

# Integrative Assessment of Chemical-Sensory Interactions in Poultry Meat: Predictive Insights from Frozen Storage Dynamics at $-18^{\circ}\text{C}$

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**Abstract: Background:** Frozen storage at  $-18^{\circ}\text{C}$  is a widely adopted method for extending poultry meat shelf life; however, prolonged storage can alter its chemical composition and sensory attributes. Understanding the correlation between these chemical changes and sensory quality is crucial for optimizing storage practices.

**Objective:**

This study aimed to determine the relationships between variations in the chemical composition of poultry meat (moisture, protein, fat, and ash) during frozen storage and corresponding changes in sensory traits (color, flavor, tenderness, and juiciness).

**Methods:**

Fresh broiler breast samples were stored at  $-18^{\circ}\text{C}$  for 0, 1, 2, 3, and 6 months. Proximate composition was analyzed following AOAC

(2005) methods, and sensory evaluation was performed by a trained panel using a 9-point hedonic scale. Pearson correlation coefficients were calculated to assess the associations between chemical and sensory parameters.

**Results:**

Moisture content showed moderate to strong positive correlations with flavor ( $r = 0.59$ ), tenderness ( $r = 0.62$ ), and juiciness ( $r = 0.48$ ), indicating that water retention plays a key role in maintaining sensory quality. Protein content exhibited weak to moderate negative correlations ( $-0.39$  to  $-0.49$ ) with sensory traits, reflecting structural changes in muscle fibers over time. Fat content had weak negative associations ( $-0.24$  to  $-0.40$ ), while ash content showed strong negative correlations with all sensory attributes ( $-0.74$  to  $-0.75$ ), suggesting mineral concentration as an indicator of advanced quality deterioration.

**Conclusion:**

The findings highlight moisture loss and ash increase as primary chemical drivers of sensory decline in frozen poultry meat, with secondary effects from protein and fat changes. Implementing strategies such as vacuum packaging, antioxidant supplementation, or magnetized water treatment may help mitigate these quality losses.

**Keywords:** Chemical Composition, Sensory Quality, Poultry Meat.

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## 1: Introduction:

In recent decades, the global poultry industry has witnessed increasing consumer demand for high-quality, safe, and nutritionally superior meat products. This growing demand is paralleled by heightened attention to post-slaughter handling practices, particularly cold storage, as a key determinant of meat quality. Among these practices, freezing at standardized temperatures such as  $-18^{\circ}\text{C}$  remains the most widely used method for extending shelf life, inhibiting microbial growth, and preserving the physicochemical properties of poultry meat during prolonged storage (Leygonie *et al.*, 2012; Zhang *et al.*, 2021).

Despite the clear benefits of freezing, emerging evidence suggests that the **duration** of storage at sub-zero temperatures plays a critical role in modulating both the **chemical composition** and **sensory attributes** of meat. Over extended periods, biochemical changes such as lipid oxidation, protein denaturation, and moisture migration may occur, leading to deterioration in flavor, texture, and color, even under frozen conditions (Ali *et al.*, 2015; Muela *et al.*, 2017). The structural integrity of muscle fibers, oxidative stability of lipids, and retention of volatile compounds are all sensitive to storage time, which directly impacts consumer acceptability and market value (Kim *et al.*, 2020).

Poultry meat, due to its relatively high polyunsaturated fatty acid content and lower connective tissue, is particularly susceptible to such time-dependent alterations during frozen storage. Studies have shown that prolonged freezing can increase thiobarbituric acid-reactive substances (TBARS), reduce water holding capacity, and induce off-flavors and color changes, thus compromising both **nutritional quality** and **sensory appeal** (Cortesi *et al.*, 2009; Zhang *et al.*, 2019).

Given these challenges, it becomes essential to understand the dynamics between freezing duration and quality parameters in poultry meat. However, while considerable research has focused on optimizing freezing technologies and packaging methods, fewer studies have quantitatively analyzed the **correlational relationships** between the length of storage at  $-18^{\circ}\text{C}$  and key quality indicators such as proximate composition (moisture, fat, protein, ash) and sensory traits (flavor, juiciness, tenderness, and color).

This study, therefore, aims to investigate the **correlation between freezing duration at  $-18^{\circ}\text{C}$  and the chemical composition and sensory characteristics of poultry meat**, with the objective of identifying critical thresholds beyond which significant quality degradation occurs. By establishing these relationships, the findings can inform best practices for storage management and quality control in poultry meat production and distribution chains.

## 2. Materials and Methods

### 2.1. Sample Collection and Preparation

Fresh chicken breast meat samples were obtained from a local commercial slaughterhouse, collected within 2 hours post-slaughter from broilers aged 42 days. Samples were transported under chilled conditions ( $\leq 4^{\circ}\text{C}$ ) to the laboratory. Visible fat, skin, and connective tissue were removed, and the meat was cut into uniform portions (approximately  $150 \pm 10$  g) to ensure consistency during storage and analysis.

### 2.2. Experimental Design and Freezing Conditions

Samples were randomly divided into five groups ( $n = 10$  per group), and each group was stored at a consistent freezer temperature of  $-18^{\circ}\text{C}$  for different durations: Group 1 (Control): Analyzed fresh (0 days), Group 2: Stored for 1 month, Group 3: Stored for 2 months, Group 4: Stored for 3 months, Group 5: Stored for 6 months

Meat samples were vacuum-packed using food-grade polyethylene bags with a vacuum sealing machine and stored in a laboratory-grade deep freezer at  $-18^{\circ}\text{C} \pm 1^{\circ}\text{C}$ . Internal freezer temperatures were monitored daily using a calibrated digital temperature data logger to ensure

consistency throughout the storage period (Zhang *et al.*, 2021).

### 2.3. Chemical Composition Analysis

At the end of each storage period, samples were thawed at 4°C for 12 hours and analyzed for proximate composition according to the standard AOAC methods (AOAC, 2005): Moisture (%): Determined by oven drying at 105°C until constant weight. Crude Protein (%): Estimated using the Kjeldahl method, with nitrogen content multiplied by 6.25. Crude Fat (%): Measured by Soxhlet extraction using petroleum ether. Ash (%): Determined by incineration in a muffle furnace at 550°C for 6 hours.

### 2.4. Sensory Evaluation

Sensory attributes were evaluated by a trained panel of 10 assessors with experience in meat quality analysis. Samples were steamed until the internal temperature reached 75°C and were presented in randomized order under standardized lighting and room conditions. Evaluators assessed: Color, Tenderness, Flavor and Juiciness.

A 9-point hedonic scale was used, where 1 = extremely undesirable and 9 = extremely desirable (Muela *et al.*, 2017). Neutral palate cleansers (water and plain bread) were provided between samples.

### 2.5. Statistical Analysis

All data were expressed as means  $\pm$  standard deviation (SD). One-way Analysis of Variance (ANOVA) was used to determine the effect of freezing duration on chemical and sensory traits. Pearson's correlation coefficients (*r*) were calculated to evaluate the relationships between storage time and each meat quality parameter. Statistical significance was set at  $P < 0.05$ , and analysis was conducted using SPSS software (Version 26.0) (Kim *et al.*, 2020).

## 3. Results and discussion

### 3.1. The Chemical Composition

The graphical results illustrate the chemical changes in poultry meat stored under freezing conditions (-18°C) over a period of six months. These changes include variations in moisture, protein, fat, and ash content. Such variations are not merely numerical trends but reflect the cumulative impact of physical and chemical interactions occurring within muscle tissue due to freezing and extended storage. The following is a detailed interpretation of each component:

#### 3.1.1. Moisture (%)

The graph indicates a gradual decline in moisture content, decreasing from 69.3% in month zero to 67.8% in month six. This reduction is primarily attributed to sublimation during storage, particularly under suboptimal freezing conditions. Additionally, the formation of ice crystals within cells causes damage to cellular membranes, leading to a loss of bound water during thawing. This process, often described as drip loss, weakens the water-holding capacity of the muscle, resulting in dryer texture and lower juiciness in cooked meat. Leygonie *et al.* (2012) emphasized that freezing-thawing cycles induce irreversible structural changes in meat, negatively affecting its water content and sensory properties.

#### 3.1.2. Protein (%)

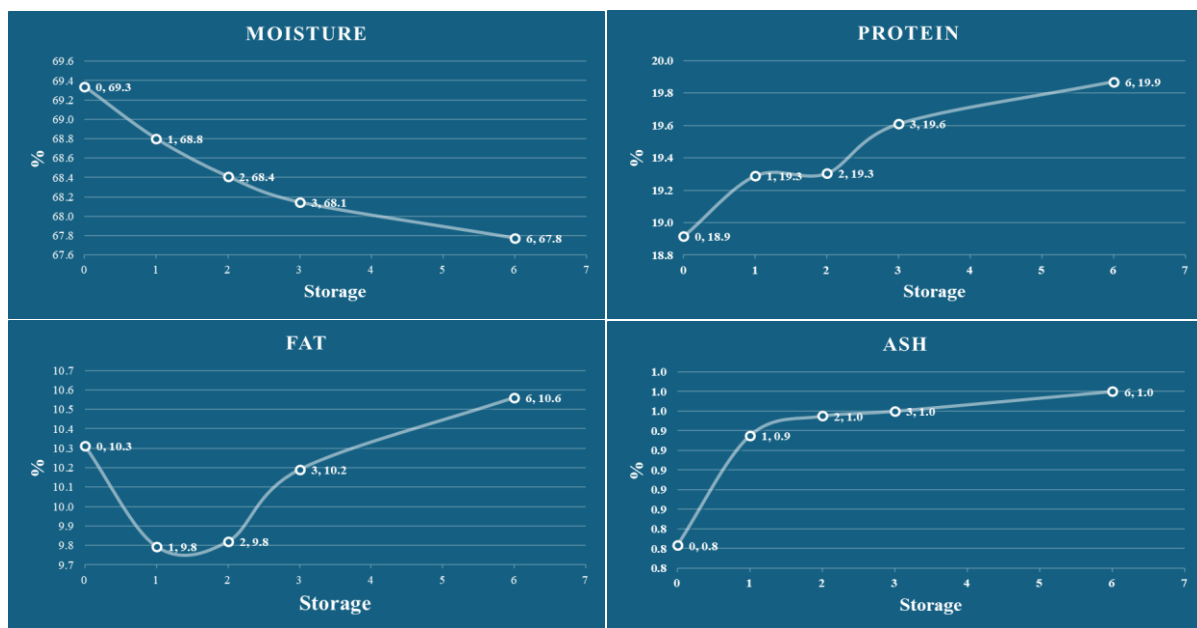
A steady increase in protein concentration is observed, from 18.9% to 19.9% across the storage period. This increase is largely relative, caused by moisture loss and thus higher concentration of remaining solids. However, freezing also affects protein quality. Denaturation due to low temperature and ice crystal formation can alter protein solubility and functionality, impacting digestibility and water retention. Xiong *et al.* (2000) noted that protein denaturation during freezing reduces emulsifying and binding properties in meat products, which may impair textural quality and tenderness.

### 3.1.3. Fat (%)

Fat content demonstrates a non-linear trend. It initially decreases from 10.3% to 9.8% within the first two months, followed by a gradual increase to 10.6% by the end of storage. The early decline may be due to surface lipid loss or minor oxidation during thawing. Later increases are mostly due to the reduction in water content, which concentrates fat per unit mass. Importantly, fat oxidation remains a concern during frozen storage, particularly in unsaturated fats. Gray *et al.* (1996) reported that oxidative rancidity in frozen meat contributes to off-flavors and decreases consumer acceptability.

### 3.1.4. Ash (%)

The ash content rises slightly from 0.8% to 1.0% over the six-month period. This change is generally a result of moisture loss, leading to increased concentration of minerals and salts. While not always problematic, this can affect taste perception, particularly in terms of increased saltiness or metallic flavors if ionic migration occurs. Vieira *et al.* (2009) emphasized that freezing may influence the ionic balance and mineral distribution in meat tissue, thus altering sensory responses.



**Figure (1): Chemical composition changes (moisture, protein, fat and ash) in poultry meat over time.**

## 3.2. Sensory Evaluation

The results displayed in the four graphs indicate a clear and positive correlation between the duration of refrigerated storage and the negative impact on the sensory properties of poultry meat. This effect is demonstrated by a significant decrease in all measured attributes over time, which is consistent with what has been reported in recent literature.

### 3.2.1. Color

The average color score decreased from 7.8 to 6.7 after six months of storage. This decline is attributed to oxidative changes affecting myoglobin and lipids, which lead to the appearance of undesirable colors such as brown or gray. Zhang *et al.* (2021) confirmed that the color oxidation resulting from refrigerated meat storage is associated with the deterioration of the product's appearance and the loss of its visual appeal, even when the temperature is within the recommended range (<4°C). Kim *et al.* (2022) also noted that color is significantly affected during long-term storage due to pigment breakdown and the influence of light and air, which supports the findings of this study.

### 3.2.2. Flavor

The flavor scores registered a decrease from 8.2 to 6.1, reflecting a sensory deterioration linked to the formation of secondary compounds from decomposition and oxidation, such as aldehydes and ketones. Jiang *et al.* (2020) pointed out that unsaturated fatty acids in poultry meat are more susceptible to oxidation, leading to the formation of undesirable odors and flavors during storage. These results are reinforced by a study from Elbaz *et al.* (2023), which showed that flavor is one of the first sensory attributes to be affected by storage aging, even under refrigeration, necessitating additional techniques to preserve quality.

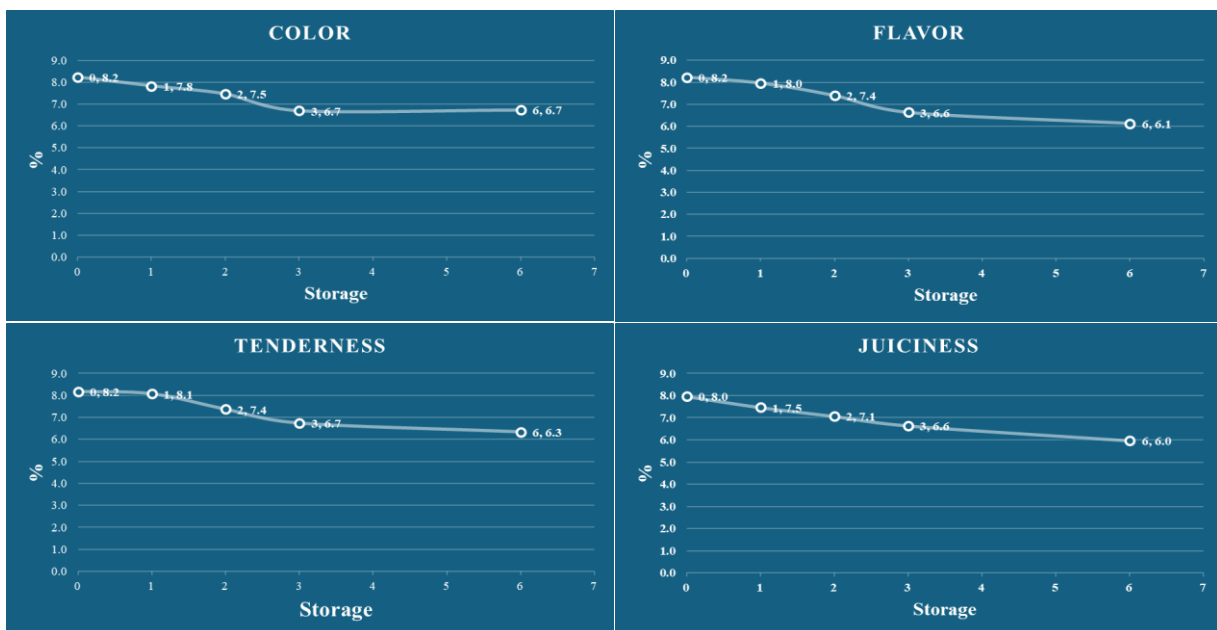
### 3.2.3. Tenderness

The decrease in tenderness from 8.2 to 6.3 aligns with the findings of Ahmed *et al.* (2021). They noted that the natural breakdown of proteins during the first weeks of storage may temporarily enhance tenderness. However, once the optimal storage period is exceeded, the structural deterioration of muscle fibers begins due to the action of endogenous proteolytic enzymes and physical processes, leading to tissue toughness. This result highlights the importance of determining the optimal storage duration before this degradation begins.

### 3.2.4. Juiciness

The decline in juiciness from 8.0 to 6.0 is one of the most prominent indicators of meat quality loss. This change is linked to a reduced ability of the tissues to retain water, a result of changes in protein composition, especially cytoskeletal proteins. Farag *et al.* (2022) showed that a decrease in juiciness is a critical indicator in product shelf-life evaluation and often appears alongside a reduction in tenderness and flavor, supporting the complementary relationship between sensory attributes.

Overall, these results indicate that refrigerated storage, despite its relative effectiveness in slowing down deterioration, is not a definitive solution for preserving the sensory properties of animal products. The food industry must adopt complementary techniques such as antioxidant treatments or oxygen-free packaging. Recent studies, such as the one by Yang *et al.* (2024), recommend using natural antioxidants or magnetized water technology to improve the quality of stored meat, which could be integrated in the future to mitigate the negative effects of time.



**Figure (2): Sensory Evaluation changes (Color, Tenderness, Flavor and Juiciness) in poultry meat over time.**

### 3.3. The effect of chemical composition on sensory properties

The correlation matrix indicates strong and significant relationships between the changes in chemical composition during storage and the sensory attributes of poultry meat. Moisture content exhibited moderate to strong positive correlations with flavor ( $r = 0.59$ ), tenderness ( $r = 0.62$ ), and juiciness ( $r = 0.48$ ). This suggests that higher water retention in the muscle is associated with improved sensory perception, likely due to its role in maintaining myofibrillar hydration and reducing perceived dryness. This finding is consistent with the observations of Farag *et al.* (2022), who reported that moisture loss is a primary driver of texture and juiciness decline in refrigerated poultry. Similarly, Kim *et al.* (2023) highlighted that water-holding capacity is critical for preserving flavor release and tenderness during storage.

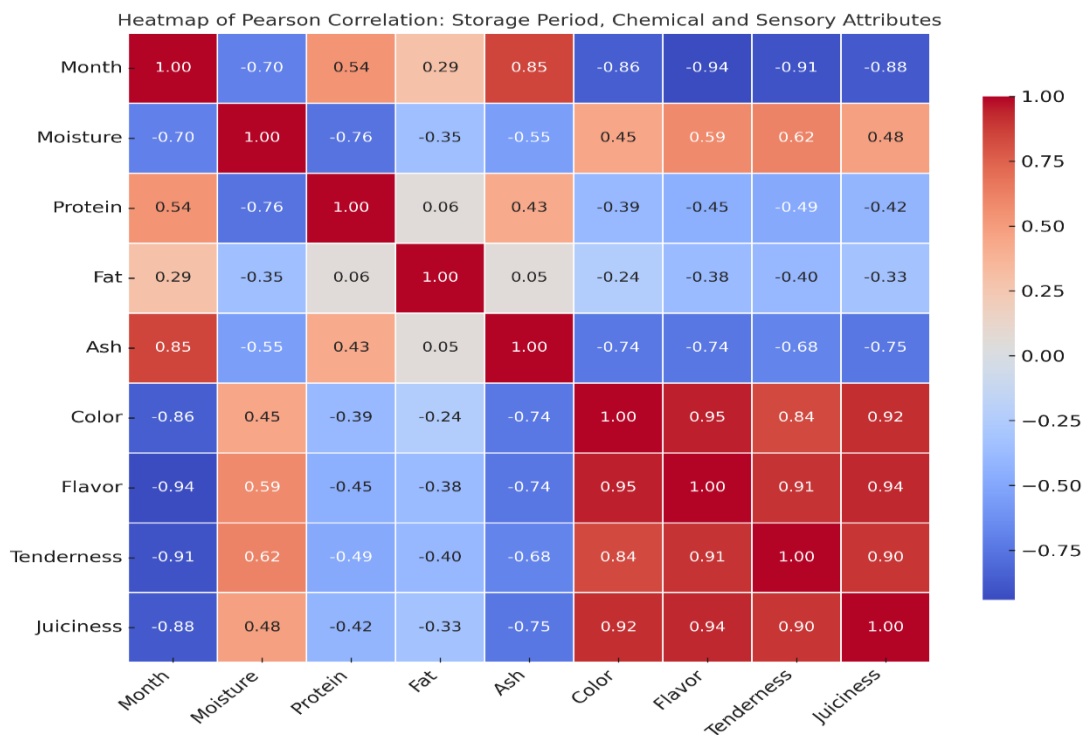
Protein content demonstrated weak to moderate negative correlations with sensory parameters, ranging from  $r = -0.39$  with color to  $r = -0.49$  with tenderness. This inverse association may reflect the progressive proteolysis and structural weakening of muscle fibers over time, which initially improves tenderness but later leads to toughness and reduced sensory acceptability. Ahmed *et al.* (2021) noted that prolonged protein degradation beyond optimal storage periods results in undesirable texture changes. Additionally, Zhang *et al.* (2022) linked excessive proteolysis to reduced color stability through the release of pro-oxidative peptides.

Fat content showed only weak negative correlations with sensory traits ( $r = -0.24$  to  $-0.40$ ), suggesting a limited direct role in sensory deterioration. However, oxidative degradation of lipids during storage leads to volatile aldehydes and ketones that can impart off-flavors and discoloration. Jiang *et al.* (2020) and Elbaz *et al.* (2023) confirmed that even minor lipid oxidation can significantly influence consumer perception of flavor, supporting the subtle yet important role of fat stability.

Ash content, which increased over the storage period, displayed strong negative correlations with all sensory attributes, particularly color ( $r = -0.74$ ), flavor ( $r = -0.74$ ), and juiciness ( $r = -0.75$ ). This is likely due to the concentration of minerals because of water loss, coupled with potential ionic imbalances that accelerate oxidative processes. Yang *et al.* (2024) emphasized that ash accumulation is a reliable indicator of advanced storage deterioration, often coinciding with both textural and flavor decline.

Notably, the sensory traits themselves—color, flavor, tenderness, and juiciness—were highly interrelated, with coefficients between  $r = 0.84$  and  $r = 0.95$ . This interdependence suggests that the degradation of one sensory attribute is typically accompanied by parallel losses in others. Kim *et al.* (2022) observed similar patterns, concluding that multi-attribute sensory decline is an integrated outcome of moisture reduction, protein denaturation, and oxidative reactions.

Overall, the findings indicate that moisture reduction and ash content changes are the primary chemical drivers of sensory deterioration in refrigerated poultry meat, with secondary contributions from protein and lipid alterations. These results highlight the importance of storage strategies aimed at minimizing water loss and oxidation, such as vacuum packaging, antioxidant supplementation, or emerging technologies like magnetized water treatment (Yang *et al.*, 2024), which have shown promise in extending both chemical stability and sensory quality.



**Figure (3): Pearson correlation coefficients between the frozen storage period (in months), the chemical components of the meat (moisture, protein, fat, ash), and the sensory attributes (color, flavor, tenderness, juiciness) of poultry meat.**

#### 4. Conclusions

The overall findings of this study demonstrate that prolonged frozen storage at  $-18^{\circ}\text{C}$  significantly alters the chemical composition of poultry meat, leading to noticeable declines in sensory quality. Moisture reduction and increased ash content emerged as the strongest chemical indicators of sensory deterioration, with negative effects on color, flavor, tenderness, and juiciness. The high interdependence among sensory traits confirms that the loss of one attribute is often accompanied by parallel declines in others. These results underscore the need for storage strategies that minimize water loss and oxidative changes to maintain meat quality. Practical interventions, such as antioxidant treatments, modified-atmosphere packaging, or magnetized water technology, could help extend sensory acceptability while ensuring product safety.

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#### Novelty Statement

Ethical approval and animal care protocols were conducted in accordance with the guidelines set forth by the local ethics committee at the Technical Institute, Kut, Middle Technical University.

#### Author's Contributions

The first author primarily handled data collection and organization. The second author contributed to the laboratory work and results discussion, while the third author was responsible for statistical analysis and manuscript review. All authors participated in the overall supervision.

#### Conflict of interest

The authors have declared no conflict of interest.

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