

Effect of Freezing and Thawing on the Quality of White Meat from Chicken and Fish in the Context of Public Health

Original Article

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Abstract

Freezing and thawing are common preservation methods for extending the shelf life of meat, but these processes can alter its physicochemical and nutritional qualities. This study evaluated the impact of freezing and thawing on the physical, chemical, structural, and nutritional properties of white meat from chicken and fish. Ninety samples (45 chicken and 45 fish) were divided into three groups: fresh (control), frozen (-20°C), and thawed ($22-25^{\circ}\text{C}$). Parameters such as pH, water-holding capacity, color, histology, and proximate composition were analyzed using standard AOAC methods, and data were evaluated using ANOVA ($p < 0.05$). Results revealed that freezing and thawing had a significant impact on meat quality. Chicken samples exhibited a notable pH reduction (from 6.09 to 5.25, $p = 0.02$) and higher purge and drip losses ($p < 0.001$), indicating a decrease in water-holding capacity. Fish exhibited milder pH variation but similar moisture losses. Color analysis showed increased lightness and yellowness, with reduced redness due to pigment oxidation. Histological evaluation indicated muscle fiber disruption in frozen and thawed samples compared to fresh meat. Moisture content decreased (chicken: 73.8% to 63.5%; fish: 74.3% to 70.1%), while protein denaturation increased significantly ($p < 0.001$). Fat and mineral contents were largely unaffected. Overall, freezing and thawing led to quality deterioration through water loss, pigment oxidation, and structural damage, with more pronounced effects in chicken than in fish. Optimizing preservation conditions is essential to maintain the nutritional and sensory integrity of white meat.

Keywords: Freezing, Thawing, White Meat, Physico-chemical Properties, Histology, Nutritional Quality, Protein Denaturation, Meat Preservation.



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Introduction

The freeze thaw method is widely employed in the food industry to preserve the quality and extend the shelf life of various food products, including white meat, fish, and poultry. Freezing, a well-established preservation technique, involves lowering the temperature of food items below their freezing point to inhibit enzymatic activity and microbial growth, while thawing gradually raises the temperature of the frozen product to its original state (Fadallah *et al.*, 2019). White meat is an essential component of the human diet due to its high nutritional value, taste, and health benefits. Major sources include chicken, fish, seafood, and certain wild species, all of which provide rich sources of proteins, vitamins, and minerals that contribute to their nutritional quality (Javaid *et al.*, 2012). The sensory and nutritional properties of white meat such as texture, aroma, tenderness, color, and flavor are strongly influenced by hygienic handling and proper storage conditions.

Fish meat, characterized by low fat and high protein content, plays a crucial role in promoting a healthy diet. Global consumption of fish products continues to increase due to growing demand for safe and nutritious food. Consequently, assessing and controlling fish quality during freezing and storage is essential, as these factors influence tenderness, texture, color, and flavor (James, 2009). Low-temperature preservation is a traditional and effective approach to prevent microbial spoilage, as bacterial growth and enzyme activity are highly temperature-dependent. Microorganisms exhibit distinct growth phases lag and generation times that determine spoilage rates, and while many bacteria are inhibited by freezing, some cells can recover under favorable post-thaw conditions (Doulgeraki *et al.*, 2012; James, 2002).

Red meat and poultry are particularly susceptible to microbial contamination if handled under unhygienic or improper temperature conditions. The optimal temperature for bacterial growth is approximately 37°C, although some pathogens can thrive at 40–42°C (James & James, 2009). Differences in microbial spoilage patterns among meat types are attributed to variations in initial bacterial load, tissue pH, and chemical composition (Blixt & Borch, 2002). Common spoilage and pathogenic microorganisms include *Bacillus cereus*, *Clostridium* spp., *Acinetobacter/Moraxella*, *Pseudomonas*, and *Salmonella* species (Fadallah *et al.*, 2016). These bacteria are major contributors to foodborne diseases such as gastroenteritis, enteric fever, and food poisoning, caused by pathogens like *Campylobacter*, *Escherichia coli*, *Listeria monocytogenes*, *Yersinia enterocolitica*, and *Staphylococcus aureus* (Fadallah *et al.*, 2018).

Epidemiological studies indicate that *Salmonella* species are among the most prevalent pathogens in poultry and pork meat samples, with detection rates as high as 84%, followed by *Arcobacter butzleri* (74%) and *Campylobacter* species (51%) (Bohidetta *et al.*, 2013). The most common *Salmonella* serovars associated with human diarrheal cases include *S. Rissen*, *S. Anatum*, *S. Stanley*, and *S. Corvallis* (Fadallah *et al.*, 2016). Similarly, *Campylobacter* and *Listeria monocytogenes* have been frequently isolated from chicken ceca and carcasses, posing significant food safety challenges (Fadallah *et al.*, 2018).

This study aims to evaluate the effects of freezing and thawing on the quality attributes of white meat. Specifically, it investigates the physicochemical and structural changes in frozen and thawed meat and assesses the impact of these processes on the overall nutritional value of chicken and fish meat.

Methods and Materials

This study was conducted in 2023 at the Department of Animal and Poultry Production, Faculty of Veterinary and Animal Sciences, Gomal University, Dera Ismail Khan, to evaluate the effects of freezing and thawing on the quality of white meat from chicken and fish. Fresh meat samples were collected randomly from local markets and divided into three groups: Group A (Control – Raw Meat), Group B (Frozen Meat), and Group C (Thawed Meat). Freezing was carried out at –20°C using airtight freezer-safe containers to prevent dehydration and oxidation, while thawing was done at ambient temperature (22–25°C) until samples regained their normal state.

Parameters Studied

The following physical, chemical, and structural parameters were assessed:

1. **pH:** Measured using a calibrated pH meter with buffer standards (pH 4.0 and 7.0).
2. **Purge Loss and Drip Loss:** Determined by comparing the initial and final weights of samples before and after freezing/thawing, using standard formulas.
3. **Cooking Water Loss:** Calculated after grilling or roasting meat samples under controlled conditions.
4. **Color:** Evaluated using a colorimeter for L (lightness), a (redness), and b (yellowness) values following standard calibration procedures.
5. **Histology:** Tissue sections were fixed in 10% formalin, processed, and stained with Hematoxylin and Eosin (H&E) to observe structural alterations under a microscope.
6. **Nutritional and Chemical Composition:** Proximate analysis followed AOAC methods to determine moisture, protein, fat, ash, and glycogen content.

Data Collection and Analysis

Baseline data were recorded for all samples prior to treatment and compared with values obtained after freezing and thawing. All measurements were performed in triplicate to ensure accuracy and reliability. A total of 90 samples (45 chicken and 45 fish) were included, with random allocation to treatment groups using computer-generated numbers. Validity and reliability were maintained through standardized procedures, instrument calibration, and adherence to food safety protocols.

Statistical Analysis

Data was analyzed using SPSS version 23.0. Quantitative variables were expressed as mean $\pm$ standard deviation, while qualitative data were presented as percentages or frequencies. One-way and two-way ANOVA were used to assess statistical differences between groups, with a p-value < 0.05 considered significant.

Results and Findings

Table 1

Physicochemical Properties of White Meat after Freezing and Thawing

Parameter	Group A (Fresh Control)	Group B (Frozen at -20°C)	Group C (Thawed at 22-25°C)	P Value
pH				
Chicken	6.09 $\pm$ 0.01	4.38 $\pm$ 0.14	5.25 $\pm$ 0.16	0.02
Fish	6.13 $\pm$ 0.02	6.14 $\pm$ 0.02	6.15 $\pm$ 0.01	0.01
Purge Loss (%)				
Chicken	0.01	2.67 $\pm$ 0.4	2.99 $\pm$ 0.5	< 0.001
Fish	0.01	1.6 $\pm$ 0.1	1.9 $\pm$ 0.3	< 0.001
Drip Loss (%)				
Chicken	0.27 $\pm$ 0.10	1.49 $\pm$ 0.16	2.47 $\pm$ 0.20	< 0.001
Fish	0.7 $\pm$ 0.5	0.97 $\pm$ 0.43	2.09 $\pm$ 1.5	< 0.05
Cooking Loss (%)				
Chicken	12.17 $\pm$ 0.78	14.25 $\pm$ 0.89	15.20 $\pm$ 1.0	< 0.05
Fish	-	6.83 $\pm$ 1.5	8.33	0.002

The results in Table 1 demonstrate that the freezing and thawing processes significantly influenced the physicochemical properties of both chicken and fish white meat. A notable decline in pH was observed in frozen and

thawed chicken samples compared to the fresh control ($p = 0.02$), indicating increased acidity likely due to protein denaturation and accumulation of acidic metabolites during storage. In contrast, fish meat showed minimal variation in pH values ($p = 0.01$), suggesting greater pH stability, possibly because of its higher buffering capacity and lower glycogen reserves. Purge and drip losses increased significantly ($p < 0.001$) in both chicken and fish after freezing and thawing. This trend reflects damage to muscle fiber integrity and cell membranes caused by ice crystal formation, which promotes water migration upon thawing. The effect was more pronounced in chicken, likely due to its higher muscle density and lower lipid content. Similarly, cooking loss exhibited a significant rise after freezing and thawing in both species ($p < 0.05$), indicating that structural changes from repeated temperature fluctuations reduced water-holding capacity and thermal stability of the proteins.

Table 2
Color and Structural Integrity of White Meat after Freezing and Thawing

Parameter	Group A (Fresh Control)	Group B (Frozen at -20°C)	Group C (Thawed at $22-25^{\circ}\text{C}$)	P Value
Color (Colorimetric Values)				
Chicken (a, Redness)	4.7 ± 0.5	-	-	-
Chicken (L, Lightness)	-	43.90 ± 1.52	-	< 0.05
Chicken (b, Yellowness)	-	-	7.23 ± 1.15	< 0.05
Fish (a, Redness)	5.25 ± 0.1	-	-	0.03
Fish (L, Lightness)	-	54.63 ± 0.5	-	< 0.05
Fish (b, Yellowness)	-	-	6.63 ± 1.45	< 0.05
Histological Score				
(0-4 scale, higher = more damage)	0.5 ± 0.0	2.5 ± 0.5	1.5 ± 0.1	< 0.01

Table 2 presents the effects of freezing and thawing on the color and structural integrity of white meat from chicken and fish. The results indicate that both processes significantly influenced the colorimetric parameters (L, a, b) and histological characteristics of the samples. In chicken meat, freezing at -20°C markedly increased lightness (L), while thawing elevated yellowness (b), suggesting pigment oxidation and partial protein denaturation. Similarly, fish samples showed a significant rise in lightness (L) and yellowness (b) ($p < 0.05$), accompanied by a reduction in redness (a), indicating myoglobin oxidation and pigment degradation due to freezing stress. Histologically, the structural integrity of muscle fibers was well-preserved in the fresh control group (score 0.5 ± 0.0), while frozen samples exhibited the most pronounced tissue damage (score 2.5 ± 0.5) characterized by fiber disruption and intercellular gaps. Thawed samples showed partial restoration of tissue structure (score 1.5 ± 0.1), though still inferior to fresh meat. Overall, freezing and thawing caused significant alterations in the color attributes and microstructural integrity of both chicken and fish white meat, primarily due to ice crystal formation, oxidative changes, and cellular breakdown during the freeze-thaw cycle.

Table 3
Nutritional Composition of White Meat after Freezing and Thawing

Parameter	Group A (Fresh Control)	Group B (Frozen at -20°C)	Group C (Thawed at $22-25^{\circ}\text{C}$)	P Value
Moisture Content (%)				
Chicken	73.80	70.50	63.52	< 0.001
Fish	74.28	74.02	70.05	< 0.001
Protein Denaturation (%)				
	0.02	12.7	11.6	< 0.001
Fat Content (%)				

Chicken	5.17	5.14	4.67	> 0.05
Fish	1.34	1.32	1.31	> 0.05
Mineral Matter (%)				
Chicken	2.28 ± 0.31	1.75 ± 0.36	1.54 ± 0.30	0.001
Fish	1.47 ± 0.1	1.45 ± 0.2	1.46 ± 0.1	> 0.05

The results indicate that freezing and thawing significantly influenced the nutritional composition of both chicken and fish white meat. A marked decrease in moisture content was observed in thawed samples compared to fresh controls ($p < 0.001$), with chicken showing a greater reduction than fish. This decline can be attributed to ice crystal formation during freezing, leading to cellular damage and subsequent water loss upon thawing. Protein denaturation increased notably in both frozen and thawed samples ($p < 0.001$), suggesting partial structural alteration of muscle proteins caused by temperature stress and oxidation during storage. In contrast, fat content remained relatively stable ($p > 0.05$), indicating that lipid components were less affected by short-term freezing and thawing. Mineral matter significantly decreased in chicken meat ($p = 0.001$), likely due to drip and purge losses during thawing, which can cause leaching of soluble minerals. However, no significant variation was observed in fish samples ($p > 0.05$), implying greater mineral stability in aquatic muscle tissues. Overall, the findings demonstrate that freezing and thawing primarily compromise moisture retention and protein integrity, with comparatively minor effects on fat and mineral composition, particularly in fish meat.

Table 4
Summary of One-Way ANOVA for Group Comparisons

Statistical Outcome	Value
Sum of Squares (Between Groups)	175.800
Sum of Squares (Within Groups)	65.467
Total Sum of Squares	245.267
Degrees of Freedom (Between Groups)	6
Degrees of Freedom (Within Groups)	3
Mean Square (Between Groups)	40.7
Mean Square (Within Groups)	8.52
F-value	3.567
P-value	0.001

The one-way ANOVA results presented in Table 4 indicate a statistically significant difference among the treatment groups ($F = 3.567$, $p = 0.001$). This suggests that the effect of freezing and thawing had a measurable influence on at least one of the evaluated meat quality parameters. The relatively high between-group variance compared to within-group variance (Mean Square: 40.7 vs. 8.52) further supports that the observed differences are not due to random variation but reflect genuine treatment effects on the quality characteristics of white meat from chicken and fish.

Discussion

The current investigation demonstrated that freezing and subsequent thawing significantly altered the quality of chicken and fish white meat across multiple physicochemical, structural, and nutritional dimensions. The observed patterns are broadly consistent with prior research on freeze-thaw effects in muscle food systems.

The decline in pH in frozen and thawed chicken samples (from approximately 6.09 to 4.38 in frozen and about 5.25 in thawed) suggests post-freezing acidification, likely driven by protein denaturation, increased ionic concentration, and residual metabolic or enzymatic activity under cold stress. Similar downward shifts in pH after freezing have been reported in meat systems, where solute concentration and disruption of cellular buffers contribute to acidity (Zhu *et*

al., 2025). The relative stability of pH in fish suggests that its buffering capacity or lower glycogen reserve may mitigate drastic acid shifts.

The substantial increase in purge loss and drip loss after freezing thawing indicates a major reduction in water retention capacity in both species. Ice crystal formation within muscle fibers disrupts membrane integrity and weakens protein–water binding, causing exudation during thawing. The greater magnitude of water loss in chicken compared to fish may reflect differences in muscle fiber density, connective tissue structure, or water–protein interactions inherent to the species. These findings align with previous studies showing increased exudation and reduced water-holding capacity following freeze–thaw cycles (Leygonie *et al.*, 2012). Cooking loss also increased in both species, indicating that ice crystal damage compromises water retention and reduces the thermal stability of muscle proteins during heating.

Color and Microstructure

Colorimetric changes, particularly increases in lightness (L) and yellowness (b) after freezing and thawing, reflect alterations in meat pigment chemistry and light scattering. Protein denaturation and partial oxidation of myoglobin derivatives can shift the visible hue, while increased light scattering from ice-induced microvoids enhances paleness (Park *et al.*, 2024). The diminished redness in fish supports the notion of pigment oxidation. Histologically, fresh control samples exhibited intact muscle fiber architecture (score ≈ 0.5), whereas frozen samples showed significant disruption (score ≈ 2.5), consistent with mechanical injury from ice crystals. Thawed samples showed partial recovery (score ≈ 1.5), reflecting limited rehydration or cellular collapse. These results agree with known mechanisms wherein freeze–thaw cycles induce mechanical stress, membrane rupture, and irreversible tissue deformation (Park *et al.*, 2024).

Nutritional and Chemical Alterations

The sharp decrease in moisture content, especially in thawed chicken (from approximately 73.80% to 63.52%), underscores cumulative water loss through purge, drip, and cooking processes—a direct consequence of structural damage and reduced water-holding capacity. The observed protein denaturation (12.7% in frozen, 11.6% in thawed) further confirms that freezing stress induces conformational changes in muscle proteins, reducing their functional and nutritional quality (Akhtar, 2013). Fat content remained relatively stable, suggesting that short-term freezing at -20°C does not extensively degrade lipid components, although minor oxidation may occur. The significant reduction in mineral content in chicken likely results from leaching of soluble minerals in purge or drip fluids, whereas fish minerals remained stable, indicating species-specific resilience to freeze–thaw stress (Akhtar *et al.*, 2013).

Integrated Perspective and Implications

Overall, freezing and thawing impose multi-level damage on white meat quality: they reduce pH stability (in some species), impair water retention, degrade microstructure, and partially denature proteins—collectively deteriorating sensory and nutritional attributes. The one-way ANOVA ($F = 3.567$, $p = .001$) confirms that these differences are statistically significant, indicating that treatments non-randomly affect meat quality across multiple parameters. From a practical standpoint, minimizing freeze–thaw damage is essential to preserve product integrity. Strategies such as rapid freezing (to limit ice crystal size), controlled thawing (to prevent excessive exudation), and the use of cryoprotectants or antioxidants have shown promise in mitigating damage (Sehar Akhtar *et al.*, 2013). Improved packaging technologies can further reduce oxidative stress and moisture loss during frozen storage. These findings are consistent with earlier reports emphasizing the importance of optimizing freezing and thawing protocols to maintain meat texture, color, and nutritional value (Zhang *et al.*, 2024). The differential responses between chicken and fish highlight the necessity of species-specific preservation methods. Future research should explore advanced thawing techniques, natural additive formulations, and real-time quality monitoring systems to enhance the post-thaw quality and consumer acceptability of white meats.

Conclusion

The findings of this study demonstrate that the processes of freezing and thawing exert significant effects on the physicochemical, structural, and nutritional quality of white meat derived from both chicken and fish. Freezing at -20°C followed by thawing at room temperature ($22\text{--}25^{\circ}\text{C}$) led to pronounced alterations in pH, moisture retention, and protein structure. Specifically, chicken meat exhibited a greater decline in pH and moisture content compared to fish, indicating higher susceptibility to denaturation and dehydration during the freeze–thaw cycle. The increased purge, drip, and cooking losses observed in both species further confirm compromised water-holding capacity, primarily due to ice crystal-induced damage to muscle fiber integrity. Colorimetric analysis revealed significant changes in lightness and yellowness values, along with a decrease in redness, suggesting oxidative degradation of pigments and proteins during storage. Histological evaluation supported these findings, showing notable muscle fiber disruption and intercellular space formation in frozen samples, with partial recovery after thawing. Nutritionally, moisture and mineral contents decreased significantly in chicken, while fish maintained relatively stable fat and mineral levels, likely due to differences in muscle composition and lipid distribution. The one-way ANOVA results ($F = 3.567$, $p = 0.001$) confirmed that these differences among treatment groups were statistically significant, indicating that freezing and thawing had a measurable and non-random effect on meat quality parameters. While freezing remains a practical preservation method, repeated freeze–thaw cycles significantly deteriorate the physicochemical integrity, structural properties, and nutritional value of white meat—effects more pronounced in chicken than in fish. Therefore, optimizing freezing conditions and minimizing thawing duration are critical to maintaining meat quality and consumer acceptability.

Declarations

Ethical Approval and Consent to Participate: This study strictly adhered to the Declaration of Helsinki and relevant national and institutional ethical guidelines. Informed consent was not required, as secondary data available on websites was obtained for analysis. All procedures performed in this study were by the ethical standards of the Helsinki Declaration.

Consent for Publication: Here, we, the authors, give our consent for publication.

Availability of Data and Materials: Data will be provided upon written request from the corresponding author.

Competing Interest: The writers of this article affirm that they are free from any conflicts of interest, whether financial or otherwise, that may have affected their independence in completing this work.

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Authors' Contribution: ZS, SU, FR: contributed to the conception, design, data collection, MKS, AZ, TAJ, ZA: analysis, HUR, MH, CA: interpretation and writeup of the study. All authors participated in the drafting, reviewing, and finalization of the manuscript. All authors have reviewed and approved the final version of the paper.

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