

ORIGINAL RESEARCH ARTICLE

Assessment of physicochemical, color and microbial properties of coated coconut shell wrapped chicken meat

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ABSTRACT

Broiler meat is widely favored as an affordable protein source and is the primary type of chicken meat worldwide. This study investigates how different packaging materials, specifically polythene and coconut shell packaging, affect the physicochemical and microbial qualities of frozen broiler meat. The well-known adverse effects of polythene on meat preservation were reduced by using coconut shells as an alternative packaging material. The thawing loss and drip loss of meat significantly increased ($p < 0.05$) when packed in polythene ($6.63 \pm 0.34\%$, $8.64 \pm 0.21\%$) compared to coated coconut shells ($6.04 \pm 0.24\%$, $7.52 \pm 0.35\%$) after 15 days of frozen storage. The results showed minimal changes in moisture, protein, and ash content. The color parameters of the coated coconut shell-packed samples significantly increased ($p < 0.05$), except for lightness during freezing, compared to fresh polythene-packed meat. Additionally, the mean total plate count and lipid oxidation rate for coated coconut shell-packaged meat (7.12 ± 0.01 log CFU/g and 0.25 ± 0.03 μmol MDA/kg) were lower than those of polythene-packaged meat (7.31 ± 0.02 log CFU/g and 0.28 ± 0.02 μmol MDA/kg), respectively. These findings highlight that coated coconut shell can serve as a sustainable packaging alternative to polyethylene, helping to preserve the quality of broiler meat while supporting food security and environmental conservation.

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1.0 Introduction

In Bangladesh, broiler meat serves as a crucial and affordable source of animal protein, contributing significantly to the dietary habits of diverse population groups. The poultry industry, comprising both backyard and commercial enterprises, plays a vital role in meeting the country's protein needs (Rahman et al., 2017). With the increase in per capita annual broiler meat consumption, the sustainable production and preservation of broiler meat becomes essential. The nutritional composition of raw and whole meat with skin, cooked per 100 grams of poultry meat, contains 196 kcal of energy, 18.6 g of protein, 15.1 g of total fat (lipid), and 0.4 g of total iron (Bordoni & Danesi, 2017). The poultry sector in Bangladesh, a vital contributor to food security and economic development, suffered severe consequences. The livestock sector's expansion is critical for lowering import costs and raising foreign exchange profits through exports (Yasmin & Alam, 2020).

Preservation methods are important for protecting the natural quality and safety of broiler meat. Techniques such as refrigeration (keeping meat at 0 °C to 4 °C) and freezing lower the temperature to inhibit microbial activity and extend shelf life (D. Dave & A.E. Ghaly, 2011). Smoking imparts flavor and acts as a preservative, while drying removes moisture to inhibit microbial growth (Toldrá, 2008). The use of preservatives, such as antimicrobial agents, helps hinder spoilage, and vacuum packaging slows down oxidation and microbial growth. Modified Atmosphere Packaging entails the strategic modulation of the internal gaseous environment to impede microbial propagation and mitigate oxidative degradation (Demirhan & Candoğan, 2016; Sun et al., 2021). Proper hygiene and safety standards by customers and during processing are critical to avoid cross-contamination and undercooking, which are significant risk concerns (Khalid et al., 2020). Improper processing, substandard storage, and contaminated equipment can lead to microbial contamination, with bacteria like *Salmonella* and *Campylobacter* commonly associated with poultry, potentially causing foodborne illnesses (Gomes et al., 2023). Cold storage conditions are crucial in maintaining optimal broiler meat quality, and recent studies emphasize the importance of factors like freezing temperature, duration, and thawing conditions (Pal et al., 2018).

Packaging is a critical aspect of food preservation, and the prevalent use of non-biodegradable plastics raises environmental concerns (Hammam, 2019). Despite the benefits of plastic in preserving product freshness, it is necessary to balance its advantages with sustainable and eco-friendly alternatives (Gheorghita, Amariei, et al., 2020). Additionally, the short shelf life of *Gallus gallus domesticus* meat necessitates effective packaging methods to extend its quality and reduce food waste (Chmiel et al., 2019). Concerns about plastic's environmental impact, particularly in terms of microplastic migration into food, highlight the need for eco-friendly packaging alternatives (Katsara et al., 2022). The European Union's initiatives to reduce plastic usage emphasize the urgency of addressing plastic waste management and transitioning to sustainable packaging (Gheorghita, Gutt, et al., 2020). To address environmental challenges, there is an increasing interest in biodegradable and renewable packaging materials, such as those made from coconut shells (Rizal et al., 2020).

Coated coconut shell-based packaging is not universally available but is abundant in coconut-producing regions where shells are generated as agro-industrial waste. In these contexts, it offers a low-cost, sustainable, and locally applicable alternative to synthetic plastic packaging for poultry products. Therefore, this study aims to compare the impact of different packaging methods (polythene and coconut shell packages) and storage conditions on the physicochemical and microbial quality of frozen broiler over time. Therefore, this study aimed to evaluate the effectiveness of coated coconut shell-based biodegradable packaging compared with conventional polythene packaging in preserving the physicochemical quality, oxidative stability, sensory attributes, and microbial safety of frozen broiler chicken meat during storage.

2.0 Materials and Methods

2.1 Ethical Statement

This investigation was undertaken within the Department of Nutrition and Food Technology, Jashore University of Science and Technology, Jashore-7408, Bangladesh. 20 broiler chickens were randomly purchased from a licensed local retail market and slaughtered using standard commercial halal practices (Addeen et al., 2014; Sukardi et al., 2022). The slaughtering and sample collection procedures followed animal welfare considerations and were conducted according to established commercial practices and previously published protocols (Addeen et al., 2014; Njoga et al., 2023).

2.2. Chicken slaughtering method and sample preparation

Post-slaughter, the carcasses were allowed to rest for approximately 3 to 5 minutes to ensure complete exsanguination and confirm the cessation of vital signs before handling. Subsequently, the chickens were immersed in hot water maintained at 60 °C for a duration of two minutes to aid in the loosening of feathers through scalding, followed by mechanical defeathering. The meat was subsequently separated from the bone and skin, and the meat was cut into uniform portions. The portions were randomly assigned to the several packaging treatments (polythene and coconut shell), and separate packages were used for every treatment and frozen storage (Kamruzzaman Md. et al., 2024).

2.3 Preparation of Coated Coconut Shell as packaging material

The preparation of coated coconut shells as a packaging material was carried out using the procedure of Jadhao et al. (2021). The dried inner coconut shells were purchased from a coconut oil processing factory. They were thoroughly cleaned, dried, and polished with rough-surface metallic paper to achieve a smooth outer and inner surface on the shell. After washing with potable water to remove impurities, the shells were dried in an oven for around 60 minutes at 60°C to ensure complete dryness. The outer layer of the coated coconut shells was coated with melted food-grade wax, and the inner layer received a coating of coconut oil to prevent moisture loss through the shell. Subsequently, the coconut shells were frozen at -18 °C for nearly 5 minutes to solidify the coconut oil. Following this, approximately 100 g of poultry meat was put into the coconut shell, and the two parts of the shell were tightly sealed using food-grade wax. Once assembled and sealed, the

coated coconut shell container was ready for frozen storage at -18 °C for 0- and 15-day durations.

2.4. Physical analysis

2.4.1. Color

The color of fresh and frozen meat samples was determined by using a digital colorimeter (Konica Minolta Chromameter CR-400), which was calibrated to get the values of lightness (L^*), redness (a^*), yellowness (b^*), Chroma (C^*), and Hue (h^0) (Zhu et al. 2019).

2.4.2. Cooking loss

By following Sabow A. (2024) procedure, the cooking loss of meat was measured. The cooking loss was determined by quantifying the weight loss that occurs during the heating (100 °C $\pm$ 2) process. Cooking loss is an important statistic that measures meat's ability to retain water during the cooking process, providing information on its water-holding capacity and overall quality.

$$\text{Cooking loss (\%)} = \frac{W1 - W2}{W1} \times 100$$

Here, W1 = initial weight of the meat sample before cooking; W2 = final weight of the meat sample after cooking.

2.4.3. Thawing loss

Following the Sabow, A. (2024) a procedure was used to measure the thawing loss. The capability of meat to retain moisture during the thawing process can be evaluated by measuring the weight loss that occurs when frozen meat is allowed to thaw. For the thawing loss measurement, weigh the frozen meat sample and record the initial weight (W1) using a balance. Place the frozen meat sample in a plastic bowl suitable for thawing. Thaw the meat sample under controlled conditions at room temperature until fully thawed. After thawing, remove any surface moisture using an absorbent material. Weigh the meat sample again and record the final weight (w2).

$$\text{Thawing loss (\%)} = \frac{W1 - W2}{W1} \times 100$$

Here, W1 = initial weight of the frozen meat sample; W2= final weight of the meat sample after thawing.

2.4.4. Drip loss

The Wang et al., (2006) approach was applied to calculate drip loss in meat. The drip loss is a parameter of meat's water retention capacity, which is affected by various factors such as muscle fiber structure, postmortem pH levels, and storage conditions (Huff-Lonergan & Lonergan, 2005). Weigh the meat sample (50 g) on a balance. Place the fresh meat sample in a petri dish and store it under controlled conditions (typically refrigerated at 4 °C) for 24 hours. Weigh the meat sample again after the drip loss has occurred.

$$\text{Drip loss (\%)} = \frac{W1-W2}{W1} \times 100$$

Here, W1= weight of the sample before chilling; W2= weight of the sample after chilling.

2.4.5. pH

The pH of fresh and frozen samples was determined by a digital pH meter (Hanna Benchtop pH Meter HI-2211) following the procedure of Raiyan et al. (2024), which was pre-calibrated by applying standard buffer solutions. About 3 g of samples were homogenized with 27 mL of distilled water with a homogenizer at 20,000 rpm for 20 seconds. The pH value was observed after immersing the pH meter in the homogenate solution at 20 °C.

2.4.6. Water Holding Capacity

With some minor modifications, the filter paper press method proposed by Szmańko et al. (2021) was employed to evaluate the water-holding capacity of fresh meat. The complete process was carried out on a table with a hard surface. Meat structure, processing conditions, and protein content are some of the variables that affect WHC. The water holding capacity was determined using the following formula:

$$\text{WHC (\%)} = \frac{C - F}{C} \times 100$$

Here, A = the weight of Whatman filter papers; B = the weight of filter papers after drying; C = the weight of the meat sample; D= The weight of the meat flake; B-A=E= Amount of protein attached to the filter paper; E+D=F= Actual weight of meat flake after pressure treatment.

2.5. Chemical analysis

2.5.1. Proximate composition

Using the Donald and Helen (2019) methods, the proximate analysis of the chicken muscle's moisture, protein, fat, and ash content was carried out.

2.5.2. Moisture

The determination of moisture in meat involves measuring the water content present in the meat sample (Siti Nur Azizah et al., 2024). The principle is based on the loss of weight that occurs when the water is removed from the sample through drying. This method indicates the water content, and it is an important parameter for assessing the freshness and quality of meat.

$$\text{Moisture content (\%)} = \frac{W1 - W2}{W} \times 100$$

Here, W= weight of the sample; W1= petri dish weight+ sample weight before drying

W2= petri dish weight + sample weight after drying.

2.5.3. Ash

The ash content of the meat sample was evaluated using the Majewska et al. (2009) method. The amount of ash content represents the total mineral content that remains after all organic matter has been completely burned. It is a measurement of the sample's inorganic residue.

$$\text{Ash content (\%)} = \frac{W1-W2}{W} \times 100$$

Here, W= weight of the sample; W1= Sample weight before Ash

W2= Sample weight after Ash

2.5.4. Heme iron

The Heme iron content of meat samples was determined by applying the procedure explained by Ozer & Sariçoban. (2010) with minor modifications. Extracting heme iron from hemoglobin and myoglobin, turning it into a stable pigment, and measuring the absorbance or color shift are the steps involved in determining the amount of heme iron in meat.

$$\text{Heme - iron (mg/100gm of sample)} = \text{Total heme pigment (ppm)} (A_{640} \times 680) \times 0.082$$

2.5.5. Lipid Oxidation

The values of TBARS in the meat were calculated by Bozkurt & Erkmén. (2004) method. It refers to the development of Thiobarbituric Acid Reactive Substances (TBARS) because of lipid oxidation. TBARS are generated when malondialdehyde (MDA) interacts with thiobarbituric acid in an acidic environment. The test is extensively used to determine the degree of lipid oxidation in meat, which might affect its quality and shelf life (Shen et al., 2018). The TBARS were obtained by quickly homogenizing 3 g of chopped sample in 27 mL of 3.86% perchloric acid over 20 seconds via a digital homogenizing device. Following that, the samples were left to

Making a paste out of a sample of meat and weighing it with a balance is the first step in the approach, which is based on the reaction of heme iron with chemicals that produce a complex and enable its measurement. In a beaker, 9 mL of acidified acetone solution (acetone: distilled water: HCl = 90:8:2) was mixed with 1 g of meat sample paste. After sealing the beaker with foil paper, it was left to stand at room temperature in the dark for one hour. Whatman filter paper was used to filter the contents of the beaker, and the absorbance was measured at 640 nm by pouring it into a cuvette.

The calculation for heme iron content was performed by the following formulas:

settle at a low temperature for an hour. The resulting solution was subsequently centrifuged for 10 minutes at 2000 rpm and cleared by Whatman No. 1 filter paper to distinguish the lipid component from the other macronutrients. Then, in the last part of this test, carried out by adding 2 mL of the 20-mm TBA solution and 2 mL of the filtered solution were poured into a test tube. Additionally, a blank sample was also created by mixing 2 mL of distilled water with 2 mL of the 20-mm TBA solution. After that, each solution was cautiously kept for fifteen hours at room temperature. Lastly, a spectrophotometer was applied to measure the TBARS concentration by measuring absorbance at 532 nm. For analysis, each sample was set up in triplicate, and the result was reported as milligrams of malonaldehyde per kilogram of wet material.

$$\text{TBARS } (\mu\text{mol MDA/kg sample}) = \frac{\text{Absorbance at 532 nm} - \text{Blank Absorbance}}{\text{Molar Absorptivity } (\epsilon) \times \text{Sample Volume (L)} \times \text{Sample Weight (kg)}}$$

2.6. Microbial analysis

The methods established by Islam et al. (2019) were followed to assess the meat's microbiological quality. The total number of live microorganisms (bacteria) on the flesh surface is recorded to estimate the total plate count in meat (Han et al., 2021). The concept is that, given proper conditions, bacteria can form colonies. The findings of this test show the meat's overall microbial burden and sanitary quality. 1 g of homogenized sample was aseptically placed in a sterile beaker, thoroughly dissolved in saline water, and then serial dilution (dilution range 10^{-1} - 10^{-8}) was conducted. After inoculating 0.1 mL of the sample into the nutrient agar Petri dish, the Petri dishes were placed in an incubator at 37 °C for 24 hours to allow microbial growth. Measure the colonies (countable range 30–300 colonies) visible on the agar surface after incubation, then quantify them using the formula.

$$\text{Total plate count (CFU/g or CFU/mL)} = \frac{\text{Number of Colonies Counted}}{\text{Dilution Range} \times \text{Volume Plated}}$$

2.7. Visual quality assessment

A trained panel of 10 people, 7 men and 3 women, ages 24 to 42, executed a visual quality assessment of the external surface, color, odor, and elasticity of different packaging of stored meat (Katiyo et al., 2020). After slaughtering, defeathering, and defatting the chicken, the meat was cut into small, boneless pieces. Then, the fresh meat was packaged in coconut shells and polythene materials and marked with an unknown code. The samples were then evaluated on day 0 and day 15. Before the assessment, the panelists were trained in the assessment procedure and proper biosafety precautions. The assessment scale is presented in **Table 1**.

Table 1. Descriptive sensory attributes criteria for fresh and frozen broiler chicken

Attributes	Description	Values
External surface	Without Slime	Excellent
	Slime Present in small surface	Fair
	Slime present in all surfaces	Poor
	Characteristics meaty odor	Excellent
Odour	Rancid odor	Fair
	Foreign	Poor

Attributes	Description	Values
Color	Pink	Excellent
	Pale pink	Fair
	Brown	Poor
	Fast return	Excellent
Muscular Elasticity	Moderate return	Fair
	No return	Poor

2.8. Statistical analysis

All physicochemical tests were conducted in triplicate to ensure analytical precision. The Statistical Package for Social Science software (SPSS 25.0 for Windows, SPSS Inc., Chicago, IL, USA) was used for the analysis, and a significance level of $P < 0.05$ was established. Data were subjected to analysis of variance (ANOVA) by Zahid et al., (2020) and the means were evaluated using Duncan's multiple range test.

3. Results and discussion

3.1. Effect of packaging materials on changes in the proximate composition of meat after 15 days of frozen storage

Table 2 shows that the moisture content of fresh chicken meat samples was 72.73 ± 0.46 %. The moisture content of the polythene-packed sample was 72.53 ± 0.39 %, and there was no significant difference ($P > 0.05$) after 15 days of storage compared to fresh meat, and the coated coconut shell-packed sample showed a negligible or slight reduction of moisture content at the end of 15 days of frozen storage. There was no significant ($P > 0.05$) difference in the moisture content observed at 15 days compared to 0 days based on different packaging materials. These findings agree with (Hamed et al., 2019). The meat was succulent and tender with a moisture content of 72.73%, while its substantial 22.80% protein content highlights its nutritional value (**Table 2**).

Table 2. Effect of packaging materials on changes in the proximate composition of meat after 15 days of frozen storage

Storage day	Fresh Meat (0 day)	15 days	
Parameters	No packaging	Polythene	Coated Coconut shell
Moisture (%)	72.73 ± 0.46	72.53 ± 0.39	72.33 ± 0.25
Ash (%)	1.64 ± 0.50	1.52 ± 0.23	1.54 ± 0.24
Protein (g/100 g) (%)	22.80 ± 0.64	22.77 ± 0.93	22.42 ± 0.23
Fat (%) (g/100 g)	2.37 ± 0.25	2.25 ± 0.31	2.11 ± 0.12

Mean values $\pm$ Standard Deviation values.

We can observe that the ash content of fresh chicken meat samples was found 1.64 ± 0.50 %. The moisture content of the polythene meat sample was 1.52 ± 0.23 %, and the coated coconut shell packed meat sample was 1.54 ± 0.24 % after 15 days of freezing (**Table 2**), and there were no significant ($P > 0.05$) differences compared to fresh meat. It was noted that there was no significant ($P > 0.05$) difference in the ash content of chicken meat after 15 days of storage observed in the coated coconut shell-packed compared to polythene-packed meat and fresh meat samples. Similar findings are also found in the study on poultry meat by Hamed et al., (2019). Maybe these statements prove that the ash content is not influenced by frozen storage time.

From **Table 2**, we can observe that the protein contents of fresh meat were 22.80 ± 0.64 g/100 g. The protein content of the polythene packed sample was 22.77 ± 0.93 g/100 g, and the coated coconut shell packed sample was 22.42 ± 0.23 g/100 g found after 15 days storage in frozen conditions (**Table 2**), and there was no significant difference compared to fresh meat. The protein content of the broiler meat samples did not differ significantly ($P > 0.05$) between polythene-packed samples compared to coated coconut shell-packed meat after 15 days of

frozen storage, which is in agreement with previous study (Ahmed & Marzany, 2022).

Table 2 also shows that the fat contents of fresh meat were 2.37 ± 0.25 g/100 g. The fat content of polythene-packed meat samples did not significantly ($P > 0.05$) decrease after 15 days of storage compared to fresh meat. The coated coconut shell-packed sample showed a slight reduction of fat content at the end of frozen storage. The fat content of the broiler meat samples did not differ significantly ($P > 0.05$) between polythene-packed and coated coconut shell-packed samples after 15 days of frozen storage. There is a similar statement by Kamruzzaman et al., (2024), and opposite findings by Bida, (2019).

3.2. Effect of packaging materials on changes in the physicochemical qualities of meat after 15 days of frozen storage

Factors like sex, age, breed, or line, pre-slaughter and post-slaughter handling, the temperature of the muscle tissue, packaging materials, and the carcass chilling speed all affect the chemical composition of poultry muscle tissue (Fernandes et al., 2016).

Table 3 shows that the pH value of fresh chicken meat samples was 6.03 ± 0.14 . There was a significant ($P < 0.05$) decrease in pH value observed in 15 days of frozen storage with polythene packaging compared to 0 days without packaging. **Table 3** also reflects a significant ($P < 0.05$) decrease in pH value noticed in 15 days of frozen storage with coated coconut shell packaging compared to 0 days without packaging. The pH value of the broiler meat samples during frozen storage between polythene and coconut shell packed meat after 15 days did not differ

significantly ($P > 0.05$). The pH of poultry meat is notably affected by freezing storage with polythene and coated coconut shell ($P < 0.05$), leading to decreased pH values with increased storage periods, and here the pH value of coated coconut shell packaged meat was decreased more than the polythene packaged meat, potentially due to myofibril protein damage during freezing and water phase transformation and possibly due to solute concentration changes during freezing (Ali et al., 2015).

Table 3. Effect of packaging materials on changes in the physicochemical qualities of meat after 15 days of frozen storage

Storage day	Fresh Meat (0 day)	15 days	
Parameters	No packaging	Polythene	Coated Coconut shell
pH	6.03 ± 0.14^a	5.93 ± 0.11^b	5.79 ± 0.08^b
Thawing loss (%)	3.10 ± 0.48^c	6.63 ± 0.34^a	6.04 ± 0.24^b
Drip loss (%)	2.05 ± 0.25^c	8.64 ± 0.21^a	7.52 ± 0.35^b
Cooking loss (%)	30.40 ± 1.06^c	32.86 ± 1.16^b	34.64 ± 0.88^a
Water Holding Capacity (%)	81.96 ± 0.30^a	78.76 ± 0.66^b	77.92 ± 0.33^b
Heme iron (mg/100gm)	3.17 ± 0.02^a	1.63 ± 0.04^b	1.69 ± 0.04^b

Mean values $\pm$ Standard Deviation values (a, b, c) means in the same row but with different superscripts differ significantly ($p < 0.05$)

We can notice that the thawing loss of fresh chicken meat samples was found 3.10 ± 0.48 (**Table 3**). There was a significant ($P < 0.05$) difference in thawing loss among these polythene and coated coconut shell packed meat samples after 15 days of frozen storage. Assessment of thawing loss **Table 3** shows that the thawing losses of polythene-packaged meat increased more than the coated coconut-shell-packaged meat compared with the fresh poultry meat. Thawing losses increased significantly ($P < 0.05$) with extended freezing storage with different packaging material attributable to ice crystal formation and cell structure rupture (Songsaeng et al., 2010). Thawing loss is a crucial metric for evaluating the quality of frozen meat and is influenced by temperature, the rate of thawing, and the meat's ability to retain water (Leygonie et al., 2012).

Table 3 also reflects that the drip loss of fresh chicken meat samples was found 2.05 ± 0.25 %. The drip loss of polythene-packed meat samples was significantly ($P < 0.05$) increased compared to fresh meat after 15 days of frozen storage. Coconut shell-packed meat also showed a significant ($P < 0.05$) increase in drip loss at the end of frozen storage. Drip loss, a key indicator of meat quality, proportionally grew with frozen storage duration. **Table 3** indicates that the drip loss of polythene-packaged meat was more than that of coated coconut-shell-packaged meat. The alignment of the study, cooking, and drip loss values rose significantly ($P < 0.05$) with extended frozen and different packaging material, indicating tissue damage during freezing (Gambuteanu et al., 2013).

The cooking loss of fresh broiler meat samples was found 30.40 ± 1.06 %, 32.86 ± 1.16 %, and 34.64 ± 0.88 % at 0 and 15 days after storage in the frozen condition with no packaging, polythene, and coconut shell packaging, respectively (**Table 3**). There was a significant ($P < 0.05$) increase in cooking loss observed in 15 days of frozen storage with polythene and coated coconut shell packaging compared to 0 days without packaging. Cooking losses revealed increased protein denaturation and water loss, aligning with findings from Wei et al., (2017) on greater changes in frozen-thawed meat. cooking and drip loss values increased significantly ($P < 0.05$) with

extended frozen and different packaging materials, indicating tissue damage during freezing (Gambuteanu et al., 2013).

Table 3 displayed that the water holding capacity of fresh broiler meat samples was 81.96 ± 0.30 %. There was a significant ($P < 0.05$) decrease in the water holding capacity observed in 15 days of frozen storage with polythene packaging compared to fresh meat. **Table 3** also reflects a significant ($P < 0.05$) decrease in water activity capacity observed in 15 days of frozen storage with coated coconut shell packaging compared to 0 days without packaging. The water holding capacity of the broiler meat samples during frozen storage between polythene and coated coconut shell packed meat after 15 days did not differ significantly ($P > 0.05$). Water holding capacity (WHC) decreased significantly ($P < 0.05$) with increased freezing periods and different packaging materials, possibly linked to declining pH and reduced water retention ability, as indicated by **Table 3** (Biglia et al., 2022).

The heme iron content of fresh broiler meat samples was 3.17 ± 0.02 mg/100 g. There was a significant ($P < 0.05$) decrease in heme iron content observed after 15 days of frozen storage in polythene packaging and coated coconut shell packaging. But there was a considerably lower reduction in coated coconut shell compared to polythene-packed samples. **Table 3** also reflects a significant ($P < 0.05$) decrease in pH value observed at the end of frozen storage with coated coconut shell packaging. The pH value of the broiler meat samples during frozen storage between polythene and coated coconut shell-packed meat after 15 days did not differ significantly ($P > 0.05$). The heme iron content in both polythene and coated coconut shell packaged meats exhibited an overall decreasing trend with extended storage time; their difference is negligible, as indicated in **Table 3**. This observed trend could be attributed to two main factors: the breakdown of heme iron and drip losses during storage, as shown by Shikh Zahari et al. (2021), which contains considerable quantities of iron, including heme iron, as noted by Ahmed et al. (2018). Interestingly, no matter the duration of storage time, polythene-packaged meat possessed slightly less heme iron compared to coated coconut shell-packaged meat.

3.3. Effect of packaging materials on changes in color attributes of meat after 15 days of frozen storage

The technological quality of meat is often indicated by its color, influenced by oxygen availability during frozen storage and by different packaging materials. The results in **Table 4** show that frozen meat samples with different packaging materials generally exhibited lower lightness (L^*) values, with a significant decline at 15 days of freezing ($P < 0.05$). Reduced surface light reflectance, attributed to decreased water retention, may contribute to this effect (Hughes et al., 2014). Redness values (a^*) generally increased, but not significantly, during frozen storage with different packaging materials, primarily due to metmyoglobin deposition, contributing to meat discoloration (Bekhit et al., 2007). Notably, 15 days of

frozen polythene packaged meat and coated coconut shell packaged meat exhibited an increase in redness (a^*) compared to fresh poultry meat. Yellowness (b^*) values showed a significant increment after 15 days of refrozen storage periods with different packaging materials compared to the fresh meat sample, possibly due to lipid oxidation and metmyoglobin production. Chroma (C^*) values significantly increased at 15 days of freezing, and not only significantly with increasing refrozen storage conditions but also using different packaging materials. Hue angle (h°) values significantly increased during the 15 days of freezing. The hue angle values, representing color language, show lower and higher angles corresponding to reddish and yellowish hues, respectively, in meat samples (Ramos et al., 2007).

Table 4. Effect of packaging materials on changes in color attributes of meat after 15 days of frozen storage

Storage day	Fresh Meat (0 day)	15 days	
Parameters	No packaging	Polythene	Coated Coconut shell
Lightness (L^*)	62.56 $\pm$ 0.53 ^a	55.09 $\pm$ 0.31 ^b	54.72 $\pm$ 0.84 ^b
Redness (a^*)	2.94 $\pm$ 0.58 ^b	4.04 $\pm$ 0.21 ^a	4.34 $\pm$ 0.24 ^a
Yellowness (b^*)	5.41 $\pm$ 0.06 ^b	7.61 $\pm$ 0.16 ^a	7.97 $\pm$ 0.12 ^a
Chroma (C^*)	10.47 $\pm$ 0.09 ^c	11.77 $\pm$ 0.31 ^a	11.17 $\pm$ 0.19 ^b
Hue angle (h°)	32.44 $\pm$ 1.32 ^b	39.70 $\pm$ 0.41 ^a	40.06 $\pm$ 0.21 ^a

Mean values $\pm$ Standard Deviation values (a, b, c) means in the same row but with different superscripts differ significantly ($p < 0.05$)

3.4. Effect of packaging materials on Descriptive visual characteristics of meat after 15 days of frozen storage

Table 5 shows the changes in external surface, odor, color, and muscular elasticity of fresh and stored under polythene and coconut shell packages. After the evaluation by the control group, the fresh meat was excellent, meaning that the sample

was without slime on the external surface, the presence of meaty odor, the color was pink, and the muscular elasticity returned moderately. After 15 days of frozen storage, the external surface of polythene-packed sample contained slime on some surfaces. The color change after 15 days of storage of polythene and coated coconut shell packaging meat was pale pink, and the muscular elasticity of both packaging meats was poor to return.

Table 5. Effect of packaging materials on descriptive sensory characteristics of meat after 15 days of frozen storage

Storage day	Fresh Meat (0 day)	15 days	
Parameters	No packaging	Polythene	Coated Coconut shell
External surface	Excellent	Fair	Poor
Odor	Excellent	Excellent	Fair
Color	Excellent	Fair	Fair
Muscular elasticity	Fair	Poor	Poor

3.5. Effect of packaging materials on changes in the lipid oxidation rate of meat after 15 days of frozen storage

The TBARS analysis yielded notable findings as shown in **Figure 1**. The TBARS value of the fresh meat sample was 0.15 ± 0.05 $\mu\text{mol MDA/kg}$. The coated coconut shell packaging treatment showed a significantly lower ($P < 0.05$) TBARS value (0.25 ± 0.03 $\mu\text{mol MDA/kg}$) than the conventional polythene packaging treatment (0.28 ± 0.02 $\mu\text{mol MDA/kg}$), indicating reduced lipid oxidation during frozen storage. These findings align with the study of a film prepared by coconut shell extract that increases the antioxidant properties of the film up to 80% (Tanwar et al., 2021). Because coconut shell extract contains several phytochemical compounds (Mazaya et al., 2020). All these reasons showed that the meat preserved with coated coconut shell packaging may have a lower TBARS value because of its strong antioxidant activity.

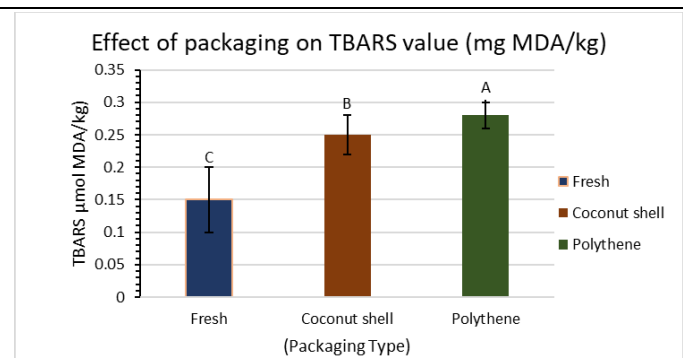


Fig.1. Effect of packaging materials on changes in the lipid oxidation rate of meat after 15 days of frozen storage

*(A, B, C) means in the same column but with different superscripts differ significantly ($p < 0.05$)

3.6. Effect of packaging materials on changes in the microbial content of meat after 15 days of frozen storage

The effect of different packaging materials on the microbial quality of broiler meat after 15 days of frozen storage is presented in Fig. 2. Fresh chicken meat exhibited a total plate count of 6.96 ± 0.01 log CFU/g, which increased significantly ($P < 0.05$) after frozen storage. Among the packaged samples, meat stored in polythene packaging showed the highest microbial load (7.31 ± 0.02 log CFU/g), whereas coated coconut shell-packaged meat exhibited a significantly lower total plate count (7.12 ± 0.01 log CFU/g) after 15 days of storage. It was observed that due to the antimicrobial activity of coated coconut shells (Mazaya et al., 2020). The lower microbial count observed in coated coconut shell-packaged meat may be attributed to the natural antimicrobial properties and show relative changes in overall microbial count rather than evidence of microbial safety to detect specific foodborne pathogens.

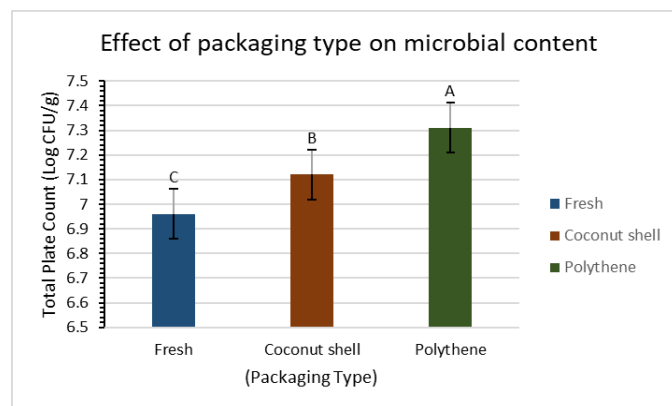


Fig.2. Effect of packaging materials on changes in the microbial content of meat after 15 days of frozen storage

*(A, B, C) means in the same column but with different superscripts differ significantly ($p < 0.05$)

Conclusion

This study investigated the impact of different packaging materials, specifically polythene and coated coconut shells, on the physicochemical, antioxidant, and microbial qualities of frozen broiler (*Gallus gallus domesticus*) meat. The findings revealed that both packaging materials influenced various measurable factors, such as pH, thawing loss, heme iron content, water holding capacity, cooking loss, color attributes, lipid oxidation rate, and microbial load. Coated coconut shell packaging demonstrated promising results in preserving certain quality attributes, such as lower thawing loss, TBARS value, and microbial load, and the other attributes showed negligible increases compared to polythene packaging and fresh meat. Due to a few methodological and experimental design limitations, the results of this study should be considered preliminary. To validate the practical applicability of coated coconut shell-based packaging systems for food preservation, future studies should use controlled prototype designs that include uncoated-shell, wax-only, and oil-only controls, multiple storage intervals, more independent experimental units, mixed-effects statistical analyses with effect-size estimation, estimation of packaging $\times$ time interactions, assessments of pathogens and spoilage organisms, and

thorough evaluations of migration, barrier, integrity, safety, and sustainability properties. Overall, the study highlights the potential of coconut shells as a biodegradable, antimicrobial, sustainable, and environmentally friendly packaging material.

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Data availability

Data will be made available on request.

Declaration of competing interest

Authors declare no conflict of interest.

REFERENCES

- Addeen, A., Benjakul, S., Wattanachant, S., & Maqsood, S. (2014). *Effect of Islamic slaughtering on chemical compositions and post-mortem quality changes of broiler chicken meat*. EBSCOhost. <https://openurl.ebsco.com/contentitem/gcd:96165060?sid=ebsco:plink:crawler&id=ebsco:gcd:96165060>
- Ahmed, B. H., & Marzany, N. A. (2022). *Physical and chemical properties of breast chicken meat subjected to different freezing and refreezing storage periods*.
- Ahmed et al. (2018). *Physico-chemical changes and microbiological quality of refrigerated broiler chicken meat slaughtered by two different methods—ProQuest*. Retrieved April 8, 2025, from <https://www.proquest.com/openview/7e95fc2d15fd2cf99870e30b4d4bae16/1?cbl=816390&pq-origsite=gscholar>
- Ali, S., Zhang, W., Rajput, N., Khan, M. A., Li, C., & Zhou, G. (2015). Effect of multiple freeze-thaw cycles on the quality of chicken breast meat. *Food Chemistry*, 173, 808–814. <https://doi.org/10.1016/j.foodchem.2014.09.095>
- Bekhit, A. E. D., Cassidy, L., Hurst, R. D., & Farouk, M. M. (2007). Post-mortem metmyoglobin reduction in fresh venison. *Meat Science*, 75(1), 53–60. <https://doi.org/10.1016/j.meatsci.2006.06.015>
- Bida, A. A. (2019). Storage and Cooling Effects on Levels of Protein Carbohydrates, Fats, Minerals and Microbes in Guinea Fowl (*Numida meleagris*) Meat Sold in Kaduna Metropolis, Nigeria. *Advances in Biochemistry*, 7(1), Article 1. <https://doi.org/10.11648/j.ab.20190701.13>
- Biglia, A., Messina, C., Comba, L., Ricauda Aimonino, D., Gay, P., & Brugiapaglia, A. (2022). Quick-freezing based on a nitrogen reversed Brayton cryocooler prototype: Effects on the physicochemical characteristics of beef *longissimus thoracis* muscle. *Innovative Food Science & Emerging Technologies*, 82, 103208. <https://doi.org/10.1016/j.ifset.2022.103208>
- Bordoni, A., & Danesi, F. (2017). Poultry Meat Nutritive Value and Human Health. In *Poultry Quality Evaluation* (pp. 279–290). Elsevier. <https://doi.org/10.1016/B978-0-08-100763-1.00011-8>
- Bozkurt, H., & Erkmen, O. (2004). Effect of nitrate/nitrite on the quality of sausage (sucuk) during ripening and storage. *Journal of the Science of Food and Agriculture*, 84(3), 279–286. <https://doi.org/10.1002/jsfa.1638>
- Chmiel, M., Roszko, M., Adamczak, L., Florowski, T., & Pietrzak, D. (2019). Influence of storage and packaging

- method on chicken breast meat chemical composition and fat oxidation. *Poultry Science*, 98(6), 2679–2690. <https://doi.org/10.3382/ps/pez029>
- D. Dave & A.E. Ghaly. (2011). Meat Spoilage Mechanisms and Preservation Techniques: A Critical Review. *American Journal of Agricultural and Biological Sciences*, 6(4), 486–510. <https://doi.org/10.3844/ajabssp.2011.486.510>
- Demirhan, B., & Candoğan, K. (2016). Active packaging of chicken meats with modified atmosphere including oxygen scavengers. *Poultry Science*, 96. <https://doi.org/10.3382/ps/pew373>
- Donald, I., & Helen, E. (2019). Proximate Composition And Organoleptic Properties Of Whole Wheat Biscuit Fortified With Moringa (*Moringa oleifera*) Leaf Powder. *International Journal of Scientific and Research Publications (IJSRP)*, 9(11), p9585. <https://doi.org/10.29322/IJSRP.9.11.2019.p9585>
- Fernandes, R. T. V., Arruda, A. M. V. D., Costa, M. K. D. O., Lima, P. D. O., Santos, L. O. G. D., Melo, A. D. S., & Marinho, J. B. M. (2016). Physicochemical and microbiological parameters of frozen and chilled chicken meat. *Revista Brasileira de Zootecnia*, 45(7), 417–421. <https://doi.org/10.1590/S1806-92902016000700009>
- Gambuteanu, C., Borda, D., & Alexe, P. (2013). The Effect of Freezing and Thawing on Technological Properties of Meat: Review. *Journal of Agroalimentary Processes and Technologies*.
- Gheorghita, R., Amariei, S., Norocel, L., & Gutt, G. (2020). New Edible Packaging Material with Function in Shelf Life Extension: Applications for the Meat and Cheese Industries. *Foods*, 9(5), 562. <https://doi.org/10.3390/foods9050562>
- Gheorghita, R., Gutt, G., & Amariei, S. (2020). The Use of Edible Films Based on Sodium Alginate in Meat Product Packaging: An Eco-Friendly Alternative to Conventional Plastic Materials. *Coatings*, 10(2), 166. <https://doi.org/10.3390/coatings10020166>
- Gomes, B., Dias, M., Cervantes, R., Pena, P., Santos, J., Pinto, M. V. V., & Viegas, C. (2023). One Health Approach to Tackle Microbial Contamination on Poultry—A Systematic Review. *Toxics*, 11. <https://doi.org/10.3390/toxics11040374>
- Hamed, H., Ma, M., Hydamaka, A. W., Elkhedir, A. E., Jin, G., Jin, Y., & Abdegadir, W. S. (2019). *Effect of Freeze and Refreeze on Chemical Composition of Beef and Poultry Meat at Storage Period 4.5 Months (SP4.5)*. 10(5).
- Hammam, A. R. A. (2019). Technological, applications, and characteristics of edible films and coatings: A review. *SN Applied Sciences*, 1(6), 632. <https://doi.org/10.1007/s42452-019-0660-8>
- Han, J., Liu, Y., Zhu, L., Liang, R., Dong, P., Niu, L., Hopkins, D., Luo, X., & Zhang, Y. (2021). Effects of spraying lactic acid and peroxyacetic acid on the quality and microbial community dynamics of vacuum skin-packaged chilled beef during storage. *Food Research International*, 142. <https://doi.org/10.1016/j.foodres.2021.110205>
- Huff-Loneragan, E., & Lonergan, S. (2005). Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. *Meat Science*, 71 1, 194–204. <https://doi.org/10.1016/j.meatsci.2005.04.022>
- Hughes, J. M., Oiseth, S. K., Purslow, P. P., & Warner, R. D. (2014). A structural approach to understanding the interactions between colour, water-holding capacity and tenderness. *Meat Science, Meat Science, Sustainability & Innovation: '60th International Congress of Meat Science and Technology 17-22 August 2014, Punta Del Este, Uruguay,'* 98(3), 520–532. <https://doi.org/10.1016/j.meatsci.2014.05.022>
- Islam, A., Sadakuzzaman, M., Hossain, M. A., Hossain, M. M., & Hashem, M. A. (2019). Effect of gamma irradiation on shelf life and quality of indigenous chicken meat. *Journal of the Bangladesh Agricultural University*, 17(4), 560–566. <https://doi.org/10.3329/jbau.v17i4.44626>
- Jadhao, V. M., Sathish Kumar, M. H., Jayaraj Rao, K., & Mathe, R. S. (2021). Evaluation of beeswax coated coconut shells for packaging of set-type dahi: An Indian fermented product. *Journal of Food Science and Technology*, 58(5), 2019–2027. <https://doi.org/10.1007/s13197-020-04714-w>
- Kamruzzaman Md., Rasel Islam Md., Ananya, R., Md. Mohasin, H., Md. Ashrafuzzaman, Z., & Rashida, P. (2024). Effect of Poor Post-Slaughter Handling on Physicochemical and Microbial Quality of Fresh Broiler in Bangladesh. *Advances in Food Production, Processing, and Nutrition*, 2(1), 008–016. <https://doi.org/10.17352/afppn.000003>
- Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2020). Sensory implications of chicken meat spoilage in relation to microbial and physicochemical characteristics during refrigerated storage. *Lwt*, 128(December 2019), 109468. <https://doi.org/10.1016/j.lwt.2020.109468>
- Katsara, K., Kenanakis, G., Alissandrakis, E., & Papadakis, V. M. (2022). Low-Density Polyethylene Migration from Food Packaging on Cured Meat Products Detected by Micro-Raman Spectroscopy. *Microplastics*, 1(3), 428–439. <https://doi.org/10.3390/microplastics1030031>
- Khalid, T., Hdaifeh, A., Federighi, M., Cummins, E., Boué, G., Guillou, S., & Tesson, V. (2020). Review of Quantitative Microbial Risk Assessment in Poultry Meat: The Central Position of Consumer Behavior. *Foods*, 9. <https://doi.org/10.3390/foods9111661>
- Leygonie, C., Britz, T. J., & Hoffman, L. C. (2012). Impact of freezing and thawing on the quality of meat: Review. *Meat Science*, 91(2), 93–98. <https://doi.org/10.1016/j.meatsci.2012.01.013>
- Majewska, D., Jakubowska, M., Ligocki, M., Tarasiewicz, Z., Szczerbińska, D., Karamucki, T., & Sales, J. (2009). Physicochemical characteristics, proximate analysis and mineral composition of ostrich meat as influenced by muscle. *Food Chemistry*, 117(2), 207–211. <https://doi.org/10.1016/j.foodchem.2009.03.100>
- Mazaya, G., Karseno, K., & Yanto, T. (2020). Antimicrobial and Phytochemical Activity of Coconut Shell Extracts. *Turkish Journal of Agriculture - Food Science and Technology*, 8(5), 1090–1097. <https://doi.org/10.24925/turjaf.v8i5.1090-1097.3282>
- Njoga, E. O., Ilo, S. U., Nwobi, O. C., Onwumere-Idolor, O. S., Ajibo, F. E., Okoli, C. E., Jaja, I. F., & Oguttu, J. W. (2023). Pre-slaughter, slaughter and post-slaughter practices of slaughterhouse workers in Southeast, Nigeria: Animal welfare, meat quality, food safety and public health implications. *PLOS ONE*, 18(3), e0282418. <https://doi.org/10.1371/journal.pone.0282418>
- Ozer, O., & Sariçoban, C. (2010). The effects of butylated hydroxyanisole, ascorbic acid, and α -tocopherol on some quality characteristics of mechanically deboned chicken patty during freeze storage. *Czech Journal of Food Sciences*, 28(2), 150–160. <https://doi.org/10.17221/160/2009-cjfs>

- Pal, M., Dana, F. D., Patel, D., & Ayele, Y. (2018). *Microbiological and hygienic quality of Meat and Meat Products*. 45.
- Rahman et al. (2017). Poultry industry of Bangladesh: Entering a new phase. *Korean Journal of Agricultural Science*, 44(2). <https://doi.org/10.7744/kjoas.20170027>
- Raiyan, A., Hossain, Md. M., Zahid, Md. A., Lina, N. N., Shuvo, S. D., & Parvin, R. (2024). "Physicochemical characterization and microbial quality evaluation of *Gracilaria tenuistipitata* added crackers". *Applied Food Research*, 4(2), 100623. <https://doi.org/10.1016/j.afres.2024.100623>
- Ramos, E. M., & de Miranda Gomide, L. A. (2007). *Avaliação da qualidade de carnes: Fundamento e metodologias*. UFV.
- Rizal, W. A., Nisa', K., Maryana, R., Prasetyo, D. J., Pratiwi, D., Jatmiko, T. H., Ariani, D., & Suwanto, A. (2020). Chemical composition of liquid smoke from coconut shell waste produced by SME in Rongkop Gunungkidul. *IOP Conference Series: Earth and Environmental Science*, 462(1), 012057. <https://doi.org/10.1088/1755-1315/462/1/012057>
- Sabow, A. (2024). EFFECTS OF VARIOUS THAWING METHODS ON PHYSICOCHEMICAL AND STRUCTURAL PROPERTIES OF BEEF. *ANBAR JOURNAL OF AGRICULTURAL SCIENCES*, 22(1), 301–317. <https://doi.org/10.32649/ajas.2024.149228.1237>
- Shen, Q., Wang, M., Tian, J., Hu, L., Ren, S., Chen, J., Ye, X., & Liu, D. (2018). Effects of Chinese pickled and dried mustard on nutritional quality, sensory quality, and shelf life of steamed pork belly. *Food Science & Nutrition*, 6, 747–756. <https://doi.org/10.1002/fsn3.612>
- Shikh Zahari, S. M. S. N., Mohamed Ali, N. S., Zabidi, A. R., Rosli, D., Abdul Manap, M. N., & Yahaya, N. (2021). Influence of neck slaughtering in broiler chicken meat on physicochemical analysis and metabolites 'fingerprinting' to enhance meat quality. *Arabian Journal of Chemistry*, 14(4), 103042. <https://doi.org/10.1016/j.arabjc.2021.103042>
- Siti Nur Azizah, Wisnu Adi Yulianto, & Ch. Lilis Suryani. (2024). *Analysis of changes in bread during frozen storage with pre-cooking and steaming | TEKNOSAINS: Jurnal Sains, Teknologi dan Informatika*. <https://jurnal.sttmicileungsi.ac.id/index.php/tekno/article/view/685>
- Songsang, S., Sophanodora, P., Kaewsritthong, J., & Ohshima, T. (2010). Quality changes in oyster (*Crassostrea belcheri*) during frozen storage as affected by freezing and antioxidant. *Food Chemistry*, 123(2), 286–290. <https://doi.org/10.1016/j.foodchem.2010.04.033>
- Sukardi, D., Hafizd, J., & Setiawan, F. (2022). Halal Certification Standards for Chicken Slaughter in Traditional Markets. *Al Hurriyah: Jurnal Hukum Islam*, 7, 204. <https://doi.org/10.30983/alhurriyah.v7i2.4474>
- Sun, Y., Zhao, X., Ma, Y., Guan, H., Liang, H., & Wang, D. (2021). Inhibitory effect of modified atmosphere packaging on *Escherichia coli* O157:H7 in fresh-cut cucumbers (*Cucumis sativus* L.) and effectively maintain quality during storage. *Food Chemistry*, 369. <https://doi.org/10.1016/j.foodchem.2021.130969>
- Szmańko, T., Lesiów, T., & Górecka, J. (2021). The water-holding capacity of meat: A reference analytical method. *Food Chemistry*, 357. <https://doi.org/10.1016/J.FOODCHEM.2021.129727>
- Tanwar, R., Gupta, V., Kumar, P., Kumar, A., Singh, S., & Gaikwad, K. K. (2021). Development and characterization of PVA-starch incorporated with coconut shell extract and sepiolite clay as an antioxidant film for active food packaging applications. *International Journal of Biological Macromolecules*, 185, 451–461. <https://doi.org/10.1016/j.ijbiomac.2021.06.179>
- Toldrá, F. (2008). *Handbook of Fermented Meat and Poultry*. John Wiley & Sons.
- Wang, H., Pato, M. D., & Shand, P. J. (2006). Biochemical Properties of Natural Actomyosin Extracted from Normal and Pale, Soft, and Exudative Pork Loin After Frozen Storage. *Journal of Food Science*, 70(4), C313–C320. <https://doi.org/10.1111/j.1365-2621.2005.tb07179.x>
- Wei, R., Wang, P., Han, M., Chen, T., Xu, X., & Zhou, G. (2017). Effect of freezing on electrical properties and quality of thawed chicken breast meat. *Asian-Australasian Journal of Animal Sciences*, 30(4), 569–575. <https://doi.org/10.5713/ajas.16.0435>
- Yasmin, F., & Alam, S. (2020). *Livestock research generated technologies and their impact on Bangladesh national economy*. 20, 77–87. <https://doi.org/10.3329/bjlr.v20i1-2.47021>
- Zahid, Md. A., Choi, J. Y., Seo, J.-K., Parvin, R., Ko, J., & Yang, H.-S. (2020). Effects of clove extract on oxidative stability and sensory attributes in cooked beef patties at refrigerated storage. *Meat Science*, 161, 107972. <https://doi.org/10.1016/j.meatsci.2019.107972>
- Zhu, Y., Li, F., Tang, J., Wang, T., & Jiao, Y. (2019). Effects of radio frequency, air and water tempering, and different end-point tempering temperatures on pork quality. *Journal of Food Process Engineering*, 42(4), e13026. <https://doi.org/10.1111/jfpe.13026>