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Research Article

Effect of different concentration of moringa leaf extract (MLE) on proximate components, cooking loss, pH and color attributes of broiler meat sausage batter

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Abstract

This study investigated the effects of varying concentrations of Moringa leaf extract (MLE) on the proximate composition, cooking loss, pH, and color attributes (CIE *L**, *a**, *b**) of broiler meat sausage batter. Employing a 3x5 factorial design, the study incorporated various storage periods (0, 14, and 28 days) and treatment groups (control, BHT, and MLE at 0.5%, 1.0%, and 1.5%). Results demonstrated that 1.5% MLE significantly reduced cooking loss (14.73 ± 0.97%) and improved protein retention (21.54 ± 0.07%) compared to the control group, which exhibited a cooking loss of 19.07 ± 3.11% and protein retention of 18.49 ± 1.49%. Additionally, MLE significantly influenced pH, reducing it from 6.69 in the control to values ranging from 6.27 to 6.33 in the treated samples ($p < 0.01$), while influencing color parameters by increasing yellowness (b = 23.85 at 1.5% MLE) and decreasing redness (a = −2.82). Proximate components, including dry matter, ash, protein, and fat, as well as cooking loss, remained unaffected ($p > 0.05$). Notably, MLE at a 1.0% concentration was identified as optimal, enhancing antioxidant properties without compromising sensory or nutritional quality. These findings underscore the potential of MLE as a functional, natural ingredients in clean-label meat products, catering to the growing consumer demand for alternatives to synthetic additives aimed at improving the quality and shelf life of broiler meat sausages.

Introduction

Poultry meat has a nutritional profile that is low in fat and high in polyunsaturated fatty acids (Im et al., 2023). Due to its low-calorie nature, poultry meat can be susceptible to lipid oxidation, primarily owing to the elevated degree of unsaturation in its muscle lipids. This oxidation process can adversely affect the meat, leading to changes in color, flavor, and texture, as well as a reduction in nutrient quality and shelf life. Various factors contribute to this oxidative deterioration, including intrinsic elements such as iron content and antioxidant enzyme activity, as well as extrinsic influences like stress, temperature fluctuations, the use of highly oxidized feed, methods of slaughter, and storage and processing conditions. Although poultry meat serves as an excellent source of protein, post-slaughter, its protein content is vulnerable to oxidation. This can trigger secondary lipid oxidation processes, compromising the functional properties, acceptability, and overall quality of the meat protein.

The growing global demand for clean-label, functional foods has prompted extensive research into natural preservatives as viable alternatives to synthetic additives such as butylated hydroxytoluene (BHT), paralleled by advancements in authentication technologies like NIR spectroscopy to combat meat adulteration (Hashem et al., 2024). BHT is commonly used in the meat industry to enhance shelf life and prevent lipid oxidation. Among these natural alternatives, Moringa oleifera leaf extract (MLE) has emerged, enriched with bioactive compounds including phenolics and flavonoids, demonstrating significant antioxidant and antimicrobial properties (Alhakmani et al., 2013; Ali et al., 2023). Recent studies have highlighted the potential of these leaves as natural preservatives, demonstrating their ability to inhibit oxidative rancidity in goat meat patties while significantly extending the shelf life of ghee (Im et al., 2023). Additionally, Moringa oleifera leaves exhibit both antifungal and antimicrobial effects, establishing their application in food preservation and as nutraceuticals across various industries (Meireles et al., 2020).

Complementary studies have explored the incorporation of other plant-based extracts such as ginger and tulsi leaves into processed meat products like sausages and meatballs, demonstrating promising effects on physicochemical stability, microbial load reduction, and sensory acceptability during storage (Hossain et al., 2021); (Siddiqua et al., 2018). For example, the addition of 2% ginger extract to spent hen sausages significantly improved flavor and overall acceptability, while 0.3% tulsi extract in beef meatballs showed superior performance in controlling lipid oxidation and microbial proliferation across a 60-day frozen storage period.

In a related context, gamma irradiation has been evaluated as a physical preservation technique, effectively minimizing microbial load and extending the shelf life of beef without substantially compromising nutritional properties, with 6 kGy found to be optimal

(Haquea et al., 2017). This points to an ongoing need to balance both biochemical integrity and microbial safety when developing shelf-stable meat products.

Post-rigor processing has also been shown to enhance physicochemical and sensory properties of broiler meat, including improved tenderness, flavor, and instrumental color attributes, further highlighting the role of aging in poultry meat quality enhancement (Khatun et al., 2025). Similarly, drip loss and water-holding capacity—critical quality indicators—have been quantitatively benchmarked using both the standard bag and filter paper methods to classify broiler meat into PSE, normal, and DFD categories (Sarker et al., 2024). These insights support more precise meat quality categorization systems, essential for modern poultry processing operations.

Moreover, advances in understanding meat tenderness at the molecular level, particularly the role of genes such as Calpain, Calpastatin, and Myostatin, offer new avenues for improving meat texture through selective breeding and postmortem handling practices (Sarker et al., 2024). In parallel, the integration of artificial intelligence with near-infrared spectroscopy is revolutionizing the way meat quality is assessed, enabling faster, non-destructive, and more accurate detection of safety and authenticity parameters in the meat supply chain (Sarker et al., 2024).

The poultry industry in Bangladesh has experienced rapid growth, driven by the increasing demand for ready-to-cook meat products and a rising consumer base that prefers convenient food options. The Bangladesh Poultry Industries Coordination Committee (BPICC) reported that by 2021, the daily requirement for chicken meat would reach approximately 3.5 to 4 thousand metric tons. This expansion aligns with a surge in consumer interest in fast food, further propelling the demand for chicken meat and leading to the emergence of various poultry processing companies throughout the country. Historically, numerous poultry products such as sausages, meatballs, chicken rolls, and nuggets were imported and often unaffordable for the middle class. However, the landscape has shifted with domestic industries now producing and marketing an array of frozen chicken meat products under distinct brand labels. The increasing availability of these products in small retail outlets has led to a diverse consumer base procuring packaged items like chicken sausages and nuggets at various price points. This burgeoning market underscores the need for research into poultry meat products and their diversification, especially in the context of the rising popularity of sausages across Bangladesh.

Results indicated an improved cooking yield of 66.68 ± 1.41%, a reduction in lipid oxidation (measured by TBARS: 0.32–0.47 mg MDA/kg), and significant microbial inhibition (total plate count: 3.2–4.1 log CFU/g) over a 30-day period at 4°C. Notably, the 0.10% extract surpassed potassium sorbate in terms of oxidative stability and sensory acceptability (Seleshe et al., 2021). Despite the advancements in diversifying meat products, challenges such as lipid oxidation and microbial proliferation continue to impact the shelf life and quality of ground meats. Lipid oxidation leads to unfavorable changes in flavor, nutritional value, and safety, thereby underscoring the necessity for further exploration of natural preservatives (Domínguez et al., 2019; Jung et al., 2010). Consequently, the meat industry is increasingly urged to investigate plant-based alternatives that not only enhance product quality but also align with the rising consumer demand for natural food options.The poultry industry in Bangladesh has experienced rapid growth, driven by the increasing demand for ready-to-cook meat products and a rising consumer base that prefers convenient food options. The Bangladesh Poultry Industries Coordination Committee (BPICC) reported that by 2021, the daily requirement for chicken meat would reach approximately 3.5 to 4 thousand metric tons. This expansion aligns with a surge in consumer interest in fast food, further propelling the demand for chicken meat and leading to the emergence of various poultry processing companies throughout the country. Historically, numerous poultry products such as sausages, meatballs, chicken rolls, and nuggets were imported and often unaffordable for the middle class. However, the landscape has shifted with domestic industries now producing and marketing an array of frozen chicken meat products under distinct brand labels. The increasing availability of these products in small retail outlets has led to a diverse

consumer base procuring packaged items like chicken sausages and nuggets at various price points. This burgeoning market underscores the need for research into poultry meat products and their diversification, especially in the context of the rising popularity of sausages across Bangladesh.

To address consumer demand for healthier and safer meat products, the incorporation of beneficial ingredients while minimizing undesirable components has become paramount. Effective strategies in this regard involve the integration of natural additives, such as vegetable oils, fish oils, and plant extracts, into meat and meat products to enhance both nutritional and sensory profiles (Arihara, 2006; Valencia et al., 2008). Research indicates that the functional properties of meat products can be significantly enhanced with the addition of high-quality fibers and fats (Bilek and Thuran, 2009; Schmiele et al., 2014; Yogesh et al., 2013), thus presenting an innovative pathway for product formulation. For instance, a recent study examined the incorporation of wheat bran (0–15%) into chicken sausages, assessing its impact on sensory attributes, proximate composition, color stability, and shelf life during refrigerated storage. The findings revealed that the addition of 5% wheat bran optimally improved dietary fiber content and overall product acceptability (Shanaullah et al., 2024). In another study, the effects of ginger extract (2% and 4%) on the sensory, physicochemical, and biochemical properties of spent hen sausages were evaluated over various storage periods (0, 15, and 30 days). The incorporation of ginger extract resulted in significant enhancements in quality and shelf life compared to control samples (Hossain et al., 2021). Additionally, research investigating the impact of bee honey (2% and 4%) on similar parameters in spent hen sausages highlighted improvements in flavor, tenderness, and overall consumer acceptability. Notably, the application of 4% honey yielded the highest sensory scores, despite an increase in lipid oxidation (as measured by TBARS) over time (Ali et al., 2022).

This study aimed to fill the research gap regarding the application of MLE in broiler sausage batter, a vital segment of Bangladesh's poultry sector that remained largely unexplored. By evaluating the combined effects of MLE at concentrations ranging from 0.5% to 1.5% on sensory, physicochemical, and microbial quality during refrigerated storage, we hypothesized that natural additives would synergistically enhance the sausages' shelf life, nutritional value, and consumer acceptability compared to traditional synthetic preservatives like pomegranate and tomato extracts (Ghafouri-Oskuei et al., 2019; Hussien et al., 2019). Ultimately, this research aspired to contribute to the development of healthier meat products in response to increasing consumer demand for safer and more nutritious options. The findings aimed to identify the optimal concentration of MLE that improved sausage quality while supporting its application as a functional ingredient in meat processing. By investigating these natural alternatives, the meat industry could innovate in ways that aligned with consumer preferences and promoted safer, higher-quality food products.

Materials and methods

Proximate analysis

The proximate composition of broiler meat sausage batter was assessed according to the standards established by the Association of Official Analytical Chemists (AOAC, 1995). Specific parameters measured included dry matter, ash, protein, and fat content.

pH determination

For pH analysis, a five-gram sample of the cooked sausage was blended with 25 ml of distilled water in a high-speed blender for 1 minute, ensuring thorough homogenization. The pH value was subsequently measured using a digital pH meter (model 210, HANNA Instruments). This process involved the preparation of a homogenate by combining the meat sample with distilled water to ensure accurate pH readings.

Cooking loss

To evaluate cooking loss, a sample weighing 5 ± 1 g was carefully wrapped in heat-stable aluminum foil and immersed in a water bath maintained at 75°C for 30 minutes. Following cooking, the sample's surface was dried, and its weight recorded. Cooking loss was quantified as a percentage of the weight loss observed in the cooked sample, calculated using the formula:

$$\text{Cooking loss}(\%) = \frac{W2 - W3}{W2} \times 100$$

Where, W2 = Weight of the sausage batter before cooking, W3 = Weight of the sausage batter after cooking

Color analysis

To assess surface color variations, the CIE L*, a*, b* values of the chicken nugget samples were measured using a Minolta Chroma Meter (Minolta CR 410, Tokyo, Japan), which was standardized against a white plate with the following specifications: (Y =93.5, X = 0.3132, y = 0.3198). This objective colorimetric assessment ensures a quantifiable comparison of color attributes among samples.

Materials collection

Broiler chickens were sourced from Kamal Ranjit (K.R) market at the Bangladesh Agricultural University, Mymensingh. Following slaughter, breast meat samples were collected and promptly frozen at -18 °C in the Poultry Science Laboratory. Ingredients such as corn flour, garlic, onion, various meat spices, garam masala, and salt were obtained from the local market. Additionally, BHT (butylated hydroxytoluene) and other necessary chemicals were procured from Dhaka.

Preparation of *Moringa oleifera* leaves extract

Moringa leaf extract was prepared by collecting fresh leaves from the Moringa oleifera tree, ensuring the stem portions were carefully trimmed away. The leaves underwent thorough washing with clean water to eliminate any dirt or impurities. Subsequently, the cleaned leaves were crushed using a mortar and pestle, with a minimal addition of water to facilitate the grinding process, until a paste-like consistency was achieved. This mixture was then blended to obtain a smooth texture. A fine sieve or cheesecloth was utilized to filter the blend, and the resultant liquid was collected in a sterile container. The extracted Moringa leaf juice was subsequently utilized in the experimental procedures.

Sample Preparation

Five kilograms of chicken breast meat were procured from the local BAU market. The evaluation encompassed sensory attributes, color analysis, proximate composition, physicochemical properties, biochemical parameters, and microbial assessments. To compare the effects of natural antioxidants against BHT, control and negative control groups were introduced in each trial. The meat samples were treated with Moringa leaf extract at concentrations of 0.5%, 1.0%, and 1.5% (designated as T3, T4, and T5, respectively), while BHT was used at a concentration of 0.01% (T2). The experimental design adhered to a 3x5 factorial framework under Completely Randomized Design (CRD), where the three factors represented different storage periods (0, 14, and 28 days) and five treatment groups (T1, T2, T3, T4, and T5). Prior to experimental execution, all equipment, jars, and containers were meticulously cleaned with hot water and detergent, dried appropriately, and left untouched until required. Data analysis was conducted using SAS software, with Duncan's Multiple Range Test (DMRT) employed as a post-hoc analysis to discern significant differences among treatment groups. Statistical evaluation facilitated the identification of the most effective treatments concerning sensory quality and nutritional composition, providing insights for future development of functional food products.

Sausage batter Preparation

Visible fat and connective tissue were meticulously trimmed from the chicken breast meat, which was subsequently cut into small pieces. The meat was ground using a meat grinder and blended with a specialized mixture of spices, including chili powder, turmeric powder, onion paste, and a combination of ginger, cinnamon, and pepper paste. Further chopping was conducted in a bowl chopper, incorporating salt and corn flour into the mixture. The blended meat was divided into five portions labeled T1 through T5. Moringa leaf extract was incorporated into treatment groups T3, T4, and T5 at concentrations of 0.5%, 1.0%, and 1.5%, respectively. Each mixture was encased in small round pieces of plastic resembling candy, with both ends securely tied with thread to prevent water ingress. The sausages were then submerged in boiling water for cooking. This procedure was replicated three times to prepare samples for analysis, with the first batch serving as a fresh reference. To maintain a low temperature throughout the blending process in the bowl chopper, slushed ice was periodically added. The finished sausages were vacuum-packed in polyethylene bags and refrigerated for a duration of up to 28 days, with assessments performed immediately after processing (0 days) and at intervals of 14 and 28 days post-storage.

Results and Discussion

The impact of different concentrations of moringa leaf extract (MLE) on the proximate components, cooking loss, pH, and color attributes of broiler meat sausage batter was thoroughly analyzed and is summarized in Table 1.

Proximate analysis of sausage batter

The dry matter content across the treatments ranged from 30.90% (T1) to 32.11% (T5), with no significant differences observed (p>0.55). The ash content similarly varied between 1.36% (T1) and 1.92% (T5), yet did not exhibit (Figure 1) significant differences (p>0.12). Crude protein mean values ranged from 18.0% (T2) to 21.54% (T5), again showing no significant differences (p>0.06). Ether extract content ranged from 5.08% to 6.75%, with the control group (T1) having the highest content while the lowest was found in the group with 1.5% MLE (T5), where no significant difference was noted (p>0.28). Overall, the study indicated that the inclusion of MLE and the synthetic antioxidant Butylated Hydroxytoluene (BHT) did not induce substantial changes in the overall proximal composition of the sausage batter, aligning with findings by Najeeb et al. (2014).

Table 1. Effect of different concentration of moringa leaf extract (MLE) on proximate component, cooking loss, pH and color attributes (CIE *L**, *a**, *b**) of broiler meat sausage batter

Parameters	Different Treatments					Level of significance
	T_1	T_2	T_3	T_4	T_5	
Dry matter (%)	30.90±0.07	31.03±0.48	31.20±0.79	31.39±0.49	32.11±0.49	p>0.55
Ash (%)	1.36±0.16	1.57±0.14	1.65±0.20	1.88±0.03	1.92±0.04	p>0.12
Crude protein (%)	18.49±1.49	18.00±0.05	19.15±0.18	20.91±0.59	21.54±0.07	p>0.06
Ether extract (%)	6.75±0.55	6.65±0.60	6.65±0.60	5.48±0.43	5.08±0.78	p>0.28
Cooking loss (%)	19.07±3.11	18.08±2.05	16.86±0.51	15.38±0.52	14.73±0.97	p>0.45
Raw pH	$6.69^{a}\pm0.05$	$6.44^{b}\pm0.04$	$6.33^{bc}\pm0.03$	$6.28^{c}\pm0.03$	$6.27^{c}\pm0.02$	p<0.01
Lightness (*L)**	68.44±0.99	71.07±1.39	65.47±2.01	65.05±0.76	61.58±4.58	p>0.13
Redness (*a)**	$2.43^{a}\pm0.17$	$2.11^{a}\pm0.07$	$0.57^{b}\pm0.42$	$-2.44^{c}\pm0.20$	$-2.82^{c}\pm0.09$	p<0.01
Yellowness (*b)**	$19.79^{b}\pm0.87$	$21.03^{ab}\pm1.13$	$22.12^{ab}\pm1.25$	$23.32^{a}\pm0.32$	$23.85^{a}\pm0.46$	p<0.05

Different superscripts in different treatments groups differ significantly (p<0.05), T_1= Control, T_2= Sausage with 0.01% BHT, T_3= Sausage with 0.5% moringa leaf extract (MLE), T_4= Sausage with 1.0% moringa leaf extract (MLE), T_5= Sausage with 1.5% moringa leaf extract (MLE)

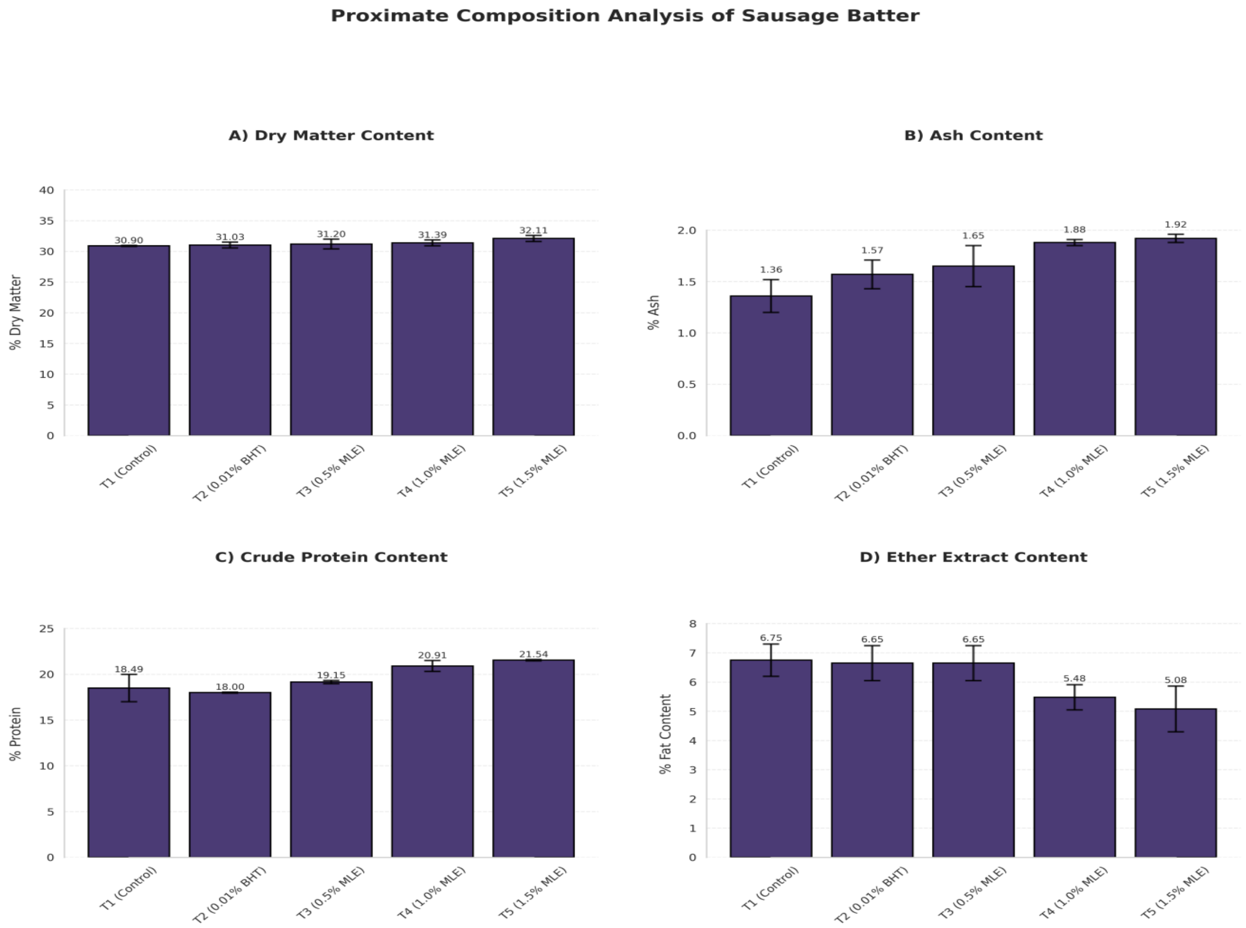

Figure 1. Proximate composition analysis across various treatments.

Cooking loss of sausage batter

Cooking loss ranged from 14.73% to 19.07% across the treatments without significant differences ($p>0.45$) (Figure 2). The lowest cooking loss occurred in the group with 1.5% moringa leaf extract (T5), while the highest was in the control group (T1). These findings suggested that while MLE concentration had a notable effect on other parameters, it maintained consistency in the moisture retention capacity during cooking.

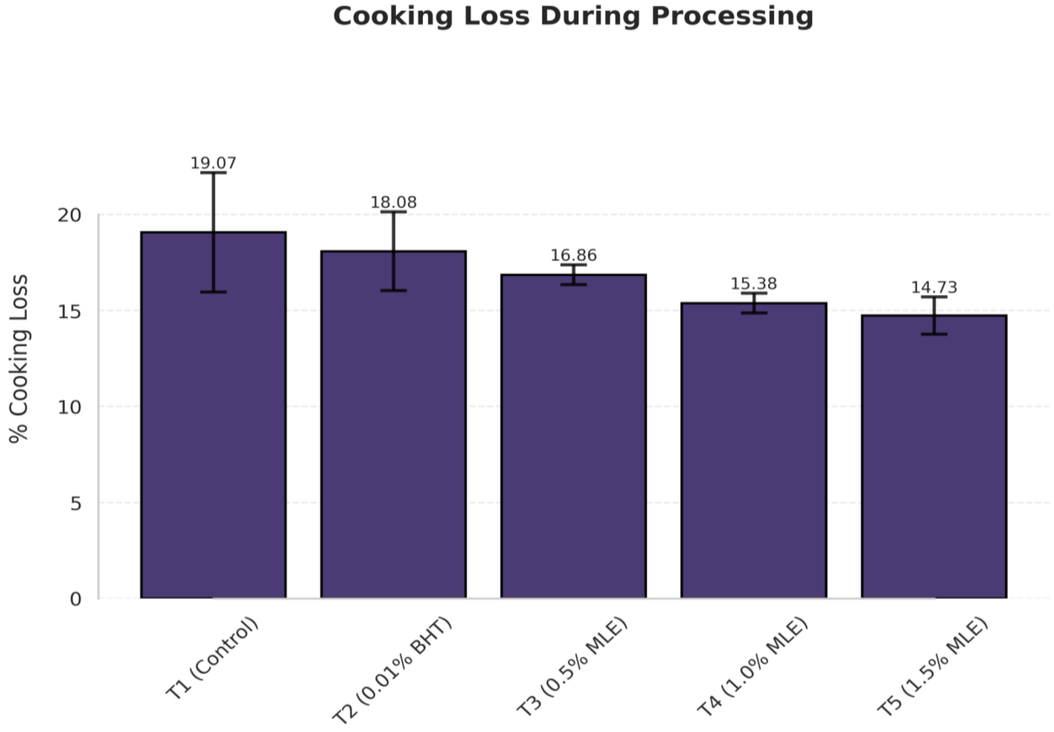

Figure 2. Cooking loss (%) across treatments with varying MLE concentrations.

pH of sausage batter

The observed fluctuations in pH exhibited a significant divergence among the various treatment groups, contradicting initial expectations. Notably, the control group exhibited the highest pH value of 6.69, while the Moringa leaf extract (MLE)-treated sausages displayed markedly lower pH values, ranging from 6.33 to 6.27 (Figure 3). This observed reduction in pH may be attributable to the metabolic activities of psychrophilic bacteria, which likely fermented the carbohydrates present in the Moringa leaf powder, thereby producing organic acids, particularly lactic acid. This finding aligns with the conclusions drawn in similar studies conducted by Jayawardana et al. (2015), Elhadi et al. (2016), and Falowo et al. (2016).

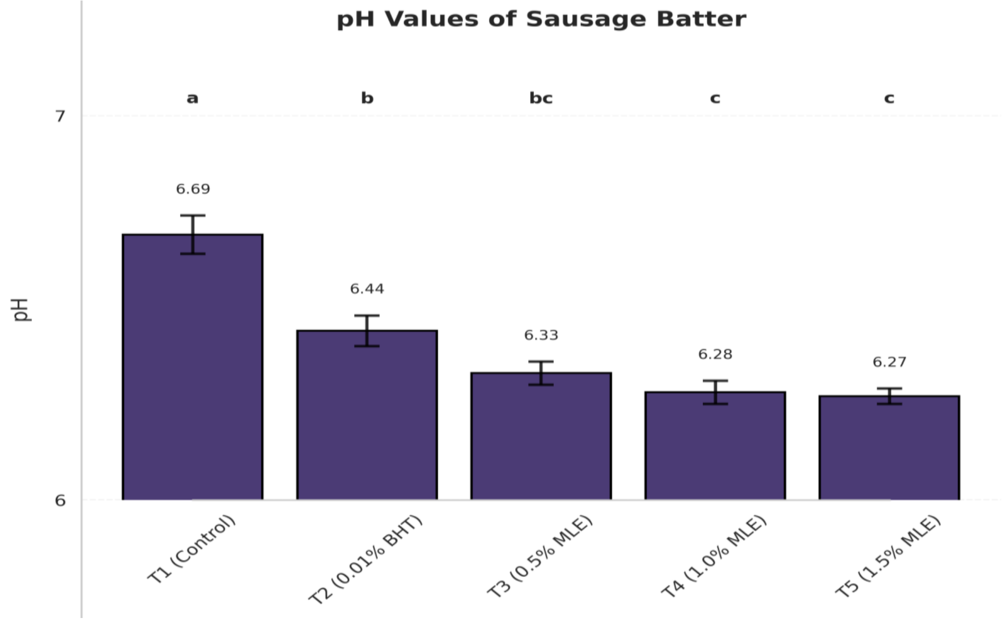

Figure 3. pH values of broiler sausage batter under different treatments.

Instrumental surface color (CIE *L**, *a**, *b**) of sausage batter

The color attributes of the broiler meat sausage batter exhibited significant variations across treatments, particularly in CIE redness (a*) and yellowness (b*). The control (T1) and BHT (T2) groups demonstrated the highest a* values, indicative of a more reddish color, while groups with 1.0% MLE (T4) and 1.5% MLE (T5) displayed the lowest a* values, which indicated reduced redness (Figure 4). Conversely, the yellowness (b*) values significantly differed ($p<0.05$), with the highest b* value observed in the group with 1.5% MLE (T5) and the lowest in the control group (T1). The notable changes in color attributes observed in this study suggest that different MLE concentrations could influence consumer perception and acceptance of the product.

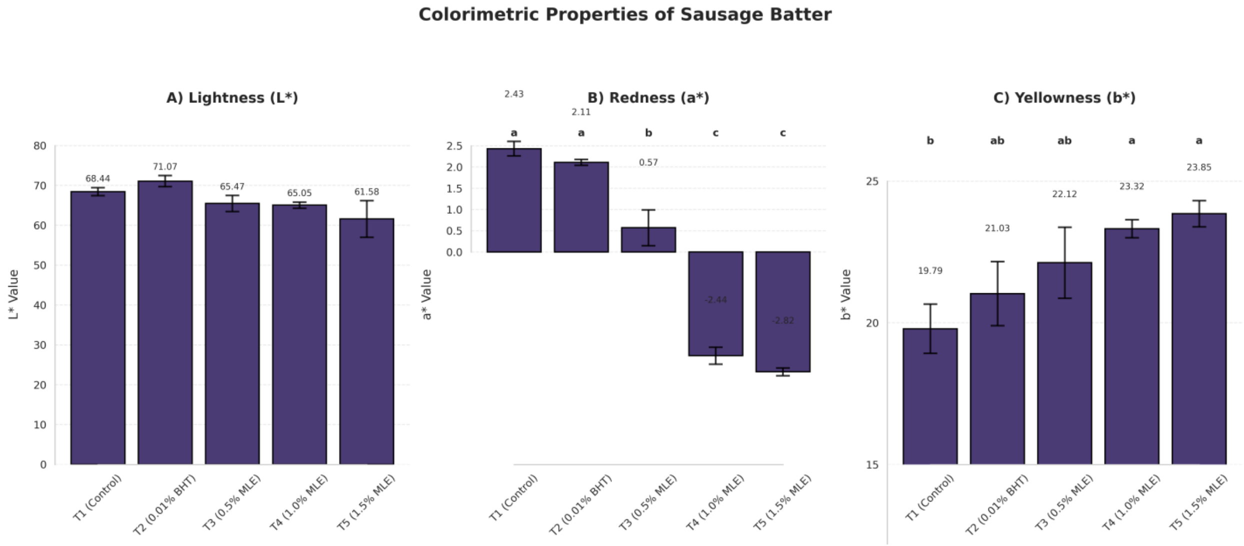

Figure 4. Color attributes (CIE L*, a*, b*) of sausage batter with MLE treatments.

The present study elucidates the stability of certain proximate components in broiler meat sausages despite fluctuations in Moringa leaf extract (MLE) concentration. Interestingly, while pH and cooking loss did not exhibit the anticipated statistical correlation, the notable influence of MLE concentration on acidity underscores its significance in the formulation's overall quality. Additionally, the observed variances in color metrics attributed to MLE application suggest that consumer preferences can be strategically influenced through adjustments in these concentrations. The findings of this investigation accentuate the complex interplay among various parameters, reinforcing the potential advantages of incorporating natural antioxidants such as MLE without compromising the essential nutrient profile of broiler meat sausage products. Similar to genotype-dependent variations in beef quality, where indigenous cattle exhibited superior juiciness and water-holding capacity (Hashem et al., 2024a), MLE's modulation of pH and color in broiler sausages underscores its role as a functional ingredient tailored to consumer preferences. A related study demonstrated the efficacy of MLE at concentrations ranging from 0.5% to 1.5%, revealing substantial reductions in cooking loss (14.73 ± 0.97%) and ether extract content (5.08 ± 0.78%). Furthermore, this study found a marked improvement in protein retention (21.54 ± 0.07%). However, the accompanying increase in yellowness (b*: 23.85 ± 0.46) and decrease in redness (a*: -2.82 ± 0.09) highlight potential sensory trade-offs (Biplob et al., 2024). Moreover, another investigation assessed the impact of a 1.0% concentration of MLE on chilled poultry meat (1–4°C) for a duration of 16 days. This study reported significant reductions in microbial growth (total viable count), lipid oxidation (TBA: 0.45 ± 0.02 mg MDA/kg), and pH (6.25 ± 0.02), while ensuring sensory acceptability (flavor rated at 7.8/9.0) and extending the shelf life compared to the control samples. Notably, olive leaf extract demonstrated similar efficacy in inhibiting microbial growth (Im et al., 2023). In addition, another study evaluated the impact of Moringa oleifera seed extract (0.5–2.0%) in chilled poultry meat. This research demonstrated significant reductions in lipid oxidation (TBARS: 0.38 ± 0.02 mg MDA/kg), microbial growth (TPC: 3.4 ± 0.3 log CFU/g), and pH (6.15 ± 0.03), while enhancing shelf life to 14 days and sensory acceptability (flavor: 8.2/10) compared to control groups. However, it is worth noting that higher concentrations (>1.5%) may compromise redness (a*: 1.8–0.5) due to antioxidant interactions (Mounika and Sahityarani, 2023). Further evaluation of Moringa oleifera leaf extract (MOLE; 1–5%) in mutton patties stored under refrigeration for 15 days revealed significant enhancements in nutritional properties (protein: 21.75 ± 0.81%, total phenolics: 41.96 ± 4.23 mg GAE/g), along with reduced lipid oxidation (TBARS: 0.38–0.47 mg MDA/kg) and microbial inhibition (total bacterial count: 4.30 ± 0.2 log CFU/g at 5% MOLE). However, as observed in other studies, higher concentrations negatively impacted redness (a*: 0.23–2.27) due to antioxidant interactions (Mashau et al., 2021a). This research also evaluated the efficacy of Moringa oleifera leaf powder (MOLP; 0.2–0.8%) in ground beef over a 15-day refrigerated storage period, revealing enhanced protein content (23.32 ± 0.81%), total phenolic content (54.59 ± 4.23 mg GAE/g), and microbial inhibition (total plate count: 4.30 ± 0.2 log CFU/g at 0.8% MOLP), alongside reduced lipid oxidation (TBARS: 0.38–0.47 mg MDA/kg), though higher MOLP concentrations similarly decreased redness (a*: 0.23–0.27) due to antioxidant interactions (Mashau et al., 2021b). In conclusion, the investigation into the impact of Moringa leaf extract on broiler meat sausage reveals that, while proximate composition largely remains unaltered, there are significant effects on pH and color attributes, highlighting the extract's crucial role in food formulations. These findings bolster the proposition of utilizing natural antioxidants in meat products, contributing positively to nutritional stability and consumer appeal. As underscored by the results, further research and development in this domain could yield enhanced meat products that align with consumer demands for both health benefits and quality.

Conclusions

This study investigates the application of Moringa oleifera leaf extract (MLE) as a natural preservative in broiler meat sausages, demonstrating that an optimal concentration of 1.0% effectively enhances quality by significantly reducing pH, improving oxidative stability, and modulating color attributes without negatively impacting proximate composition or cooking yield. MLE notably improves sensory attributes, including color and flavor; however, higher concentrations (e.g., 1.5%) may lead to undesirable off-flavors, highlighting the importance of moderation. While discoloration issues necessitate further sensory evaluation, these findings support MLE as a viable natural preservative that meets consumer preferences for clean-label ingredients. Notably, compared to synthetic antioxidants like BHT, MLE presents a promising alternative for extending shelf life in poultry products. The incorporation of MLE into broiler meat sausage batter emerges as a strategic approach for developing functional meat products with natural antioxidant and antimicrobial properties. Although MLE does not significantly alter nutritional composition or cooking loss, its efficacy in lowering pH and modifying color parameters indicates its potential role in enhancing shelf life and overall product quality.

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