/H	2.33 ± 0.04 ^{cB}	3.26 ± 0.20 ^{bA}	4.25 ± 0.09 ^{aA}	2.52 ± 0.11 ^{zA}	2.91 ± 0.04 ^{yB}	3.38 ± 0.01 ^{xB}

Values are expressed as g/100 g of fat. CT: control English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. For each group, values followed by same lowercase letter within same row (raw: a–c; cooked: x–z) are not significantly different ($p > 0.05$), and uppercase letters in same row (A, B) compare same fatty acid, summary, or index for same sample but with different treatments (raw or cooked) according to Tukey's multiple range test.

Regarding the health indices (Table 3), in the raw sausages, the partial pork backfat replacement of animal fat by a gelled emulsion elaborated with pumpkin seed oil and orange peel flour had a significant effect ($p < 0.05$) on ΣPUFA/ΣSFA and the hypocholesterolemic/hypercholesterolemic ratios, as well as the atherogenicity and thrombogenicity indices. The ΣPUFA/ΣSFA ratio in the ESGE33 and ESGE66 raw sausages was 0.33 and 0.83, respectively, while in CT, it was 1.40. These results are consistent with the current recommendations by Heck et al. [39] with the ΣPUFA/ΣSFA ratio being higher than 0.4 for English breakfast reformulation. Similarly, the h/H ratio increased in the

reformulated samples with respect to CT. Barros et al. [40] reported that higher hypocholesterolemic/hypercholesterolemic ratios denote healthier meat products than those with lower ratios. The atherogenic and thrombogenic indices (AI and TI) decreased for reformulated sausages, with significant differences ($p < 0.05$) compared to the control sample. The AI decreased by about 28.6% and 46.9% in ESGE33 and ESGE66, respectively, while the TI fell to about 27.3% and 43.6% in ESGE33 and ESGE66 with respect to CT. Meat products with low atherogenicity and thrombogenicity indices may have reduced platelet aggregation and lower esterified fatty acid, cholesterol, and phospholipid levels, thus decreasing cardiovascular disease risk [41]. In cooked sausages (Table 3), a similar trend was observed, although the changes were less pronounced. Reformulated samples showed lower atherogenicity and thrombogenicity, while the Σ PUFA/ Σ SFA and h/H ratios increased in ESGE33 and ESGE66 compared with the control (CT). The results obtained were in agreement with those reported by Stamenić et al. [42], who mentioned that the replacement of pork backfat in chicken Frankfurters by emulsion gels elaborated with linseed, walnut, or algal oil significantly enhanced the atherogenic and thrombogenic indices and increased hypocholesterolemic/hypercholesterolemic ratios. Similarly, Idyryshev et al. [43] reported that replacing beef fat with a structured emulsion gel (based on pine nut oil, inulin, carrageenan, and whey protein concentrate) in bologna sausages yielded a PUFA/SFA ratio of 1.00 and reduced the atherogenic and thrombogenic indices by over 80%.

3.3. Physico-Chemical Properties of English Breakfast Sausages

Variations in the lipid systems used during reformulation, such as gelled emulsions, can induce significant modifications in the physico-chemical properties of meat products. Table 4 summarizes the physico-chemical properties of raw English breakfast sausages elaborated with a pumpkin seed oil and orange peel flour gelled emulsion as a partial pork backfat replacer. In the present study, neither pH nor water activity (a_w) was significantly affected by replacement level ($p > 0.05$). Similar trends have been reported in previous studies on fresh or breakfast-type sausages reformulated with oil-based gels or emulsions, which generally maintain the balance and water-binding capacity of the product matrix [32,44]. Typical pH values for traditional breakfast sausages range between 4.76 and 6.30, while those of reformulated versions generally increase within 6.1–6.3 depending on the oil and hydrocolloid used [35]. The water activity values obtained in the present work (0.964–0.975) were consistent with those reported for other fresh sausages and emulsified meat products (0.94–0.98), confirming that the gelled emulsion did not compromise microbial stability or product.

Color is among the most critical quality attributes of food products, as it strongly influences consumer perception, acceptance, and purchasing decisions. The instrumental color parameters of raw sausages are presented in Table 4. Significant differences ($p < 0.05$) were observed in the external color of the samples when pork backfat was partially replaced by PS-GE. Control sausages exhibited higher lightness (L^*) and yellowness (b^*) values than those of ESGE33 and ESGE66, whereas redness (a^*) was significantly reduced only in ESGE66 compared with the control. Internally, this trend was partially reversed; reformulated sausages displayed slightly higher L^* values and hue angle (h^*) but similar a^* , b^* , and C^* values. The total color difference (ΔE^*) relative to the control was also calculated to evaluate perceptible changes. According to Martínez et al. [45], $\Delta E^* > 3$ indicates a difference visible to the human eye. In this study, both the ESGE33 and ESGE66 formulations exhibited external and internal ΔE^* values exceeding this threshold, indicating a noticeable change in appearance that could potentially influence consumer acceptability. Comparable effects have been reported in reformulated pork and poultry sausages where the partial replacement of backfat produced slightly darker and less reddish products [27,46].

Table 4. Physico-chemical properties of raw control English breakfast sausages and sausages with partial replacement of pork backfat with gelled emulsion elaborated with pumpkin seed oil and orange peel flour.

	CT	ESGE33	ESGE66
pH	5.50 ± 0.04 ^a	5.40 ± 0.06 ^a	5.41 ± 0.04 ^a
Aw	0.964 ± 0.023 ^a	0.975 ± 0.003 ^a	0.973 ± 0.003 ^a
External color			
L*	56.32 ± 5.38 ^a	49.83 ± 3.93 ^b	51.79 ± 3.93 ^b
a*	4.14 ± 0.94 ^a	3.55 ± 1.28 ^{ab}	3.11 ± 1.12 ^b
b*	14.97 ± 3.72 ^a	12.18 ± 2.48 ^b	11.01 ± 1.93 ^b
C*	11.62 ± 2.03 ^b	12.61 ± 2.52 ^b	15.56 ± 3.74 ^a
h*	72.17 ± 5.48 ^b	75.66 ± 4.78 ^a	74.20 ± 2.90 ^{ab}
ΔE*	-	7.14 ± 1.59 ^a	6.15 ± 0.98 ^a
Internal color			
L*	47.72 ± 2.99 ^b	54.72 ± 4.59 ^a	51.61 ± 5.59 ^{ab}
a*	3.83 ± 1.03 ^a	2.86 ± 1.24 ^a	2.78 ± 1.13 ^a
b*	12.78 ± 2.02 ^a	16.07 ± 4.32 ^a	15.67 ± 4.26 ^a
C*	13.35 ± 2.16 ^a	16.37 ± 4.28 ^a	15.67 ± 4.26 ^a
h*	73.50 ± 3.21 ^b	79.39 ± 4.75 ^a	78.63 ± 5.04 ^a
ΔE*	-	7.56 ± 2.03 ^a	4.49 ± 0.74 ^b

CT: control English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. Values followed by same lowercase letter (a, b) within same row are not significantly different ($p > 0.05$) according to Tukey's multiple range test.

The texture profile analysis (TPA) results of cooked English breakfast sausages are shown in Table 5. The partial replacement of pork backfat by PS-GE resulted in significant decreases ($p < 0.05$) in hardness, chewiness, and resilience compared with the control formulation, whereas springiness did not differ significantly ($p > 0.05$) among treatments. The reduction in hardness and related parameters in fresh sausages reformulated with various hydrogels or gelled emulsions agrees with that reported by Martínez et al. [47], who demonstrated a reduction in textural parameter values in fresh deer sausage where pork backfat was replaced (50%, 75%, and 100%) by emulsified chia, poppy, melon, or pumpkin oil, and by Badar et al. [48] in beef burgers, where fat content was replaced using a high-internal-phase Pickering emulsion produced with flaxseed-derived diglycerides. This behavior can be explained by two main factors. Firstly, the chemical composition of the resulting meat matrix differed, particularly in terms of its protein, moisture (higher), and fat (lower) proportions. Secondly, variations in the physico-chemical characteristics between pork backfat and the gelled emulsion also contributed to these textural differences [46]. Cohesiveness followed a different pattern, with ESGE66 showing a statistically lower value ($p < 0.05$) than CT, while ESGE33 did not differ significantly ($p > 0.05$).

Table 5. Textural properties of cooked control English breakfast sausages and sausages with partial replacement of pork backfat with gelled emulsion elaborated with pumpkin seed oil and orange peel flour.

Sample	CT	ESGE33	ESGE66
Hardness (N)	65.94 ± 4.76 ^a	49.64 ± 11.22 ^b	43.38 ± 5.56 ^b
Springiness	0.25 ± 0.01 ^a	0.24 ± 0.04 ^a	0.28 ± 0.14 ^a
Cohesiveness	0.35 ± 0.07 ^a	0.28 ± 0.08 ^{ab}	0.20 ± 0.02 ^b
Chewiness	5.91 ± 0.69 ^a	3.04 ± 1.30 ^b	2.58 ± 0.53 ^b
Resilience	0.12 ± 0.03 ^a	0.09 ± 0.02 ^b	0.06 ± 0.01 ^b

CT: control English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. Values followed by same lowercase letter (a, b) within same row are not significantly different ($p > 0.05$) according to Tukey's multiple range test.

3.4. Cooking Loss of English Breakfast Sausages

The cooking process induces both lipid displacement and moisture reduction in the samples. It is important to note that the magnitude of these alterations may ultimately impact product acceptance [49]. The English breakfast sausages were cooked at 180 °C in an oven, and then cooking loss was evaluated. Figure 1 exhibits the cooking loss values for the control (CT) and reformulated (ESGE33 and ESGE66) sausages, which incorporated a gelled emulsion of pumpkin seed oil and orange peel flour as a partial substitute for pork backfat replaced by non-meat components, most commonly dietary fibers.

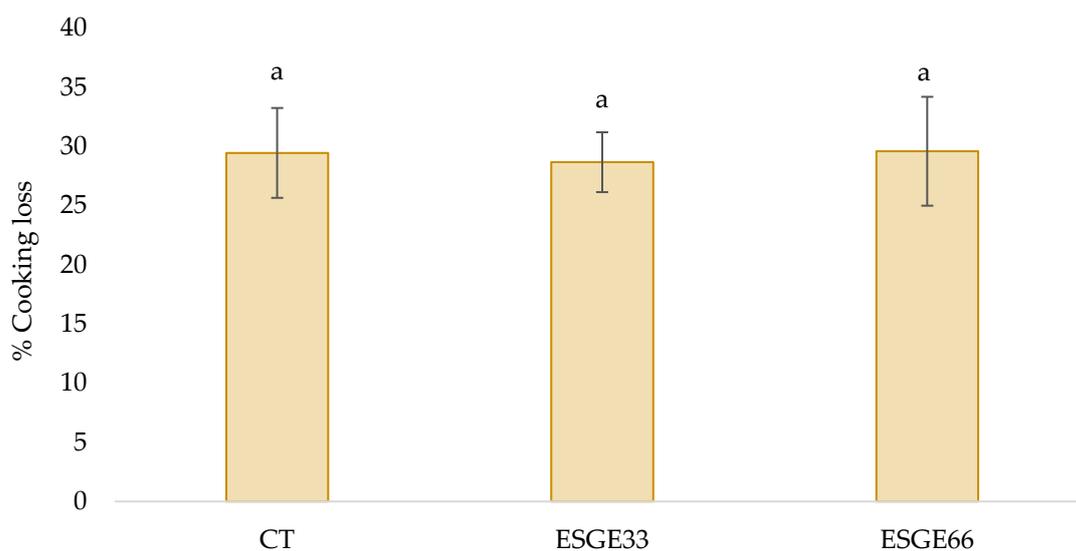


Figure 1. Result of cooking loss of English breakfast sausages with pumpkin seed oil as partial animal fat replacer. CT: control English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. Bars with same lowercase letter are not significantly different ($p > 0.05$) according to Tukey's multiple range test.

All sausage samples showed similar cooking loss without statistical differences between them ($p > 0.05$) with values around 29–30%. So, the incorporation of PS-GE to substitute pork backfat in English breakfast sausage does not negatively affect this parameter. The observed variations could be explained by the balance between the release of melted fat and the evaporation or exudation of water during thermal processing. Cooking losses among treatments can be explained by compensatory mechanisms between these two phenomena. This agrees with previous reports indicating that structured emulsions improved the stability of the protein matrix and reduced moisture and fat exudation during cooking [50]. Nevertheless, this parameter is frequently analyzed in meat products where animal fat is fully or partially replaced.

Reports in the scientific literature indicate that the effect of dietary fibers on cooking loss can vary considerably. For instance, Pietrasik and Soladoye [44] reported between 18.5% and 32.1% cooking loss in breakfast sausages formulated with 26% pork backfat for the high-fat formulation and breakfast sausage with low fat (13% pork backfat) with pea starch as the binder. Conversely, de Araujo et al. [51] found much lower values (approximately 2.32%) in fresh chicken sausages where animal fat was completely replaced by inulin. Comparable findings were also presented by Choe and Kim [52], who observed no significant differences in cooking losses between the control and treatments with 20% replacement of animal fat using a mixture of chicken skin and wheat fiber.

3.5. Lipid Oxidation of English Breakfast Sausages

Lipid oxidation is widely recognized as one of the main factors responsible for the deterioration and spoilage in fresh and processed meat products. In reformulated products, oxidative rancidity can negatively influence important quality attributes such as color, texture, nutritional composition, flavor, and aroma, ultimately reducing consumer acceptance [53]. The lipid oxidation levels in the English breakfast sausages, measured both before and after the thermal process, are shown in Figure 2. In the raw samples, the substitution of pork backfat with PS-GE did not result in a significant alteration in the TBARS value evolution. Even with the incorporation of pumpkin seed oil as an animal fat replacer, no statistically significant differences ($p > 0.05$) in lipid oxidation were detected between the control (1.08 mg MDA/kg) and the ESGE33 and ESGE66 treatments (1.28 and 1.51 mg MDA/kg, respectively). This suggests that the inclusion of pumpkin seed oil did not adversely affect oxidative stability, even though it is a rich source of PUFAs, which are typically more oxidation-prone than animal fats. The efficiency of the orange peel extract to protect the lipid fraction could be one reason for the lower lipid oxidation status of samples. Orange peel extract is rich in bioactive compounds, mainly phenolic acids and flavonoids, including hesperidin, narirutin, diosmin, and naringin, among others [54,55], which have been widely demonstrated to possess antioxidant activity [56] because they are able to inhibit the formation of free radicals due to the hydrogen donated from phenolic compounds, blocking the oxidation process [57]. Another possibility that explains the lipid oxidation values might be the emulsion gel's capacity to trap oil. This mechanism is hypothesized to impede oxygen diffusion, effectively safeguarding the meat system's lipid component [58].

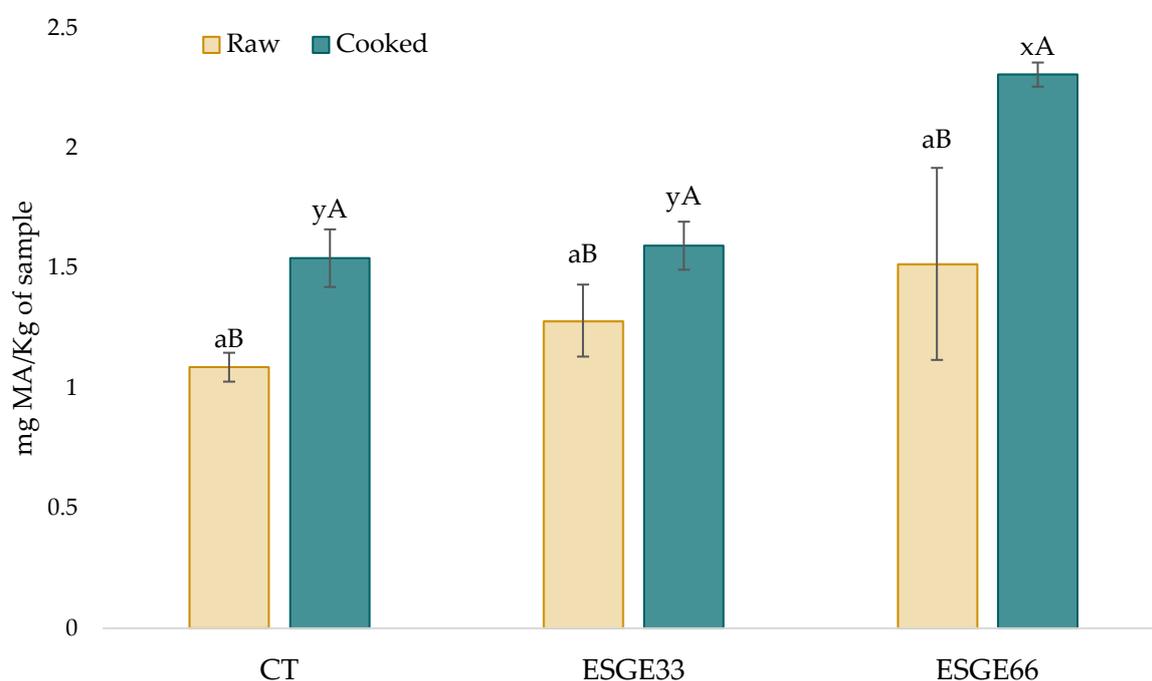


Figure 2. Lipid oxidation values of raw and cooked English breakfast sausages and sausages with partial replacement of pork backfat with gelled emulsion elaborated with pumpkin seed oil and orange peel flour. CT: control English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. For each group, bars with same lowercase letter (raw samples: a; cooked samples: x, y) are not significantly different ($p > 0.05$), and uppercase letters (A, B) compare same property for same sample but with different treatments (raw or cooked) according to Tukey's multiple range test.

Cooking treatment is a key factor responsible for initiating oxidative reactions in meat products. When evaluating the effect of heat treatment on each formulation, it was observed that all the samples (CT, ESGE33, and ESGE66) were affected by cooking. The TBARS values increased ($p < 0.05$) in all of them compared to their corresponding raw sample. The ESGE33 cooked formulation exhibited oxidation values similar to the cooked control sample ($p > 0.05$). Conversely, the ESGE66 cooked sample showed a 49% rise in oxidation levels, with statistically significant differences compared to the CT cooked sample ($p < 0.05$). This result suggests that a greater degree of fat substitution was associated with increased oxidative susceptibility. The elevated malondialdehyde (MDA) levels observed are likely influenced by the high proportion of polyunsaturated fatty acids characteristic of the pumpkin seed oil composition, combined with the applied cooking process.

In the scientific literature, there are no studies on the oxidation degree of English-style breakfast sausages, a fresh meat product that requires heat treatment for consumption, with partial fat replacement, but the replacement of fat in other fresh meat products such as burgers is widely studied. Thus, the results obtained in this work were in concordance with those reported by Badar et al. [29], who reported that fat substitution by walnut oil emulsion gel, peanut oil emulsion gel, or walnut and peanut emulsion gel in buffalo patties increased the oxidation values. These authors concluded that this fact is due to the high polyunsaturated degree of the oils used. In a more recent work, Stamenić et al. [42] investigated the effect of fat replacement in chicken Frankfurters by emulsion gels elaborated with linseed, walnut, or algal oil. These authors found that lipid oxidation was increased in the linseed and algal oil treatments, with the walnut oil group showing moderate TBARS levels with values ranging between 1.20 and 2.35 mg MDA/kg. Moreover, the samples exhibited a minor formation of secondary oxidation products. It should also be emphasized that all English breakfast sausage formulations had malondialdehyde concentrations below the sensory acceptability threshold, except for the cooked sample ESGE66 (2.30 mg MDA/kg of sample). According to Domínguez et al. [59], values exceeding 2 mg MDA/kg indicate perceptible rancidity and a decline in sensory quality.

3.6. Sensorial Analysis of English Breakfast Sausages

Sensory evaluation is a crucial aspect of meat product research, as it provides insight into both product quality and consumer acceptability. When formulating strategies to reduce fat content in meat products, sensory assessment becomes especially important, given the significant role of fat in defining their organoleptic characteristics. Fat contributes positively to multiple sensory attributes, including texture, juiciness, color, tenderness, and overall palatability. Moreover, it plays a key role in the development of typical and desirable flavors and aromas through mechanisms such as lipolysis, moderate lipid oxidation, and the generation of lipid-derived volatile compounds [60]. The sensory properties of cooked English breakfast sausages reformulated with a pumpkin seed oil and orange peel flour gelled emulsion as a partial pork backfat replacer are shown in Figure 3.

The color score assigned to the control sample (CT) was significantly higher ($p < 0.05$) than those of ESGE33 and ESGE66. This finding was consistent with the instrumental color measurement, which also revealed notable variations in color parameters between the control and the fat-replaced formulations. This outcome was expected, as the pumpkin seed oil and the orange peel flour used in the gelled emulsion contributed to a distinct color. No significant differences ($p > 0.05$) were detected in the perceived odor, hardness, juiciness, flavor, or fat sensation among the control and reformulated sausages. This suggests that despite measurable compositional variations for cooked samples in fat and protein content, these were not detected by the sensory panel.

An evaluation of the overall acceptability (Figure 4) revealed that the different treatments had no significant effect ($p > 0.05$) on this attribute. This suggests that color did not play a decisive role in determining the panelists' overall evaluation of the products. Other authors have similarly reported that the sensory acceptance of reformulated sausages remains comparable to traditional formulations when the lipid phase is properly structured to replicate the texture and melting behavior of pork fat [28,37,47,61,62].



Figure 3. Sensory analysis results of cooked English breakfast sausages and sausages with partial replacement of pork backfat with gelled emulsion elaborated with pumpkin seed oil and orange peel flour. CT: control English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; Where 1: Dislike extremely, 2: Dislike very much, 3: Dislike moderately, 4: Dislike slightly, 5: Neither like nor dislike, 6: Like slightly, 7: Like moderately, 8: Like very much, 9: Like extremely. ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. Different lowercase letters (a, b) indicate statistically significant differences ($p < 0.05$) according to Tukey's multiple range test.

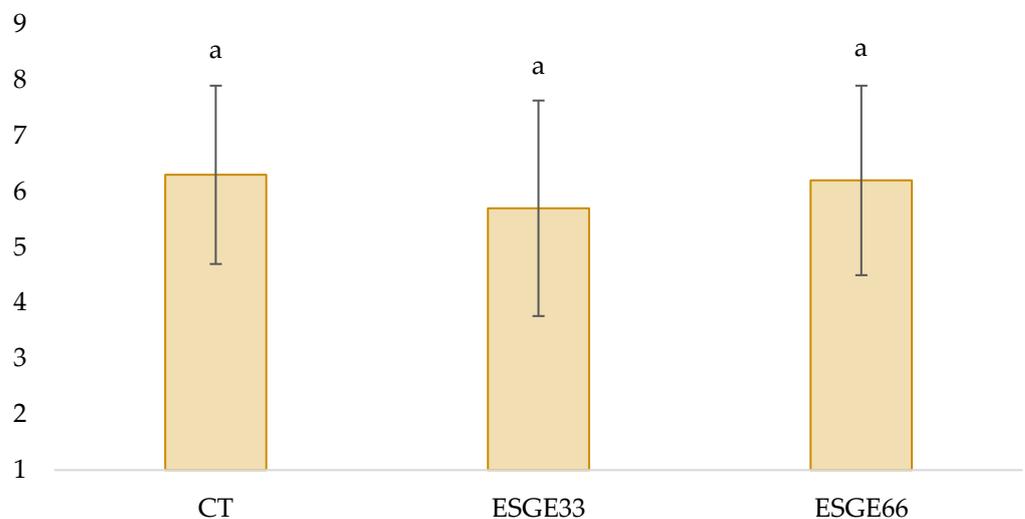


Figure 4. Acceptability result of cooked English breakfast sausage and sausages with partial replacement of pork backfat with gelled emulsion elaborated with pumpkin seed oil and orange peel flour. CT: control

English breakfast sausage; ESGE33: English breakfast sausage with 33% PS-GE as animal fat replacer; Where 1: Dislike extremely, 2: Dislike very much, 3: Dislike moderately, 4: Dislike slightly, 5: Neither like nor dislike, 6: Like slightly, 7: Like moderately, 8: Like very much, 9: Like extremely. ESGE66: English breakfast sausage with 66% PS-GE as animal fat replacer. Bars with same lowercase letter are not significantly different ($p > 0.05$) according to Tukey's multiple range test.

4. Conclusions

The partial replacement of pork backfat with a pumpkin seed oil and orange fiber gelled emulsion (PS-GE) produced English breakfast sausages with improved lipid profiles and satisfactory technological and sensory properties. Reformulation significantly reduced saturated fatty acid levels and increased polyunsaturated fatty acid levels, particularly those of linoleic acid, enhancing nutritional indices such as the Σ PUFA/ Σ SFA and h/H ratios and reducing atherogenicity and thrombogenicity. Additionally, the incorporation of PS-GE slightly affected textural parameters. Despite a moderate increase in lipid oxidation at higher substitution levels, oxidative stability remained within acceptable limits. Color differences were perceptible but did not influence sensory acceptance.

These findings demonstrate that PS-GE can be effectively used as a partial animal fat replacer in fresh sausages, contributing to reduced saturated fat content and healthier lipid composition without compromising product quality. The further optimization of antioxidant strategies within the gelled emulsion matrix could enhance oxidative stability in high-replacement formulations.

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Institutional Review Board Statement: This research was carried out following the principles outlined in the Declaration of Helsinki and received prior approval from the Responsible Research Office at Miguel Hernández University (OIR-Reg. 221028120554, UMH, Elche, Alicante, Spain).

Informed Consent Statement: Before starting the sensory analyses, all participants were informed about the unique characteristics of the product they would be tasting, as well as the details of the analysis. They also provided their written informed consent.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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