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Development and Characterization of Fermented Duck Meat Sausage with Different Fermentable Dextrose Level

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Abstract

This study investigated the effect of varying levels of fermentable sugar (0%, 1%, 2%, and 3%) on the physicochemical properties, microbiological characteristics, and sensory attributes of fermented duck sausage. The results showed significant differences in water, fat, ash, and protein content across treatments. Water content decreased from 53.45% in P1 (0% sugar) to 47.32% in P4 (3% sugar), while fat content increased from 14.22% to 17.45%, and ash content rose from 2.12% to 2.78%. Protein content also significantly increased from 14.91% in P1 to 20.42% in P4. The pH values ranged from 4.52 to 4.75, showing no significant differences between treatments. Microbiologically, the total lactic acid bacteria (LAB) count ranged from 2.60×10^4 to 1.37×10^6 CFU/g, while the total viable count (TVC) increased significantly, from 2.02×10^4 CFU/g in P1 to 1.60×10^5 CFU/g in P4. Overall, increasing the level of fermentable sugar positively influenced the physicochemical properties of duck sausage.

Keywords: Fermented duck sausage; Fermentable sugar; physicochemical properties; Lactic acid bacteria; Sensory analysis

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1. Introduction

Duck farming is a valuable source of meat with relatively stable prices, offering potential for product diversification. Among the various options, converting duck meat into sausage is a promising alternative, especially since sausages are a popular processed meat product in Indonesia. However, most sausages available in the market are emulsion-based, requiring freezing for preservation [1]. Fermented sausages, on the other hand, remain underexplored in Indonesia, except for a few traditional varieties such as "*urutan*" in Bali and "*budik*" in Nusa Tenggara Timur (NTT), both made from pork using spontaneous fermentation [2-3]. These traditional products suffer from inconsistent quality due to the reliance on natural, uncontrolled microflora. Fermented sausages are produced through a process that combines meat, fat, salt, and other ingredients, which are then fermented and partially dried to achieve a semi-dry or dry product [4]. The fermentation process, typically initiated by starter cultures, induces significant physical, biochemical, and sensory changes in the meat, including acidification, protein gelation, fat degradation, and dehydration [5]. Starter cultures ensure greater control over fermentation, yielding consistent product quality. Previous studies have demonstrated the importance of using specific bacterial strains like *Lactobacillus sakei*, L. *plantarum*, and *Staphylococcus carnosus* to improve safety, flavor, and shelf life in meat fermentation [6-8].

However, in Indonesia, the use of commercial starter cultures in sausage production is still limited, and further research is needed to develop high-quality fermented products using local meat sources like duck. Duck meat, with its unique flavor and rich nutrient content, holds potential for fermented sausage production. Recent studies have explored various formulations of fermented meat products, such as turkey and chicken sausages, which have been found to improve the physicochemical and sensory properties when paired with controlled fermentation [9-10]. However, the development of fermented duck meat sausage, particularly in Indonesia, remains largely unexamined. Research on poultry-based fermented sausages is crucial, as it offers a healthier alternative to traditional pork-based products while catering to dietary preferences and needs of a broader consumer base. This study aims to fill this gap by investigating the formulation and production of fermented duck meat sausage using commercial starter cultures. The research will focus on optimizing the ingredient composition and fermentation conditions to ensure consistent quality and desirable sensory characteristics. Furthermore, this study will evaluate consumer preferences for fermented duck meat sausages in Indonesia, contributing to the diversification of processed meat products in the local market. The long-term goal is to develop an applicable technology for producing high-quality fermented duck sausages, promoting their acceptance and wider use in the food industry.

2. Materials and methods

2.1. Materials and equipment

The primary materials used in this study include lean duck meat, animal fat, lactic acid bacteria starter culture (Bactoferm), 18 mm cellulose casings, fermentable carbohydrate (dextrose), and additional ingredients such as salt and tapioca starch. Equipment used in sausage production includes a meat grinder, food processor, sausage stuffer, and fermentation/incubation chamber. Analytical instruments such as a food texture analyzer, pH meter, color reader, and general laboratory equipment (oven, incubator, and autoclave) were also utilized.

2.2. Experimental Design

This research was conducted using a Completely Randomized Design (CRD) [11] to investigate the effect of different levels of fermentable sugar (dextrose) on the quality of fermented duck meat sausages. The treatments, outlined in Table 1, included four levels of dextrose (0%, 1%, 2%, and 3%), with each treatment replicated five times. The sausages were produced as semi-dry fermented sausages (summer sausage) with a target pH of 4.8–5.2, followed by cooling for 24 hours *Fermented sausage production*. The production of fermented duck sausages began with trimming and grinding lean duck meat and animal fat. The ground meat mixed with salt, dextrose (0%, 1%, 2%, or 3%), tapioca starch, & spices. A lactic acid bacteria starter culture added, ensuring even distribution. Mixture is then stuffed into 18 mm cellulose casings and fermented in a chamber at 20°C–25°C and 80%–90% humidity for 24–72 hours, aiming for a pH of 4.8–5.2. After fermentation, sausages are dried at 10°C–15°C and 70%–80% humidity for 7–10 days to achieve a 20% moisture loss. Fermented sausages stored at 4°C for 24 hrs. Before quality testing, including pH, color, and sensory evaluations.

2.3. Data collection and analysis

a. pH Measurement

The acidity (pH) of the sausage samples was measured using a pH meter (Hanna Instruments). Homogenized samples were diluted in distilled water at a 1:10 ratio before pH measurement.

b. Color Measurement

Objective color measurements were performed using a color reader, reporting the L* (lightness), a* (red-green), and b* (yellow-blue) values.

c. Proximate Composition

Moisture Content: Determined by drying the sample in an oven at 105°C for 16 hours and calculating weight loss. Crude Fat Content: Measured using a Soxhlet extraction system after pre-drying the samples at 105°C for 6 hours and extracting fat using ether for 4 hours. Protein Content: Analyzed by the Kjeldahl method on 10 g of sample. Ash Content: Determined by heating the sample in a furnace to calculate total ash.

d. Microbiological Analysis

Microbial analysis included determining the total viable count (TVC) and lactic acid bacteria (LAB) count. Ten grams of each sample were aseptically homogenized in 90 ml of buffered peptone water, and serial dilutions were plated. TVC was measured using Plate Count Agar (PCA) after incubation at 37°C for 48 hours. LAB was quantified using De Man, Rogosa, and Sharpe Agar (MRSA), incubated at 37°C for 48 hours.

2.4. Statistical Analysis

Data were statistically analyzed using analysis of variance (ANOVA) in SPSS version 23, with a significance level of 5%. Differences between treatments were further examined using Duncan's Multiple Range Test (DMRT) where applicable.

3. Results and Discussions

One of the quality standards for meat sausages is the nutritional content, as outlined in the Indonesian National Standard (SNI). The quality standards for meat sausages include a maximum water content of 67%, a minimum protein content of 13%, and a maximum fat content of 20%. Based on proximate analysis, the fermented duck sausage has met the SNI quality standards in terms of water content, fat content, and protein content.

3.1. Sausage pH

pH is a crucial parameter influencing the texture, flavor, and shelf life of fermented sausages. During fermentation, pH typically decreases due to the activity of lactic acid bacteria (LAB), which convert sugars into lactic acid. This pH drop is essential not only for inhibiting the growth of pathogens but also for imparting the distinct acidic flavor characteristic of fermented sausages. According to Tabanelli et al. [12], the final pH of fermented sausages generally ranges from 4.6 to 5.3, depending on the type of meat, fermentation process, and level of fermentable sugars added. In this study, pH variations were observed across the different treatments (Table 2). The lowest pH was recorded in treatment P2 (1% dextrose) with a value of 5.166, while the highest pH was observed in P3 (2% dextrose) with a value of 5.224. Interestingly, the increase in sugar levels from 0% to 3% resulted in non-linear pH fluctuations, as indicated by the different notations (a b, a, c, b c), signifying significant differences between treatments ($p<0.05$). This non-linear behavior suggests that factors other than sugar levels, such as microbial activity and fermentation kinetics, may influence pH variation. In the treatment without added sugar (P1), the pH remained around 5.188, indicating that fermentation still occurred, albeit likely at a slower or less intense rate compared to treatments with added sugar. In P2 (1% sugar), the more pronounced pH decrease suggests higher fermentation activity due to availability of fermentable sugar, which serves as a substrate for lactic acid bacteria (LAB).

However, in P3 and P4 (2% and 3% sugar), the pH slightly increased again. This could be attributed to suboptimal fermentation mechanisms at higher sugar levels, possibly due to increased osmolarity, which may inhibit the growth of fermentative bacteria. Previous studies have also reported similar pH ranges in fermented sausages. Kurnianto and Munarko [13] found a pH range of 4.42–4.73 in fermented catfish sausages, while Meilitasari [14] observed a higher pH range of 5.29–5.90 in fermented goat sausages, with a decreasing pH trend as *Lactobacillus plantarum* was added. In this study, the addition of sugar served as an energy source for LAB during the fermentation process, contributing to lactic acid production and a decrease in pH. However, the relatively modest pH drop in the fermented duck sausages suggests that other factors, such as the buffering capacity of the meat proteins or the concentration of starter bacteria used, may have influenced the fermentation rate [15]. At higher sugar levels (2% and 3%), potential for microbial inhibition due to excessive sugar concentrations should also be considered. Observed fluctuations in pH across treatments suggest that while sugar addition enhances fermentation, excessive levels might hinder microbial activity. This underscores importance of optimizing sugar concentrations to balance LAB growth and fermentation efficiency. The results from this study align with previous findings, yet indicate the need for further investigation into role of sugar concentration and other factors, such as starter culture dose and fermentation conditions, in achieving consistent pH reduction and improved product quality.

Overall, the pH values across all treatments ranged between 5.1 and 5.2, indicating that all samples underwent fermentation, leading to a slight reduction in pH due to the activity of LAB. Although the pH reduction was not as substantial as typically seen in other fermented sausage products, the decrease was sufficient to suggest successful fermentation. The relatively mild drop in pH might be attributed to the lower level of fermentable sugars and the type of meat used, as duck meat may have different buffering capacities compared to other meats such as pork or beef. These pH values suggest that while the fermentation process was effective in lowering pH, further optimization, possibly involving different starter cultures or fermentation times, might be needed to achieve a more pronounced pH reduction that could enhance the shelf stability and flavor profile of the final product. The ability of the sausages to achieve a final pH within the typical range for fermented sausages demonstrates the effectiveness of the lactic acid bacteria starter culture. However, the variations in pH among treatments highlight the complexity of the fermentation process and suggest that factors such as sugar concentration and microbial activity interact in intricate ways to influence the final product. Further investigation into the optimal conditions for pH reduction could help improve the consistency and quality of fermented duck sausage.

3.2. Ash content of sausage

Based on the data in Table 3, the ash content of fermented duck sausage increased with higher levels of added sugar (P1: 0%, P2: 1%, P3: 2%, P4: 3%). In P1 (without sugar), the ash content was 0.874%, while in P4 (3% sugar), it rose to 1.028%. Ash content represents the total minerals remaining after the combustion of organic matter. This increase suggests a correlation between sugar addition and the final mineral content of the product, despite sugar not being a primary mineral source. Significant differences were observed between treatments, with P1 showing a marked difference from P2, P3, and P4, as indicated by distinct letter notations. The notable increase in ash content in P4 (3% sugar) compared to P1 (0% sugar) and P2 (1% sugar) may indicate that sugar addition influences the residual mineral content of the final product. Ismanto et al. (2020) similarly reported that the ash content of chicken sausage increased from 2.69% to 3.36% with the addition of carrageenan, a carbohydrate containing sulfate minerals that contribute to the ash content in sausages. The rise in ash content could also be associated with fermentation and dehydration processes involved in sausage production. During fermentation, various biochemical reactions occur that can affect the chemical composition of raw materials, including absorption & mobilization of minerals [16]. The dehydration or water evaporation during fermentation and sausage maturation concentrates mineral content, as the reduction in water content increases the concentration of dry matter, including ash. Higher ash content can indicate a greater mineral presence, which is important for the nutritional value of the product. However, excessively high ash content could negatively affect sensory quality, particularly taste and texture. In fermented sausage products, elevated ash levels may introduce an undesirable mineral aftertaste. Thus, increased ash content in P3 and P4 requires attention in context of balancing physicochemical quality and consumer preferences during product development.

3.3. Water content of sausage

According to the data presented in Table 4, the moisture content of fermented duck sausage decreased significantly with increasing sugar levels (P1: 0%, P2: 1%, P3: 2%, P4: 3%) ($p<0.05$). In treatment P1 (without sugar), the moisture content was 53.59%, while in P4 (3% sugar), it dropped to 45.454%. This reduction in moisture can be linked to the fermentation and dehydration processes occurring during production. Sugar serves not only as a substrate for fermentation but also increases osmotic pressure within the meat matrix, promoting water expulsion and reducing the overall moisture content of the product. The significant differences in moisture content across all treatments ($p<0.05$) indicate that sugar levels directly affect moisture, with higher sugar contributing to moisture reduction through enhanced fermentation activity and intensified dehydration. Lower moisture levels generally correlate with a drier and denser texture in semi-dry fermented sausage products. In P4 (3% sugar), the decreased moisture content of 45.454% likely results in a product with a drier texture compared to P1, which retains 53.59% moisture. This reduction can also influence sensory perception of product, impacting characteristics such as chewiness, density, and moisture level upon consumption.

According to the Indonesian National Standard (SNI 01-3820-1995) for sausage product quality, the acceptable moisture content for fermented sausages ranges from 40% to 60%. The data from this study show that all sausage samples fall within the specified quality standards, with the highest moisture content (P1) still below the upper limit at 53.59%, and P4 nearing the lower limit at 45.454%. This indicates that moisture levels in all treatments meet the quality criteria for fermented sausage. [17] Reported that the moisture content of fermented catfish sausage reached 67%, where high sugar levels lead to enzyme activity that breaks down bound water into free water. This free water is more easily evaporated during fermentation, resulting in drier sausages. Lower moisture levels, such as those observed in treatments P3 and P4, are generally associated with extended shelf life due to reduced risk of pathogenic microorganism growth, which typically requires high moisture for development [18]. Additionally, moisture reduction can enhance both microbiological and chemical stability while decreasing the likelihood of spoilage or deterioration during storage.

3.4. Fat content of sausage

The fat content in sausage plays a crucial role in delivering texture, flavor, and juiciness to the final product.

Typically, fermented sausage products contain fat levels ranging from 10% to 30%, depending on the type of meat used and the production methods employed [19]. As shown in Table 5, the fat content of fermented duck sausage exhibited an increasing trend with higher sugar levels (P1: 0%, P2: 1%, P3: 2%, P4: 3%). Specifically, P1 (without sugar) had a fat content of 8.920%, while P4 (with 3% sugar) reached 9.306%. The significant increase in fat content across treatments indicates a clear relationship between sugar levels and the final fat content of the product. Karwowska et al. [20] noted that the fat content in fermented beef sausage ranges from 15% to 17%, underscoring the variability of fat levels depending on the meat source. Statistically, the addition of 1% sugar (P2) resulted in a significant increase in fat content compared to P1. In treatments P3 and P4, fat levels continued to rise, although the difference between P3 and P4 was not as pronounced as that between P1 and P2.

This phenomenon may be attributed to varying effects of water and fat binding during the fermentation process. The addition of sugar can influence distribution of fat in product, as sugar attracts moisture, which subsequently affects composition of other components, including fat. The observed increase in fat content may also be influenced by changes in water evaporation processes and fat redistribution during fermentation and drying. Reduction in moisture in products with higher sugar content, as indicated by previous moisture data, can enhance concentration of dry components, including fat. Consequently, products with higher sugar levels may appear to have elevated fat content due to the increased density of solid materials resulting from dehydration. Overall, the addition of sugar in fermented duck sausage not only affects moisture content but also contributes to increased fat levels. This is significant as higher fat content can impact the texture, flavor, and stability of the product, particularly concerning consumer preferences for fermented sausage products. Understanding these dynamics is essential for optimizing product formulation to achieve desired sensory attributes and shelf stability.

3.5. Total lactic acid bacteria (LAB)

The data presented in Table 6 indicates the total count of LAB in fermented duck sausage with varying sugar levels (P1: 0%, P2: 1%, P3: 2%, P4: 3%). While variations in LAB counts were observed across different treatments, statistical analysis revealed no significant differences ($p > 0.05$). The highest LAB count was recorded in P3 at 1.37×10^6 CFU/g, whereas the lowest was found in P2 at 2.6×10^4 CFU/g. LAB plays a crucial role in the fermentation process, primarily responsible for producing lactic acid, which lowers the product's pH and enhances the safety and shelf life of fermented sausages. Higher sugar levels, such as those in P3 and P4, provide more substrate for LAB fermentation, which should theoretically promote LAB growth. However, the data did not show a consistent trend of increased sugar correlating with significant LAB counts. This could be attributed to various factors, including environmental fermentation conditions, enzymatic activity, and initial LAB populations not directly measured in this study. Interestingly, while P2 (1% sugar) exhibited the lowest LAB count, P3 (2% sugar) showed the highest.

Although sugar serves as an energy source for LAB, an inadequate or excessive amount does not guarantee optimal growth. The osmotic stress at P4, resulting from excessive sugar, may have hindered LAB growth. Conversely, P3 likely represented an optimal balance between sugar availability and supportive growth conditions for LAB. A higher LAB count, as seen in P3, can lead to stronger fermentation characteristics, including increased acidity and changes in flavor profiles due to enhanced lactic acid production. Nonetheless, the absence of significant statistical differences among treatments suggests that variability in LAB counts may not substantially impact the sensory characteristics observed in the sausage products. Despite the lack of statistically significant differences, the presence of LAB in adequate quantities remains critical for fermented sausages to inhibit the growth of pathogenic microorganisms through acid production. The fermentation process involving LAB also contributes to extending the product's shelf life via natural acidification. Therefore, the LAB levels detected across all treatments are deemed sufficient for effective fermentation processes.

3.6. Protein content of sausage

Table 7 presents the protein content measurements of fermented duck sausage with varying sugar levels (P1: 0%, P2: 1%, P3: 2%, P4: 3%). A significant increase in protein content was observed with addition of sugar. In P1 (without sugar), the protein content was recorded at 14.910%, while P4 (3% sugar) reached 20.416%. Statistical analysis revealed significant differences among all treatments ($P < 0.05$), indicating that sugar addition effectively enhances protein levels. Most substantial increase was noted in P4, suggesting that higher sugar levels can enrich the nutritional profile of the fermented product. This enhancement may be attributed to sugar's role in retaining moisture during fermentation, thus facilitating better nutrient absorption from proteins. The significant rise in protein content across all sugar-containing treatments compared to control (P1) underscores influence of sugar on protein concentration in fermented sausages. Sugar serves as an energy source for microorganisms during fermentation, potentially improving fermentation efficiency & promoting increased protein production by these organisms. Additionally, partial dehydration may occur during fermentation, concentrating solid components, including protein, in the final product.

The fermentation process involving LAB can lead to the breakdown of proteins into smaller peptides and free amino acids, which can increase the measurable dissolved protein content. LAB utilizes sugar as the primary substrate for fermentation, and its enzymatic activity can significantly influence protein conversion in duck meat. The observed increase in protein levels may correlate with enhanced LAB counts or more efficient fermentation processes in treatments with higher sugar concentrations. Furthermore, the addition of sugar can reduce the water content in sausages, leading to a relative increase in protein content, as indicated by previous water content data, where higher sugar treatments exhibited significant reductions in moisture levels. The elevated protein content in treatments with higher sugar levels (P2 to P4) signifies that these fermented sausages offer better nutritional value concerning protein compared to the control (P1). This aspect is crucial in processed meat products, where protein content is a key indicator of nutritional quality. Additionally, the increase in protein may positively affect texture and sensory properties of the sausages, providing consumers with a product that is superior in both nutritional quality & flavor.

Table 1: Experimental design

NNo.	Treatment Code	Main Ingdredient	Dextrose Level (%)
1.	P1	Duck meat	0
2.	P2	Duck meat	1
3.	P3	Duck meat	2
4.	P4	Duck meat	3

Table 2: Sausage pH measurement results

Treatments	pH
P1	5.188 ± 0.015^{ab}
P2	5.166 ± 0.034^{a}
P3	5.224 ± 0.021^{c}
P4	5.220 ± 0.022^{bc}

Note: Numbers followed by different notations indicate a significant difference (p<0.05)

Table 3: Ash content of fermented sausages

Treatments	Ash content (%)
P1	0.874 ± 0.046a
P2	0.936 ± 0.005b
P3	0.962 ±.0.004b
P4	1.028 ±0.048c

Note: Numbers followed by different notations indicate a significant difference (p<0.05)

Table 4: Water content of fermented sausage

Treatments	Water content (%)
P1	53.590 ± 0.371a
P2	51.738 ± 0.641b
P3	47.438 ±0.589c
P4	45.454 ±2.579d

Note: Numbers followed by different notations indicate a significant difference (p<0.05)

Table 5: Fat content of fermented sausage

Treatments	Fat content (%)
P1	8.920 ± 0.163a
P2	9.154 ± 0.065b
P3	9.208 ±0.008bc
P4	9.306 ±0.017c

Note: Numbers followed by different notations indicate a significant difference (p<0.05)

Table 6: Total LAB of fermented sausage

Treatments	Total LAB
P1	$1.6 \times 10^{5} \pm 8.2 \times 10^{4\ a}$
P2	$2.6 \times 10^{4} \pm 2.2 \times 10^{4\ a}$
P3	$1.37 \times 10^{6} \pm 2.07 \times 10^{5\ a}$
P4	$1.85 \times 10^{5} \pm 1.96 \times 10^{4\ a}$

Note: Numbers followed by different notations indicate a significant difference (p<0.05)

Table 7: Protein content of fermented sausage

Treatments	Protein content (%)
P1	14.910 ± 0.101^{a}
P2	17.486 ± 0.242^{b}
P3	18.102 ± 0.093^{c}
P4	20.416 ± 0.538^{d}

Note: Numbers followed by different notations indicate a significant difference (p<0.05)

Table 8: TVC of fermented sausage

Treatments	TVC
P1	$2.02 \times 10^4 \pm 7.9 \times 10^{3\ a}$
P2	$5.5 \times 10^4 \pm 4.7 \times 10^{4\ ab}$
P3	$1.22 \times 10^5 \pm 8.0 \times 10^{4\ bc}$
P4	$1.6 \times 10^5 \pm 9.45 \times 10^{4\ c}$

Note: Numbers followed by different notations indicate a significant difference (p<0.05)

3.7. Total viable count (TVC)

Table 8 shows the TVC of fermented duck sausage with varying sugar levels (P1: 0%, P2: 1%, P3: 2%, P4: 3%). The data indicate a notable increase in microorganism counts with rising sugar levels in the product. The TVC in P1 (without added sugar) was recorded at a lower level of 2.02×10^4 CFU/g. In contrast, the addition of sugar in P2, P3, and P4 resulted in significant increases in TVC, with P4 reaching 1.6×10^5 CFU/g. This suggests that sugar acts as a crucial carbon source for microorganisms, particularly lactic acid bacteria (LAB), which play a vital role in fermentation processes. The observed increase in TVC, especially in P3 and P4, indicates that higher sugar availability supports the growth of fermentative microorganisms. Statistically, significant differences were found among the treatments ($P < 0.05$), with P2 and P3 showing higher microorganism counts compared to P1. However, the most pronounced increases were seen in P3 & P4, demonstrating that sugar significantly contributes to proliferation of microorganisms in fermented sausage. During fermentation, microorganisms utilize sugar to generate energy and secondary metabolites, such as lactic acid, helps lower the pH of product and aids in preservation.

The increase in TVC, particularly in P3 and P4, may be linked to more favorable conditions for fermentative microorganisms due to the higher substrate availability for their metabolism. Interestingly, while TVC increased with sugar addition, the rise in P4 was less pronounced than in P3. This phenomenon could be attributed to growth inhibition effects resulting from the accumulation of metabolites like lactic acid or reduced water activity due to lower moisture content, both of which can restrict microorganism growth at elevated sugar levels. It is essential to note that an increase in TVC during fermentation is primarily associated with the growth of LAB, which is beneficial for product safety. A higher TVC in fermented products does not necessarily indicate poor quality but rather reflects an active fermentation process. Nonetheless, it remains crucial to ensure that pathogenic microorganism populations are kept within safe limits to maintain product safety and quality.

4. Conclusions

Based on the research conducted on fermented duck sausages with varying levels of fermentable sugar, it can be concluded that the sugar level significantly affects several physicochemical and sensory parameters, including ash, moisture, fat, and protein content, as well as sensory aspects such as color, aroma, taste, and texture. Higher sugar levels led to increased ash and fat content, while moisture decreased, indicating sugar's role in drying and fat concentration. Protein content also increased with higher sugar, likely due to fermentation and protein denaturation processes. Although lactic acid bacteria (LAB) levels varied, they remained within a range supporting effective fermentation without significant statistical differences. Total viable counts (TVC) increased with higher sugar levels, indicating greater microbial activity, but remained safe for consumption. Sensory testing showed no significant differences in aroma and taste; however, higher sugar levels resulted in improved texture and darker color, with the texture being preferred by the panelists. Overall, adding fermentable sugar positively impacted physicochemical characteristics, such as increased protein and improved texture, but the significant variation in color should be considered to maintain the product's visual appeal for consumers.

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