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Quality Effects of Substituting Sheep Fat with Recycled Chicken Fat in Sausages from Aged Ewe Meat

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Abstract :

This study included six treatments: T1 represented the positive control using 100% tail fat, whereas T2 served as the negative control using 100% thigh fat. Treatments T3, T4, T5, and T6 involved substituting chicken fat at levels of 25, 50, 75, and 100%, respectively. All treatments were replicated three times, and the sausages were stored across five different storage periods to evaluate the effects of storage duration. Fatty acid analysis revealed a decrease in saturated fatty acids and an increase in unsaturated fatty acids in chicken fat samples, whereas tail fat and thigh fat exhibited higher levels of saturated fatty acids and a notable reduction in unsaturated fatty acids. These trends were reflected in the sausage formulations: treatments T1 and T2 showed increased saturated fatty acids and decreased unsaturated fatty acids, while the substitution treatments (T3–T6) demonstrated the opposite pattern, with higher unsaturated and lower saturated fatty acids. Oxidative stability indicators showed that MDA, FFA, and PV values significantly decreased in the substitution treatments, whereas treatments T1 and T2 exhibited elevated levels in all oxidation indices. With regard to physical characteristics, the substitution treatments recorded improved water-holding capacity (WHC), reduced weight loss during storage.

Keywords: Meat from older sheep, sausages, refrigeration, meat processing.

تأثير استبدال دهن الأغنام بدهن الدجاج المعاد تدويره على جودة النقانق المصنوعة من لحم النعاج المسنة

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مستخلص:

تضمنت الدراسة ست معاملات: كانت T1 معاملة السيطرة الموجبة باستخدام دهن الالية بنسبة 100٪ في حين مثّلت T2 معاملة السيطرة السالبة بدهن الفخذ بنسبة 100٪ أما المعاملات T3 وT4 وT5 وT6 فقد شملت نسب استبدال مختلفة لدهن الدجاج بلغت 25 و50 و75 و100٪ على التوالي. صُنعت النقانق وفق هذه التركيبات وتم تكرار كل معاملة ثلاث مرات كما تمت متابعة تأثير مدة التخزين عبر خمس مدد زمنية. أظهر التحليل الاحصائي حدوث انخفاض في تركيز الأحماض الدهنية المشبعة وارتفاع في الأحماض الدهنية غير المشبعة في دهن الدجاج، بينما ظهر العكس في دهون الالية والفخذ التي سجلت ارتفاعاً في الأحماض المشبعة وتراجعاً في غير المشبعة. انعكس ذلك على خصائص النقانق، إذ سجلت المعاملتان T1 وT2 زيادة في الأحماض المشبعة وانخفاضاً في غير المشبعة، بينما أظهرت معاملات الاستبدال (T3–T6) نتائج معاكسة تمثلت بزيادة الأحماض غير المشبعة وانخفاض المشبعة. كما بيّنت نتائج مؤشرات الأكسدة أن معاملات الاستبدال شهدت تراجعاً معنوياً في قيم MDA وFFA وPV، في حين ارتفعت هذه القيم بشكل واضح في المعاملتين T1 وT2 . أما من الناحية الفيزيائية فقد تميزت معاملات الاستبدال بزيادة قابلية الاحتفاظ بالماء (WHC) وانخفاض نسب الفقد بالوزن أثناء التخزين.

الكلمات المفتاحية : لحم النعاج المسنة ، النقانق ، التبريد ، تصنيع اللحم.

Introduction

In recent years, global health concerns have intensified as the prevalence of chronic diseases such as obesity, diabetes, and cardiovascular disorders continues to rise. These conditions are strongly associated with dietary patterns, particularly the frequent consumption of foods high in saturated fatty acids (SFAs) and cholesterol [1]. Red meat fats typically contain 30 - 40% SFAs, 40–50% monounsaturated fatty acids (MUFAs), and 5–10% polyunsaturated fatty acids (PUFAs) [2]. In contrast, chicken fat is distinguished by its relatively low saturated fat content compared to sheep and bovine fats, making it a nutritionally superior option that aligns with current public health recommendations targeting the reduction of dietary saturated fat intake [3].

The utilization of chicken fat also offers environmental and economic benefits. Converting poultry by-products into functional food ingredients contributes to waste reduction, decreases environmental pollution, and enhances the sustainability of poultry production systems. These by-products provide valuable lipid components with significant nutritional and technological potential, thereby transforming what is typically considered waste into materials of high functional and economic value [4]. Numerous studies indicate that chicken fat contains substantial levels of MUFAs and PUFAs, which are recognized for their ability to lower low-density lipoprotein (LDL) cholesterol and support cardiovascular health. The nutritional profile of chicken fat is further improved when derived from poultry fed plant-based diets rich in unsaturated fatty acids, such as flaxseed oil [5]. Aged ewes commonly slaughtered between five and six years of age represent a notable source of sheep meat in the market. However, their meat is often characterized by increased toughness, pronounced fibrousness, and a high proportion of insoluble collagen. These characteristics diminish consumer acceptance and limit the commercial potential of aged ewe meat when marketed as a premium fresh product [6]. Consequently, incorporating such meat into processed products such as sau-

sages becomes a practical approach to improving its marketability. Given the growing demand for healthier fat alternatives and the limited research available on fat replacement strategies in processed meat systems, there is a critical need to investigate suitable substitutes that provide both nutritional and technological advantages. Accordingly, the present study aims to offer an extensive evaluation of ingredients and techniques used in developing fat replacers, with particular focus on chicken fat as a promising alternative to sheep fat in sausage formulations. The study examines the chemical composition, functional characteristics, and sensory implications of incorporating chicken fat, as well as the challenges associated with its application such as improving its stability, enhancing its emulsifying properties, and ensuring its performance during thermal processing. Chicken fat holds significant potential as a replacement for sheep fat in sausage production due to its favorable fatty acid profile and its ability to contribute to reduced saturated fat content without compromising product quality. However, its effective utilization relies on optimizing processing technologies that preserve the sensory attributes, texture, and overall acceptability of the final product. Therefore, the objective of this research is to assess the impact of substituting sheep fat with chicken fat on the physicochemical, functional, and sensory properties of sausages prepared from aged ewe meat, thereby providing scientific insights that support the development of healthier and high-quality meat products.

Materials and Methods

This study was conducted at the Animal Production Department, Agricultural College, University of Anbar. As the primary ingredient for this study, a total of five clinically healthy local female Awassi ewes aged approximately 6 years, with an average live body weight of 55-60 kg were used. These ewes were purchased immediately after slaughter at the Hit County abattoir in the Al-Anbar province of Iraq. The thigh portion of the aged was chosen for experimental investigation. The aged was removed from the bone after the fat was removed, and then separated in accordance with the ethical guide-

lines of animal use. A 10 kg boneless aged was refrigerated for 10-12 hours to eliminate rigor mortis. The aged was then cut with a knife into small pieces of 3-4 cm^3 to facilitate subsequent mincing with an electric mincer using sterile gloves. The aged pieces were homogenized to ensure an even distribution of the thigh aged components because the aged was a composite of various carcasses. Simultaneously, three types of fat were prepared for use in this investigation. These three types of fat were ewe fat, leg fat, and chicken fat, with 2.5 kg of each type of fat. The other components of the mixture included salt (15 $g.kg^{-1}$) garlic (2.8 $g.kg^{-1}$), breadcrumbs (25 $g.kg^{-1}$), and a mixture of spices (6.5 $g.kg^{-1}$).

The components, along with the additives, were separately chopped using an electric grinder equipped with a disc featuring approximately 6.8 mm diameter holes, repeated twice to ensure consistency. Sausages discs, each weighing 100 g, were randomly formed.

This study was conducted in the laboratories of the College of Agriculture, University of Anbar. with six treatments, and each treatment was repeated three times. Ninety Sausages samples were prepared using a fixed mixture ratio of 80% aged and 20% fat. The fat type was varied while maintaining the same weight ratio of the mixture. Treatment included T1: Sausages made from ewe aged + 20 percent ewe tail fat; T2: Sausages made from ewe aged + 20 percent ewe leg fat; T3: Sausages made from ewe aged + 15 percent ewe leg fat and + 5 percent chicken fat; T4: Sausages made from ewe aged + 10 percent ewe fat and + 10 percent chicken fat; T5: Sausages made from ewe aged + 5 percent ewe leg fat and + 15 percent chicken fat; and T6: Sausages made from ewe aged + 20 percent chicken fat. The variables observed included pH, cooking loss, water-holding capacity, and tenderness of emulsion-type Sausages. The samples were divided into five groups, each containing 18 samples, to be prepared for specific required tests on the following days: first, fourth, eighth, twelfth, and sixteenth. The final samples were stored at 4°C for no longer than 16 d before being prepared for testing and analysis.

The physical and chemical properties, oxidation indicators, microbiological analysis, and sensory evaluation of the manufactured Sausages samples were studied and analyzed over five selected days. The statistical analysis was performed using SAS statistical software (SAS, 2004) [7]. A significant difference between the means was determined by Duncan's multiple range test (Duncan, 1995) at the significance level of ($P \leq 0.05$).

Fatty Acid

The fat content was determined according to the method using a Soxhlet extraction device for lipid extraction [8].

Chromatographic examination of the samples was conducted by evaluating fatty acid compounds using a Shimadzu gas chromatograph (GC-2010) manufactured in Japan. A flame ionization detector (FID) was utilized under the specified conditions as presented in table 1, employing a SE-30 capillary column measuring 30 m in length and 0.25 mm in diameter [9].

Table 1: The specified conditions of flame ionization detector (FID)

Parameters	Temperature
Injection zone temperature	280o C
Detector temperature	310o C
Separation column temperature	120 – 290 (10 C / MIN)
Gas flow rate	100 KPa

Water holding capacity

To measure the water-holding capacity, 50 g of Sausages were mixed homogeneously with 50 ml of distilled water for one minute [10].

Weight loss percentages

Using the method described by [11].

Oxidation Indicators

Malondialdehyde (MDA): To estimate lipid oxidation in tissues, the amount of malondialdehyde, a product of lipid oxidation in various tissues, was measured by determining the value of thiobutyric acid (TBA) [12].

Free Fatty Acid (FFA) and peroxide value (PV): FFA and PV were determined with certain modifications [13].

Results and Discussion

The present study investigated the physical and chemical properties, oxidation indicators, microbiology, and sensory evaluation of manufactured Sausages samples for five selected days.

Fatty acid

In the experiment, the fatty acid analysis revealed significant differences in lipid composition. Table 2 shows that chicken fat recorded the lowest concentrations of palmitic acid and stearic acid (saturated fatty acids), with 13.08 and 7.06%, respectively. In contrast, ewe leg fat recorded the highest concentrations of both fatty acids, with 21.45 and 15.34% respectively. In comparison, tail fat was 17.65 and 12.05, respectively. The table indicates that chicken fat contains lower levels of these two fatty acids than ewe fat (from tail and leg areas), suggesting that the substitution reduces the amount of saturated fatty acids. Oleic acid is a monounsaturated fatty acid and the most common polyunsaturated fatty acid found in chicken fat. It is considered a health benefit (it contributes to lowering harmful cholesterol). This enhances the nutritional value of the product. The same table shows that chicken fat had the highest concentration of this fatty acid, reaching 32.98 %, whereas ewe tail fat recorded 28.08, followed by ewe leg fat at 21.78. Furthermore, chicken fat had the highest level of polyunsaturated fatty acids, with concentrations of 12.65, 3.05, and 2.05 %, respectively, compared to other fats. These are important health indicators because they include omega-3 and omega-6 fatty acids. Furthermore, a comparison was made with the existing literature that studied chicken fat and revealed good agreement (table 2).

Table 2: Fatty acid % analysis of the fats used in the experiment.

Fatty acid	Current work			Previous work		
	Chicken fat	Tail fat	Leg fat	[14]	[15]	[16]
Palmitic acid C16:0	13.08^{c}	17.65^{b}	21.45^{a}	24.18	18.55	18.18
Stearic acid C18:0	7.06^{c}	12.05^{b}	15.34^{a}	5.69	8.31	5.25
Oleic acid C18:1	32.98^{a}	28.08^{b}	21.78^{c}	36.15	33.67	39.22
Linoleic acid (C18:2, n-6)	12.65^{a}	5.98^{b}	3.13^{c}	22.55	19.31	25.57
Linolenic acid (C18:3, n-3)	3.05^{a}	1.05^{b}	0.58^{c}	1.63	2.25	3.16
Arachidonic acid (C20:4)	2.05^{a}	1.11^{b}	0.88^{c}	-	-	-

Means with different superscript letters within a row differ significantly ($P \leq 0.05$).

The statistical analysis results presented in Table 3 indicate variations in the percentage of fatty acids among the experimental treatments (partial and total fat replacement). It was observed that treatment T1 exhibited an increase in the two fatty acids, palmitic acid and stearic acid (both of which are saturated fatty acids), achieving values of 35.22 and 15.06 % for each acid, respectively. In contrast, T6 demonstrated a lower percentage of these two acids when compared to the other experimental treatments, with values of 16.33 and 5.48 % for each acid, respectively.

Furthermore, the other replacement treatments (T3, T4, and T5) showed a notable decrease in these two acids relative to the control treatments (T1 and T2).

Table 3: Fatty acid % content impact due to the partial and total substitution of chicken fat in refrigerated Sausages

Fatty acid	Current work						Literature
	T1	T2	T3	T4	T5	T6	[18]
Palmitic acid C16:0	32.43^{b}	35.22^{a}	25.65^{c}	23.45^{d}	20.54^{e}	16.33^{f}	24.38
Stearic acid C18:0	13.07^{b}	15.06^{a}	9.78^{c}	8.95^{d}	8.00^{e}	5.48^{f}	5.83
Oleic acid C18:1	28.12^{e}	22.43^{f}	33.62^{d}	35.66^{c}	37.31^{b}	38.76^{a}	37.61
Linoleic acid (C18:2, n-6)	8.00^{e}	5.10^{f}	13.88^{d}	15.74^{c}	17.14^{b}	18.41^{a}	25.10
Linolenic acid (C18:3, n-3)	1.08^{e}	0.78^{f}	1.87^{d}	2.26^{c}	2.35^{b}	2.89^{a}	1.32
Arachidonic acid (C20:4)	0.75^{e}	0.39^{f}	1.23^{d}	1.41^{c}	1.34^{b}	1.65^{a}	-

Regarding oleic acid in the experimental treatments, it is evident from the same table that T6 recorded the highest percentage of this acid, reaching

38.76 %, whereas T2 exhibited the lowest percentage, at 22.43 %. The other experimental treatments showed a significant increase, particularly in the replacement treatments (T3, T4, and T5), compared with the two control treatments. Concerning the fatty acids linoleic acid

(C18:2, n-6), linolenic acid (C18:3, n-3), and arachidonic acid in the experimental treatments, it is noted from the same table that treatment T6 recorded the highest percentages of these fatty acids. The remaining experimental treatments also exhibited a significant increase, especially in the replacement treatments (T3, T4, and T5), compared with the two control treatments. These findings align with the results reported when 30% of chicken fat was substituted with pork fat.

Physical characteristics

water-holding capacity

Table 4 illustrates the impact of the interaction between the experimental treatments (partial and total fat replacement) and storage duration on water-holding capacity (WHC). A notable increase ($P \leq 0.05$) was evident in T6 during the initial storage duration (1 d), achieving 60.136%, which surpasses the performance of the other experimental treatments. Conversely, the lowest WHC percentage was noted under the influence of the interaction between treatments and storage duration in T1 and T2 during the fifth duration (16 days), reaching 41.346% and 40.44%, respectively. Furthermore, it is observed from the same table that all replacement treatments (T3, T4, and T5) exhibited a higher moisture percentage than the two control treatments (T1 and T2). Regarding the individual effects of the treatments, treatment T6 demonstrated the highest WHC percentage, significantly exceeding the other experimental treatments ($P \leq 0.05$), reaching 52.242 %. In contrast, treatments T1 and T2 had the lowest WHC percentages compared to the other experimental treatments, at 46.795% and 46.314%, respectively. The other replacement treatments showed a significant increase in mois-

ture content relative to that of the control treatments (T1 and T2).

This finding aligns with the observations made when beef fat was substituted with chicken skin strips in the production of chicken sausages, as they noted an increase in the moisture and water-holding capacity of the meat [19]. This is also consistent with the findings when chicken and duck skin were utilized as substitutes for pork fat in sausages made from chicken breast, where they observed an enhancement in the water-holding capacity [18]. The high proportion of unsaturated fatty acids in chicken fat may account for this phenomenon [21]. The melting point of fat plays a crucial role in determining the characteristics of meat products such as Sausages. Poultry fat has a relatively low melting point (28–33°C) in contrast to sheep or cow fat, which melts at higher temperatures (45–55°C). This lower melting point results in more fluid consistency for poultry fat, enhancing its distribution and uniformity during the mixing process, and aids in the creation of a more stable emulsion of fat, water, and protein. In contrast to ruminant fat, which tends to aggregate and create voids that can lead to moisture loss, poultry fat effectively fills these voids, thereby minimizing moisture leakage during processing or cooking and enhancing the water-retention capacity of the product. Research has demonstrated that fats with low melting points, such as poultry fat, yield more stable emulsions and enhance the functional properties of the product, particularly with respect to moisture retention, water-holding capacity (WHC), weight loss, and cooking loss. Additionally, poultry fat is characterized by a higher concentration of phospholipids, which are surface-active agents that aid in the stabilization of emulsions within meat mixtures because of their capacity to bind water and fat. This action prevents phase separation during mixing and heating, thereby improving the texture and stability of the product and significantly boosting WHC. Furthermore, the elevated phospholipid levels in chicken fat enhance its emulsifying capabilities and positively influence the final product characteristics, such as moisture retention, WHC, weight loss, diameter shrinkage, and cooking loss **[20].**

Table 4: Influence of partial and total replacement of chicken fat and storage periods in refrigerated Sausages on water holding capacity %.

Days Treatments	Days number					
	1	4	8	12	16	Average Treatments
T1	51.753^{j}	50.129^{m}	46.533^{p}	44.213^{t}	41.346^{z}	46.795^{e}
T2	51.143^{l}	50.033^{n}	46.423^{q}	43.53^{w}	40.44^{Z3}	46.314^{f}
T3	52.45^{i}	51.766^{j}	49.75^{o}	43.849^{v}	40.893^{Z2}	47.742^{d}
T4	54.563^{f}	53.313^{h}	51.206^{k}	44.169^{u}	41.253^{Z1}	48.901^{c}
T5	58.773^{b}	55.763^{d}	53.666^{g}	44.79^{s}	41.9^{y}	50.978^{b}
T6	60.136^{a}	58.223^{c}	55.123^{e}	45.213^{r}	42.513^{x}	52.242^{a}
Average duration	54.803^{a}	53.205^{b}	50.45^{c}	44.294^{d}	41.391^{e}	SEM 0.638

Average significance level for storage durations and their interaction ($P \leq 0.05$)
Different letters within a row indicate significant differences ($P \leq 0.05$) between storage durations.
Different letters within a column indicate a significant difference ($P \leq 0.05$) between treatments

Weight loss

Table 5 presents the influence of the interaction between experimental treatments (partial and total fat replacement) and storage duration on weight loss. A notable reduction ($P \leq 0.05$) was noted in T6 during the initial storage duration (1 d), reaching 2.077%, which was the least weight loss in comparison to the other experimental treatments. In contrast, the most significant weight loss was observed under the interaction effect in T2 during the fifth storage period (16 d), reaching 5.551%. Additionally, the same table indicates that all replacement treatments (T3, T4, and T5) exhibited the lowest weight loss compared to the two control treatments (T1 and T2). Concerning the individual effects of the treatments, T6 demonstrated the least weight loss relative to the other experimental treatments, achieving 3.257%, whereas T2 exhibited the highest weight loss, reaching 4.146%, surpassing all experimental treatments. Regarding the individual

effect of storage duration, the first period (1 d) recorded the lowest weight loss compared to the subsequent experimental periods, reaching 2.316%, whereas the sixth period (16 days) recorded the highest weight loss percentage, reaching 4.890%.

Table 5: Influence of partial and total replacement of chicken fat and storage periods in refrigerated Sausages **on weight loss %.**

Days / Treatments	Days number					
	1	4	8	12	16	Average Treatments
T1	2.322^{s}	3.554^{kl}	3.711^{g}	4.766^{d}	5.223^{b}	3.915^{b}
T2	2.745^{r}	3.765^{l}	3.716^{g}	4.954^{c}	5.551^{a}	4.146^{a}
T3	2.32^{s}	3.256^{m}	3.63^{h}	4.564^{e}	5.022^{c}	3.758^{c}
T4	2.265^{t}	3.156^{o}	3.333^{jk}	4.344^{g}	4.87^{f}	3.594^{d}
T5	2.167^{u}	3.009^{p}	3.156^{n}	4.171^{i}	4.445^{g}	3.390^{e}
T6	2.077^{v}	2.885^{q}	3.078^{o}	4.016^{j}	4.231^{h}	3.257^{f}
Average duration	2.316^{e}	3.271^{d}	3.437^{c}	4.469^{b}	4.890^{a}	SEM 0.063

Average significance level for storage durations and their interaction ($P \leq 0.05$)
Different letters within a row indicate significant differences ($P \leq 0.05$) between storage durations.
Different letters within a column indicate a significant difference ($P \leq 0.05$) between treatments.

The increased moisture content and water-holding capacity (WHC), along with reduced weight loss, in beef Sausages when sheep or beef fat is substituted with poultry fat, can be attributed to the distinct physical and chemical characteristics of chicken fat. It possesses a higher level of unsaturated fatty acids, rendering it softer and more fluid than the ruminant fat. This enhanced the capacity of the mixture to distribute and retain water within the protein matrix during mixing and processing. Furthermore, poultry fat typically has a relatively high moisture content and demonstrates superior emulsifying properties, leading to a more uniform and stable product with

respect to water retention. Research suggests that these combined factors enhance the functional properties of the product and elevate the moisture content and water-holding capacity compared with products containing ruminant fat [**17**].

Malondialdehyde (MDA)

An analysis of the interaction between experimental treatment (partially and fully replacing fat) and storage duration is shown in Table 6. The table shows that the highest value observed under this interaction occurred in T2 during the fifth period (16 days), reaching 1.224 (mg MDA kg^{-1} Meat). Conversely, the lowest values were noted during the initial period of the experiment (1 d), with readings of 0.137, 0.156, 0.128, 0.121, 0.117, and 0.111 (mg MDA kg^{-1} Meat) for treatments T1, T2, T3, T4, T5, and T6, respectively. Furthermore, it is evident from the interaction factors that the highest ratios were recorded for treatments T1 and T2, in contrast to the replacement treatments (T3, T4, T5, and T6), which exhibited a significant decline during the storage period. Regarding the individual effects of the treatments, treatment T6 demonstrated the lowest percentage of MDA in comparison to the other experimental treatments, achieving a value of 0.493 (mg MDA kg^{-1} meat), while T2 exhibited the highest percentage of MDA among the experimental treatments, reaching 0.603 (mg MDA kg^{-1} meat). Additionally, all replacement treatments experienced a significant reduction in MDA levels compared to the control treatments (T1 and T2). In terms of the individual effects of the storage periods, the first period (1 day) recorded the lowest percentage of MDA relative to the other experimental periods, at 0.128 (mg MDA kg^{-1} Meat), whereas the fifth period (16 days) recorded the highest percentage of MDA, reaching 1.024 (mg MDA kg^{-1} Meat). It is also noted that the effect of storage period indicates that longer storage durations correlate with increased MDA percentages.

Table 6: Influence of partial and total replacement of chicken fat and storage periods on MDA (mg MDA kg^{-1} Meat) in refrigerated Sausages**.**

Days Treatments	Days number					
	1	4	8	12	16	Average Treatments
T1	0.137^{y}	0.278^{t}	0.436^{n}	0.857^{h}	1.022^{b}	0.546^{b}
T2	0.156^{x}	0.289^{s}	0.460^{m}	0.888^{g}	1.224^{a}	0.603^{a}
T3	0.128^{z}	0.266^{u}	0.432^{n}	0.845^{i}	1.011^{c}	0.536^{c}
T4	0121^{z1}	0.251^{v}	0.412^{o}	0.833^{j}	1.000^{d}	0.523^{d}
T5	0.117^{z2}	0.244^{vw}	0.400^{p}	0.821^{k}	0.955^{e}	0.507^{e}
T6	0.111^{z3}	0.235^{w}	0.389^{q}	0.800^{l}	0.934^{f}	0.493^{f}
Average duration	0.128^{e}	0.260^{d}	0.421^{c}	0.840^{b}	1.024^{a}	SEM 0.045

Average significance level for storage durations and their interaction (P≤0.05)
Different letters within a row indicate significant differences (P≤0.05) between storage durations.
Different letters within a column indicate a significant difference (P≤0.05) between treatments.

Free Fatty Acid (FFA)

Table 7 depicts how the interaction of the experimental treatments (partial and total fat replacement) with storage duration influences FFA. The table point out that the highest value observed under this interaction occurred in T2 during the fifth storage period (16 days), reaching 0.752%. Conversely, the lowest values were noted across all experimental treatments during the initial storage period (1 d), with values of 0.156, 0.165, 0.154, 0.150, 0.148, and 0.144 % for treatments T1, T2, T3, T4, T5, and T6, respectively. Furthermore, the highest ratios were associated with treatments T1 and T2, in contrast to the replacement treatments (T3, T4, T5, and T6), which exhibited a significant decline throughout the storage period. Regarding the individual effects of treatments, treatment T6 demonstrated the lowest FFA percentage among the experimental treatments, at 0.431, while T2 exhibited the highest FFA percentage, reaching 0.466%. Additionally, all replacement treatments experienced a significant reduction compared with the two control treatments (T1 and T2). In terms of the individ-

ual effects of storage period, the first period (1 d) recorded the lowest FFA percentage compared to the other experimental periods, at 0.152%, whereas the fifth period (16 days) recorded the highest FFA percentage, reaching 0.719 %. It was also observed that the effect of storage duration indicated that longer storage periods correlated with higher FFA percentages.

Table 7: Influence of partial and total replacement of chicken fat and storage periods on FFA% in refrigerated Sausages**.**

Days Treatments	Days number					
	1	4	8	12	16	Average Treatments
T1	0.156^{r}	0.254^{pq}	0.487^{l}	0.622^{g}	0.735^{b}	0.450^{b}
T2	0.165^{r}	0.267^{p}	0.504^{k}	0.643^{f}	0.752^{a}	0.466^{a}
T3	0.154^{r}	0.250^{pq}	0.480^{m}	0.613^{h}	0.722^{c}	0.443^{c}
T4	0.150^{r}	0.253^{pq}	0.477^{n}	0.606^{i}	0.711^{d}	0.439^{d}
T5	0.148^{r}	0.253^{pq}	0.476^{o}	0.600^{j}	0.702^{e}	0.435^{e}
T6	0.144^{r}	0.247^{q}	0.473^{o}	0.596^{j}	0.695^{e}	0.431^{f}
Average duration	0.152^{e}	0.254^{d}	0.482^{c}	0.613^{b}	0.719^{a}	SEM 0.026

Average significance level for storage durations and their interaction (P≤0.05)
Different letters within a row indicate significant differences (P≤0.05) between storage durations.
Different letters within a column indicate a significant difference (P≤0.05) between treatments.

Peroxide Value (P.V)

Table 8 outlines the influence of the interaction between experimental treatments (partial and total fat replacement) and storage duration on PV. The table indicates that the highest value observed under the interaction effect was in T2 during the fifth period (16 days), reaching 9.167 (meq^{-1} fat), whereas the lowest value was noted in T6 during the initial storage period, at 8.833 (meq^{-1} fat). Furthermore, the highest percentages were recorded in T1 and T2, in contrast to the replacement treatments (T3, T4, T5, and T6), which exhibited a significant decline during the storage period. Concerning the individual effects of the treatments,

T6 demonstrated the lowest percentage in PV compared to the other experimental treatments, at 5.018 (meq^{-1} fat), whereas T2 showed the highest percentage of PV among the remaining treatments, reaching 5.447 (meq^{-1} fat). Additionally, all replacement treatments experienced a significant reduction compared with the control treatments (T1 and T2).

Regarding the individual effects of storage period, the first period (1 d) recorded the lowest PV. percent compared to the other experimental periods, at 1.081 (meq^{-1} fat), while the fifth period (16 days) recorded the highest PV. percent, reaching 8.980 (meq^{-1} fat). It was also observed that as the storage period increased, PV. percent tended to increase. This phenomenon may be attributed to the lower levels of oxidation indicators (MDA, FFA, and PV) present in the replacement treatments containing chicken fat (T3, T4, T5, and T6). The reduction in the redox indices in the replacement coefficients (T3, T4, T5, and T6) could be linked to the role of vitamin E in sustaining the intracellular redox balance, which is crucial for preventing damage to phospholipids in cell membranes. Research has indicated that alpha-tocopherol supplements can diminish lipid oxidation within tissues and enhance meat quality during storage. They also play a role in alleviating fatty liver inflammation and in the prevention of certain metabolic disorders, including diabetes [22] [23]. Within the poultry sector, the use of alpha-tocopherol supplements has been shown to diminish abdominal fat accumulation in broiler chickens, achieved not only through metabolic modification, but also by decreasing lipid oxidation. This process enhances the integrity of cell membranes in adipose tissue and mitigates oxidative damage that leads to fat deposition. Furthermore, research conducted on chickens revealed that the addition of vitamin E results in a notable increase in n-3 fatty acids and a reduction in the n-6/n-3 ratio [20].

A research study has shown that Oxidation is a significant factor that leads to a reduction in both productive and reproductive performance in chicken flocks. To mitigate these adverse effects, antioxidants are incorporated into poultry feed, sourced either from

natural feed components or external supplements. Vitamin E is regarded as a fundamental antioxidant and has been demonstrated to bolster the antioxidant defense system [24].

A separate investigation aimed at assessing alpha-tocopherol levels in various meats revealed that chicken thigh exhibited the highest concentration, followed by chicken breast and pork shoulder, while the lowest concentrations were found in the longissimus dorsi muscle of sheep meat [25]. Vitamin E (alpha-tocopherol) is one of the most potent antioxidants present in chicken fat and tissues. It is a fat-soluble vitamin. Adequate levels of vitamin E in chicken fat improve its oxidative stability, thereby decreasing the likelihood of rancidity and quality degradation during storage or heat processing [26]. In these processes, vitamin E is transformed into tocopheroxy radical, a relatively stable radical that does not participate in oxidation reactions. Furthermore, vitamin E aids in decelerating the breakdown of oxidized substances such as lipid peroxides. In the presence of vitamin C, alpha-tocopherol is restored from its oxidized state, thereby preserving .

Table 8: Influence of partial and total replacement of chicken fat and storage periods on PV (meq-1 fat) in refrigerated Sausages.

Days Treatments	Days number					
	1	4	8	12	16	Average Treatments
T1	1.15^{s}	3.55^{o}	5.469^{j}	8.044^{f}	9.024^{b}	5.447^{b}
T2	1.13^{s}	3.57^{o}	5.466^{j}	8.076^{e}	9.167^{a}	5.481^{a}
T3	1.08^{t}	3.345^{p}	5.423^{k}	7.872^{g}	9.022^{b}	5.348^{c}
T4	1.08^{t}	3.344^{p}	5.279^{l}	7.623^{h}	9.000^{c}	5.265^{d}
T5	1.04^{v}	3.221^{q}	5.123^{m}	7.111^{i}	8.836^{d}	5.066^{e}
T6	1.01^{w}	3.133^{r}	5.008^{n}	7.110^{i}	8.833^{d}	5.018^{f}
Average duration	1.081^{e}	3.360^{d}	5.294^{c}	7.639^{b}	8.980^{a}	SEM 0.296

Average significance level for storage durations and their interaction ($P \leq 0.05$)
Different letters within a row indicate significant differences ($P \leq 0.05$) between storage durations.
Different letters within a column indicate a significant difference ($P \leq 0.05$) between treatments.

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