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Effect of Chilling, Freezing and Freeze-Thaw Cycles on Quality Characteristics of Goat Meat (Chevon)

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Authors' Contribution
AHS and MAJ designed the research experiment. GSB, GBK, SGT and TAK formulated the data of research and conducted the statistical analysis. ST conducted the experiments. MAM and HT helped in experimental procedures.

Key words
Chevon, Chilling, Freezing, Quality characteristics, Thaw cycles

ABSTRACT

Chevon is well-known for its abundant nutritional value and greater unsaturated to saturated fatty acid ratio. It is internationally regarded as a lean red meat with favorable nutritional characteristics. The influence of different times was observed on the physicochemical characteristics of chilled, frozen, and thawed chevon compared to fresh meat. The values of pH and water holding capacity decreased with increasing storage period of chilled, frozen, and thawed chevon samples, while drip loss and cooking loss increased as the storage period increased. Proximate composition such as moisture, protein, fat, ash, and glycogen decreased with the increasing storage period of chilled, frozen, and thawed chevon samples. Nutritive values of chilled, frozen, and thawed chevon samples also decreased with the increasing storage period. From the results of the current study, it is concluded that low-temperature-based treatments as well as thaw cycles decreased meat quality with time.

INTRODUCTION

Chevon, commonly known as goat meat, is famous for its exceptional nutritional profile, marked by a favorable unsaturated to saturated fatty acid ratio and a high protein content (Webb *et al*., 2005; Akram *et al*., 2019). Renowned internationally as a lean red meat, it boasts of being a rich source of essential micronutrients, notably potassium, iron, and vitamin B12, making it a valuable component of a balanced diet (Darnton-Hill *et al*., 2015; Mazhangara *et al*., 2019). Moreover, its consumption has been linked to numerous health benefits, including a reduced risk of obesity and metabolic diseases like insulin resistance, type II diabetes mellitus, cardiovascular diseases, and metabolic syndrome (Wang *et al*., 2016).

However, despite its nutritional prowess, the quality of chevon can deteriorate over time, particularly during storage, due to various physical and biochemical changes influenced by factors such as temperature and preservation methods (Phothiset and Charoenrein, 2014). Preservation techniques, such as chilling and freezing, play a vital role in extending the shelf life of meat products by inhibiting microbial growth and enzymatic activity (Gómez *et al*., 2020). Nevertheless, these preservation methods may also have implications for meat quality attributes, including texture, flavor, and nutritional content, which are crucial considerations for consumers and the meat industry alike.

Furthermore, the practice of subjecting meat to repeated freeze-thaw cycles, prevalent in both retail and household settings, has emerged as a significant concern due to its potential to exacerbate quality degradation (Phothiset and Charoenrein, 2014). Understanding the intricacies of storage and preservation techniques and their impact on chevon quality is imperative for safeguarding its nutritional integrity and meeting consumer expectations.

Even though, the recognized importance of these

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preservation methods, comprehensive understanding and optimization to mitigate adverse effects on goat meat quality are ongoing challenges. This study aims to critically evaluate the influence of chilling, freezing, and freeze-thaw cycles on the quality characteristics of goat meat. By doing so, this study seeks to contribute to the development of improved preservation strategies that can retain the nutritional and sensory quality of chevon, thereby supporting consumer health and the economic viability of the goat meat industry.

MATERIALS AND METHODS

Sample collection

Fresh goat meat (Longissimus dorsi muscle, located along the vertebral column from the base of the neck to the tail) samples of adult goats (1 to 1.5 years of age) were collected from the Tandojam market and brought to the laboratory of the Department of Animal Products Technology, Sindh Agriculture University, Tandojam for analysis. Each meat sample was divided into four parts: raw (control), chilled, frozen and freeze-thawed group. The control group was analyzed on the first day (fresh meat) of the collection while samples from chilled (4°C), frozen (-10°C) and thawed were analyzed for their physical properties (pH value, cooking loss, drip loss and water holding capacity), chemical properties (Moisture, Protein, glycogen, ash and fat), and calorific values. The calorific value of meat was calculated based on macronutrients analysis at various intervals i.e., 4th, 7th, 14th, 21st and 28th day.

Physical analysis

Water holding capacity, pH value, cooking loss and drip loss was determined using protocols reported by Wardlaw *et al*. (1973), Ockerman (1985), Kondaiah *et al*. (1985) and Sen *et al*. (2004), respectively.

Chemical analysis

Moisture content, total solids, protein (Kjeldhal), Fat (Ether extraction) and ash contents was determined according to the methods described by the Association of Official Analytical Chemists (AOAC, 2005). Furthermore, the glycogen content of meat samples was determined by the spectrophotometric method (Kemp *et al*., 1953).

Nutritive value

The nutritive value was calculated from the proximate analysis by using following the formula.

K. cal (per 100g) = [(% Protein) (4)] + [(% Fat) (9)] + (% Carbohydrates) (4)]

Statistical analysis

The study used statistical analysis, employing ANOVA to compare means across multiple groups. A post-hoc LSD test was then applied to identify significant differences between individual group pairs.

RESULTS

Changes in physical characteristics

Table I shows changes in pH, water holding capacity,

Table I. Physical parameters of fresh, chilled, frozen and thawed chevon at different storage periods.

Meat sample	Time interval (Days)	pH	WHC (%)	Drip loss (%)	Cooking loss (%)
Fresh	0	6.24±0.42^{a}	64.34±0.31^{a}	3.75±0.22^{m}	38.75±0.42^{m}
Chilled	04	5.80±0.34^{d}	57.91±0.67^{e}	5.65±0.39^{i}	45.85±0.87^{g}
	07	5.64±0.11^{g}	54.64±0.53^{i}	6.98±0.45^{e}	48.25±0.54^{e}
	14	5.48±0.49^{j}	50.12±0.29^{m}	8.12±0.98^{a}	52.85±0.37^{c}
Frozen	04	5.98±0.23^{b}	61.88±0.88^{b}	4.08±0.56^{l}	40.85±0.49^{l}
	07	5.90±0.87^{c}	59.29±0.55^{d}	4.98±0.34^{j}	42.65±0.54^{k}
	14	5.81±0.66^{d}	57.37±0.23^{f}	5.66±0.22^{i}	44.85±0.88^{i}
	21	5.72±0.30^{e}	55.01±0.11^{h}	6.30±0.43^{g}	47.25±0.11^{f}
	28	5.57±0.19^{h}	53.26±0.45^{k}	7.08±0.67^{c}	53.15±0.28^{b}
Thawed	04	5.81±0.32^{d}	59.67±0.76^{c}	4.44±0.25^{k}	43.55±0.67^{j}
	07	5.68±0.55^{f}	56.28±0.98^{g}	5.82±0.88^{h}	45.55±0.53^{h}
	14	5.57±0.19^{h}	53.73±0.34^{j}	6.55±0.56^{f}	48.65±0.27^{d}
	21	5.51±0.56^{i}	51.88±0.23^{l}	7.03±0.72^{d}	52.75±0.18^{c}
	28	5.45±0.90^{k}	48.08±0.66^{n}	8.02±0.44^{b}	56.45±0.45^{a}
P-value	-	0.0131	0.0180	0.0151	0.0158
SE-value		0.0326	0.0326	0.3695	0.0692

WHC, water holding capacity.

cooking loss and drip loss in chilled, frozen, and thawed goat meat against fresh meat. The pH value of the fresh goat meat sample was 6.24±0.42 while in chilled meat it was 5.80±0.34, on 14th day. Whereas in frozen meat, pH significantly declined as the storage time period increased; it was 5.98±0.23, on the 4th and 5.57±0.19 on 28th day. In thawed meat, in each cycle, pH also showed a decreased trend with storage; it was in between 5.81±0.32 and 5.45±0.90 after 28 days of storage. Among all groups, it was noted that the pH value decreased with an increase in the storage period.

In fresh meat, water holding capacity was observed as 64.34±0.31% whereas on the 4th day treated samples (chilled), it was 57.91±0.67% in chilled meat samples, 61.88±0.88% in frozen meat samples and 59.67±0.76% in thawed meat. On 14th day these values were, respectively, 50.12±0.29%, 57.37±0.23%, and 503.73±0.34%, in chilled, frozen and thawed meat samples. Results denoted that the water holding capacity significantly declined as the duration of storage increased.

The cooking loss of the control sample of goat meat was observed as 38.75±0.42%. After 14 days of chill, freezing and thawing, the cooking loss was, respectively, 52.85±0.37%, 44.85±0.88% and 48.65±0.27%. This loss was 53.15±0.28% and 56.45±0.45%, respectively in frozen and thawed meat samples after 28 days. Results indicated that cooking loss of chilled, frozen and thawed meat was significantly increased at various interval days.

A wide change in drip loss was recorded in different groups as the storage period of meat increased. The drip loss of fresh goat meat sample was recorded 3.75±0.22% while in chilled meat, it was 8.12±0.98%, in frozen meat, it was 5.66±0.22%, and in thawed meat, it was 6.55±0.56 after 14 days. After 28 days, this loss was 7.08±0.67% and 8.02±0.44% in frozen and thawed meat samples. It was observed that, drip loss was also increased in different groups that as the storage period increased ($P<0.05$).

Changes in chemical characteristics

Table II shows changes in moisture, protein, fat, ash and glycogen content in fresh, chilled, frozen, and thawed goat meat samples analyzed at various intervals. The moisture content in the fresh goat meat sample was 74.95±0.34% however in chilled meat, it was 71.35±0.56% on 4th day and 67.15±0.71% on14th day. In frozen meat, moisture content was as 72.75±0.45%, 70.55±0.29%, and 64.35±0.30% in 4th, 14th and 28th day, respectively. Moreover, in thawed meat, in each cycle of moisture content was 71.05±0.25% and 61.30±0.55% after 4 and 28 days, respectively. It was recorded that the moisture content of chilled, frozen, and thawed meat was significantly decrease as the storage period increased.

Table II. Chemical parameters of fresh, chilled, frozen and thawed chevon at different storage periods.

Meat sample	Time interval (Days)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Glycogen (%)	Nutritive values (K.cal/100g)
Fresh	0	74.95±0.34^{a}	20.60±0.77^{a}	2.43±0.31^{a}	1.14±0.70^{a}	1.23±0.19^{a}	107.83±0.33^{a}
Chilled	04	71.35±0.56^{d}	18.55±0.45^{e}	2.11±0.87^{e}	1.05±0.45^{d}	1.14±0.98^{d}	97.81±0.96^{e}
	07	70.05±0.89^{g}	17.84±0.32^{g}	1.97±0.35^{h}	0.98±0.73^{f}	1.05±0.45^{g}	93.31±0.78^{g}
	14	67.15±0.71^{j}	15.22±0.23^{m}	1.80±0.90^{k}	0.81±0.42^{k}	0.85±0.77^{k}	80.50±0.44^{m}
Frozen	04	72.75±0.45^{b}	19.95±0.19^{b}	2.22±0.17^{b}	1.12±0.30^{b}	1.18±0.27^{b}	104.57±0.30^{b}
	07	71.85±0.18^{c}	19.03±0.11^{c}	2.17±0.11^{c}	1.00±0.18^{e}	1.14±0.22^{d}	100.23±0.18^{c}
	14	70.55±0.29^{f}	18.33±0.37^{f}	2.02±0.36^{g}	0.92±0.58^{h}	1.07±0.65^{f}	95.84±0.48^{f}
	21	68.45±0.35^{i}	17.55±0.66^{h}	1.92±0.29^{i}	0.88±0.26^{i}	0.99±0.82^{i}	91.52±0.59^{i}
	28	64.35±0.30^{m}	16.22±0.89^{k}	1.84±0.33^{j}	0.78±0.33^{l}	0.86±0.17^{k}	84.94±0.43^{k}
Thawed	04	71.05±0.25^{e}	18.93±0.76^{d}	2.14±0.45^{d}	1.07±0.41^{c}	1.16±0.33^{c}	99.64±0.89^{d}
	07	69.05±0.88^{h}	17.29±0.91^{i}	2.07±0.22^{f}	0.95±0.67^{g}	1.11±0.20^{e}	92.31±0.36^{h}
	14	66.65±0.73^{k}	16.86±0.55^{j}	1.96±0.56^{h}	0.84±0.16^{j}	1.02±0.67^{h}	89.18±0.19^{j}
	21	64.45±0.70^{l}	15.65±0.48^{l}	1.80±0.77^{k}	0.75±0.39^{m}	0.95±0.29^{j}	82.66±0.38^{l}
	28	61.30±0.55^{n}	13.36±0.33^{n}	1.72±0.82^{l}	0.67±0.50^{n}	0.81±0.80^{l}	72.18±0.40^{n}
P-value	-	0.0422	0.0180	0.0162	0.0155	0.0119	0.0312
SE-value		0.0423	0.0291	0.0274	0.0371	0.0320	0.0975

Likewise, protein, fat, ash and glycogen of content goat meat of different sample groups decreased as the storage time of meat increased (P≤0.05). In the fresh goat meat (chevon) sample, protein content was recorded as 20.60±0.77%, while it was 18.55±0.45% in chilled meat, 19.95±0.19% in frozen meat and 18.93±0.76% in thawed meat samples after 4 days of storage. After 14 days these values were, respectively, 15.22±0.23%, 18.33±0.37%, and 16.86±0.55% in chilled, frozen and thawed samples. After 28 days, the protein content was, respectively, 16.22±0.89% and 13.36±0.33% in frozen and thawed samples.

The fat and ash content of fresh, chilled, frozen and thawed meat indicated significant (P≤0.05) change after longer period of storage. On 14th day, fat content of chilled meat was recorded as 1.80±0.90%, in frozen meat it was 2.02±0.36%, while in thawed meat it was 1.96±0.56%. After 29 days, fat content was 20.60±0.33% and 1.72±0.82%, respectively, in the frozen and thawed samples.

Ash content in the control sample was 1.14±0.70%. In chilled meat it was recorded as 0.81±0.42% on 14th day, in frozen meat it was 0.78±0.33% and in thawed meat it was 0.67±0.50% on 28th day of storage. Results showed that ash content of chilled, frozen and thawed meat reduced (P≤0.05) over longer period of storage.

Glycogen content likewise showed declining trend with time period. In the fresh meat glycogen level was 1.23±0.19%, while on 14th day was recorded as 0.85±0.77% in chilled meat. In frozen meat glycogen content were 1.18±0.27 and 0.86±0.17% on 4th and 28th day, respectively. In thawed meat, it was recorded as 1.16±0.33 and 0.81±0.80% on day 4 and 28 of storage, respectively. Based on ANOVA, it was found that the glycogen content of distinct meat samples were statistically different (P≤0.05) among all meat samples.

The results indicated that the calorific value was 107.83±0.33 K.cal/100g in the fresh goat meat sample. While on 4th, 7th, and 14th day, the calorific value of chilled meat was recorded as 97.81±0.96, 93.31±0.78 and 80.50±0.44 K.cal/100g, respectively. In frozen meat, it was determined as 104.57±0.30, 95.84±0.48 and 84.94±0.43 K.cal/100g on 4th, 14th and 28th day, respectively. Whereas the thawed meat, had 99.64±0.89, 89.18±0.19 and 72.18±0.40 K.cal/100g, respectively after storage for 4, 14 and 28 days. Statistically, results showed that the calorific value of chilled, frozen and thawed meat decreased as the storage period increased (P≤0.05).

DISCUSSION

The present study showed significant changes in these quality characteristics of goat meat over various storage periods.

pH

The decline in pH over storage periods in chilled, frozen, and thawed goat meat samples, it's crucial to delve deeper into the mechanisms driving this phenomenon and its implications for meat quality. pH serves as a critical indicator of meat acidity or alkalinity, directly impacting its sensory attributes, microbiological stability, and overall shelf-life (Koh *et al*., 2019). Understanding the factors influencing pH changes during storage is essential for maintaining meat quality and ensuring consumer satisfaction. Post-mortem glycolysis emerges as a fundamental mechanism contributing to pH changes in meat during storage. Following slaughter, glycogen in muscle tissue metabolizes to lactic acid through the action of glycogenolytic and glycolytic enzymes (Wu *et al*., 2024). This process leads to a decrease in pH, known as post-mortem pH decline, which is essential for meat tenderization and flavor development (Kim *et al*., 2013). Moreover, microbial activity significantly influences pH dynamics during meat storage. Microorganisms residing on the meat surface and in the surrounding environment engage in fermentation processes, generating organic acids that contribute to pH reduction (Xiong *et al*., 2022). Additionally, spoilage bacteria proliferate during storage, producing metabolites that further lower the pH of meat samples (Wang *et al*., 2018).

WHC

WHC serves as a critical quality attribute of meat, directly influencing its juiciness, tenderness, and overall eating experience (Kim *et al*., 2022). Recognizing the factors influencing WHC changes during storage is crucial for optimizing meat processing and preservation techniques. Protein denaturation emerges as a primary mechanism contributing to the decline in WHC during meat storage. Thermal processing or prolonged storage can lead to the denaturation of proteins, resulting in reduced water-binding capacity and increased drip loss, ultimately diminishing the juiciness of meat samples (Wu *et al*., 2024; Koh *et al*., 2019). Additionally, the breakdown of muscle structure and connective tissue further exacerbates WHC reduction. Proteolytic enzymes, such as calpains and cathepsins, degrade structural proteins, leading to tissue softening and water loss (Hong *et al*., 2014). Moreover, lipid oxidation during storage can exacerbate WHC reduction by generating reactive oxygen species, disrupting muscle integrity, and further compromising the ability of meat to retain water (Xiong *et al*., 2022). This oxidative process contributes to the overall deterioration

of meat quality and impacts its sensory attributes.

Cooking loss

Cooking loss, often expressed as the percentage of weight lost during cooking, serves as a critical indicator of meat quality deterioration, reflecting the loss of moisture and fat from the meat and impacting its juiciness, tenderness, and overall sensory attributes (Wei *et al*., 2017). Understanding the factors influencing changes in cooking loss during storage is essential for optimizing meat processing and preservation techniques. One of the primary mechanisms contributing to increased cooking loss in meat samples is protein denaturation and shrinkage during thermal processing (Kaewthong *et al*., 2019). Protein denaturation occurs when proteins undergo structural changes due to heat exposure, leading to the loss of water-binding capacity and increased drip loss during cooking (Wu *et al*., 2024). This process compromises the meat's ability to retain moisture, resulting in decreased juiciness and tenderness. Additionally, the breakdown of muscle structure and connective tissue can further contribute to cooking loss by allowing moisture to escape during heating (Hong *et al*., 2014). As heat is applied during cooking, the structural integrity of muscle fibers and collagen matrix is compromised, facilitating the release of moisture from the meat. This process exacerbates cooking loss and influences the textural properties of the meat, affecting its overall eating experience.

Drip loss

Drip loss, representing the amount of moisture lost from meat during storage and processing, is a critical parameter influencing meat juiciness, tenderness, and overall eating quality (Jayanthi *et al*., 2017). Understanding the factors driving changes in drip loss during storage is fundamental for optimizing meat processing and preservation techniques. One of the primary mechanisms contributing to increased drip loss in meat samples is the breakdown of muscle structure and connective tissue during storage. Proteolytic enzymes, such as calpains and cathepsins, play a significant role in degrading structural proteins, leading to tissue softening and subsequent water loss (Hammad *et al*., 2019). This degradation compromises the integrity of the meat, facilitating the release of moisture. Moreover, microbial activity during storage can exacerbate drip loss by producing enzymes that degrade proteins and carbohydrates. These microbial enzymes further contribute to the breakdown of muscle structure and connective tissue, leading to increased drip loss (Kim *et al*., 2022). As a result, the meat becomes more susceptible to moisture loss during storage, impacting its juiciness and tenderness.

Moisture content

The reduction in moisture content aligns with findings from previous research (Bowker *et al*., 2010) and underscores the importance of understanding the factors influencing moisture loss during storage. Moisture loss in meat can result from various factors, including drip loss, protein denaturation, and lipid oxidation (Koh *et al*., 2019). Additionally, enzymatic activity and microbial degradation contribute to moisture loss by breaking down proteins and carbohydrates in the meat matrix (Wang *et al*., 2018). These processes compromise the structural integrity of the meat, leading to the release of moisture over time. Implementing proper storage practices, such as rapid chilling and freezing, can help minimize moisture loss and preserve meat quality over extended periods. These practices help maintain the structural integrity of the meat and mitigate the effects of enzymatic and microbial degradation on moisture content.

Protein content

Enzymatic activity, lipid oxidation, and microbial degradation collectively contribute to this phenomenon (Xiong *et al*., 2022). Proteolytic enzymes, such as calpains and cathepsins, play a pivotal role in breaking down proteins into peptides and amino acids, leading to a decline in protein content over time (Xiong *et al*., 2022). This enzymatic degradation compromises the structural integrity of proteins, resulting in alterations in meat texture and tenderness. Furthermore, lipid oxidation products generated during storage can exacerbate protein degradation, forming reactive compounds that further degrade proteins and impact meat quality (Damaziak *et al*., 2019).

Additionally, microbial activity during storage can contribute to protein degradation through the production of metabolites that enzymatically degrade proteins. Microbial enzymes can catalyze the breakdown of proteins and peptides, leading to a reduction in protein content and potentially affecting the sensory attributes of the meat (Damaziak *et al*., 2019).

Fat content

The decrease in fat content observed in chilled, frozen, and thawed goat meat samples may be attributed to lipid oxidation and enzymatic degradation (Wang *et al*., 2018). Lipid oxidation instigates the breakdown of fats, leading to the formation of volatile compounds and consequent reduction in fat content over time (Chen *et al*., 2017). This oxidative degradation alters the composition of fats, potentially impacting the flavor, aroma, and overall quality of the meat. Moreover, enzymatic activity, particularly that of lipases, further accelerates fat degradation by catalyzing

the hydrolysis of triglycerides into free fatty acids and glycerol (Wu *et al*., 2024).

Ash content

The reduction in ash content in chilled, frozen, and thawed goat meat samples may be because of collective contribution of enzymatic activity, microbial degradation, and mineral leaching (Augustynska-Prejsnar *et al*., 2018). Ash content serves as a marker for the mineral composition of meat, encompassing essential elements like calcium, phosphorus, potassium, and magnesium, which contribute to its nutritional value and stability. Enzymatic activity and microbial metabolism during storage catalyze the breakdown of organic matter, releasing minerals from the meat matrix and resulting in reduced ash content (Xiong *et al*., 2022). This enzymatic and microbial-driven mineral release alters the nutritional profile of the meat, impacting its overall quality. Furthermore, the leaching of minerals during thawing and cooking processes exacerbates the decrease in ash content observed in thawed meat samples (Koh *et al*., 2019). As meat undergoes thawing and cooking, minerals are released into the surrounding medium, further depleting the ash content and affecting the nutritional integrity of the meat.

Glycogen content

The decreasing trend in glycogen content observed in chilled, frozen, and thawed goat meat samples reveals a complex interplay of physiological and environmental factors influencing postmortem metabolism and storage conditions (Kim *et al*., 2022). Glycogen, a crucial carbohydrate reservoir stored in muscle tissue, serves as an essential energy source during postmortem processes, particularly for the onset of glycolysis and subsequent pH decline (Andersen *et al*., 2021). The progressive reduction in glycogen content over storage periods signifies its gradual utilization during postmortem metabolic activities and is indicative of its depletion as storage duration increases (Bowker *et al*., 2010). However, this decline is not solely attributed to endogenous enzymatic activity but is also influenced by external factors, such as temperature variations and microbial presence. Temperature fluctuations can significantly impact glycogenolysis rates, with higher temperatures accelerating enzymatic activity and microbial growth, thus hastening the depletion of glycogen reserves (Xiong *et al*., 2022). Additionally, microbial enzymes may directly contribute to glycogen degradation, further diminishing its content in meat samples (Zheng *et al*., 2020).

Calorific value

The calorific value of goat meat is crucial to recognize its significance in assessing the energy content derived from its macronutrient composition, including protein, fat, and carbohydrates (Legako *et al*., 2015). This criterion provides valuable insights into the nutritional profile of goat meat and its potential contribution to dietary energy intake. The observed declining trend in the calorific value of chilled, frozen, and thawed goat meat samples is consistent with reductions in protein and fat content over storage time (Bowker *et al*., 2010). As these essential macronutrients decrease, the overall energy content of the meat diminishes accordingly, which can have implications for dietary energy intake and nutritional quality. Consumers may need to adjust their dietary choices to compensate for this decrease in energy content. However, it's essential to consider that the proximate analysis, while informative about macronutrient composition, offers only a partial understanding of the overall nutritive value of goat meat. Factors such as micronutrient content, amino acid profile, and the bioavailability of nutrients also play crucial roles in determining its nutritional quality (Orlova *et al*., 2021). Furthermore, cooking methods and processing techniques can significantly influence the digestibility and bioavailability of nutrients in meat, further affecting its nutritional value.

CONCLUSION

The study investigates the impact of chilling, freezing, and freeze-thaw cycles on goat meat quality. Results show that prolonged storage leads to a decline in various quality attributes such as pH, water holding capacity, moisture, protein, fat, ash, glycogen content, and calorific value. These changes indicate potential alterations in nutritional composition, highlighting the importance of proper storage practices to mitigate quality deterioration. Minimizing freeze-thaw cycles and optimizing storage conditions are crucial for preserving goat meat quality.

DECLARATIONS

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IRB approval

The research work was approved by the board of studies (November 2019) at Department of Animal Product Technology, Faculty of Animal Husbandry and Veterinary Sciences, Sindh Agriculture University, Tandojam.

Ethical statement

The experiment was approved by the ethical committee of the Faculty of Animal Husbandry and Veterinary Sciences, Sindh Agriculture University, Tandojam before the practical execution of this research work.

Statement of conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abhijith, A., Warner, R.D., Dunshea, F.R., Leury, B.J., Ha, M. and Chauhan, S.S., 2023. A review of some aspects of goat meat quality: Future research recommendations. *Anim. Prod. Sci*., **63**: 1361-1375. https://doi.org/10.1071/AN22355

Akram, M.B., Khan, M.I., Khalid, S., Shoaib, M. and Hassan, S.A., 2019. Quality and sensory comparison of ostrich and goat meat. *SSR Inst. Int. J. Life Sci*., **5**: 2168. https://doi.org/10.21276/SSR-IIJLS.2019.5.1.9

Andersen, P.V., Afseth, N.K., Gjerlaug-Enger, E. and Wold, J.P., 2021. Prediction of water holding capacity and pH in porcine longissimus lumborum using Raman spectroscopy. *Meat Sci*., **172**: 108357. https://doi.org/10.1016/j.meatsci.2020.108357

Association of Official Analytical Chemistry (AOAC). 2005. *Official methods of analysis of AOAC* (International Gaithersburg, USA).

Augustynska-Prejsnar, A., Ormian, M. and Sokołowicz, Z., 2018. Physicochemical and sensory properties of broiler chicken breast meat stored frozen and thawed using various methods. *J. Fd. Qual*., **3**: 1-9. https://doi.org/10.1155/2018/6754070

Bowker, B., Grant, A., Forrest, J.C., Hamann, D.D., Gray, J.I. and Lanier, T.C., 2010. Effect of postmortem aging and freezing on the Warner-Bratzler shear force of beef longissimus from two quality grades. *Meat Sci*., **86**: 864–870.

Casey, N.H., Van Niekerk, W.A. and Webb, E.C., 2003. Goats meat. In: *Encyclopedia of food sciences and nutrition* (eds. B. Caballero, L. Trugo and P.S. Finglass). Academic Press, London. pp. 2937–2944. https://doi.org/10.1016/B0-12-227055-X/00564-2

Chen, T.H., Zhu, Y.P., Han, M.Y., Wang, P., Wei, R., Xu, X.L. and Zhou, G.H., 2017. Classification of chicken muscle with different freeze–thaw cycles using impedance and physicochemical properties. *J. Fd. Eng*., **196**: 94-100. https://doi.org/10.1016/j.jfoodeng.2016.10.003

Damaziak, K., Stelmasiak, A., Riedel, J., Zdanowska-Sąsiadek, Z., Bucław, M., Gozdowski, D. and Michalczuk, M., 2019. Sensory evaluation of poultry meat: A comparative survey of results from normal sighted and blind people. *PLoS One,* **14**: e0210722. https://doi.org/10.1371/journal.pone.0210722

Darnton-Hill, I., Mkparu, U. and Mkparu, U.C., 2015. Micronutrients in pregnancy in low- and middle-income countries. *Nutrients*, **7**: 1744–176. https://doi.org/10.3390/nu7031744

Gómez, I., Janardhanan, R., Ibañez, F.C. and Beriain, M.J., 2020. The effects of processing and preservation technologies on meat quality: Sensory and nutritional aspects. *Foods*, **9**: 1416. https://doi.org/10.3390/foods9101416

Hammad, H., Ma, M., Damaka, A.W.H.Y., Elkhedir, A. and Jin, G., 2019. Effect of freeze and re-freeze on chemical composition of beef and poultry meat at storage period 4.5 months (SP4. 5). *J. Fd. Process. Technol*., **10**.

Hong, G.P., Chun, J.Y., Jo, Y.J. and Choi, M.J., 2014. Effects of water or brine immersion thawing combined with ultrasound on quality attributes of frozen pork loin. *Korean J. Fd. Sci. Anim. Resour*., **34**: 115. https://doi.org/10.5851/kosfa.2014.34.1.115

Jayanthi, D., Rajkumar, R., Senthilkumar, P. and Arun, L., 2017. Effect of packaging methods and storage periods on physico-chemical characteristics of goat meat. *Int. J. Sci. environ. Technol*., **6**: 179-190.

Kaewthong, P., Pomponio, L., Carrascal, J.R., Knøchel, S., Wattanachant, S. and Karlsson, A.H., 2019. Changes in the quality of chicken breast meat due to super chilling and temperature fluctuations during storage. *J. Poult. Sci*., **56**: 308-317. https://doi.org/10.2141/jpsa.0180106

Kemp, A., Van, K. and Heijiningen, A.J.M., 1953. A calorimetric micro-method for the determination of glycogen in tissues. *Biochem. J. Sci*., **56**: 646. https://doi.org/10.1042/bj0560646

Kim, G.D., Jeong, J.Y., Jung, E.Y., Yang, H.S., Lim, H.T. and Joo, S.T., 2013. The influence of fiber size distribution of type IIB on carcass traits and meat quality in pigs. *Meat Sci*., **94**: 267-273. https://doi.org/10.1016/j.meatsci.2013.02.001

Kim, S., Kim, G., Moon, C., Ko, K., Choi, Y., Choe, J.

and Ryu, Y., 2022. Effects of aging methods and periods on quality characteristics of beef. *Fd. Sci. Anim. Resour*., https://doi.org/10.5851/kosfa.2022.e63

Koh, K.C., Chung, K.Y., Kim, H.S., Kang, S.J., Choi, C.B., Jo, C. and Choe, J., 2019. Determination of point of sale and consumption for Hanwoo beef based on quality grade and aging time. *Fd. Sci. Anim. Resour*., **39**: 139. https://doi.org/10.5851/kosfa.2019.e11

Kondaiah, N., Anjaneyulu, A.S.R., Rao, V.K., Sharma, N. and Joshi, H.B., 1985. Effect of salt and phosphate on the quality of buffalo and goat meats. *Meat Sci*., **15**: 183-192. https://doi.org/10.1016/0309-1740(85)90036-1

Legako, J.F., Dinh, T.T.N., Miller, M.F. and Brooks, J.C., 2015. Effects of USDA beef quality grade and cooking on fatty acid composition of neutral and polar lipid fractions. *Meat Sci*., **100**: 246-255. https://doi.org/10.1016/j.meatsci.2014.10.013

Mazhangara, I.R., Chivandi, E., Mupangwa, J.F. and Muchenje, V., 2019. The potential of goat meat in the red meat industry. *Sustainability*, **11**: 3671. https://doi.org/10.3390/su11133671

Ockerman, H.W., 1985. *Quality control of post-mortem muscle tissue*. Department of Animal Science, Ohio State University.

Orlova, O.N., Mkrtichyan, V.S., Skrypnik, L.V. and Krichun, L.V., 2021. Research of the overall chemical and amino acid composition of meat from young animals of new sheep genotypes. *Теория и практика переработки мяса*, **6**: 248-254. https://doi.org/10.21323/2414-438X-2021-6-3-248-254

Phothiset, S. and Charoenrein, S., 2014. Effects of freezing and thawing on texture, microstructure and cell wall composition changes in papaya tissues. *J. Sci. Fd. Agric*., **94**: 189-196. https://doi.org/10.1002/jsfa.6226

Sen, A.R., Santra, A. and Karim, S.A., 2004. Carcass yield, composition and meat quality attributes of sheep and goat under semiarid conditions. *Meat Sci*., **66**: 757. https://doi.org/10.1016/S0309-1740(03)00035-4

Wang, X., Lin, X., Ouyang, Y.Y., Liu, J., Zhao, G., Pan, A. and Hu, F.B., 2016. Red and processed meat consumption and mortality: Dose–response meta-analysis of prospective cohort studies. *Publ. Hlth. Nutr*., **19**: 893-905. https://doi.org/10.1017/S1368980015002062

Wang, Z., He, Z. and Li, H., 2018. The effect of repeated freeze-thaw cycles on the meat quality of rabbit. *World Rabbit Sci*., **26**: 165-177. https://doi.org/10.4995/wrs.2018.8616

Wardlaw, F.B., McCaskill, L.H. and Acton, J.C., 1973. Effect of postmortem muscle changes on poultry meat loaf properties. *J. Fd. Sci*., **38**: 421-423. https://doi.org/10.1111/j.1365-2621.1973.tb01444.x

Webb, E.C., Casey, N.H. and Simela, L., 2005. Goat meat quality. *Small Rumin. Res*., **60**: 153–166. https://doi.org/10.1016/j.smallrumres.2005.06.009

Wei, R., Wang, P., Han, M., Chen, T., Xu, X. and Zhou, G., 2017. Effect of freezing on electrical properties and quality of thawed chicken breast meat. *Asian-Australas. J. Anim. Sci.,* **30**: 569-575. https://doi.org/10.5713/ajas.16.0435

Wu, Z., Xu, M., He, W., Li, X., Qiu, C. and Zhang, J., 2024. Unraveling the physicochemical properties and bacterial communities in rabbit meat during chilled storage. *Foods*, **13**: 623. https://doi.org/10.3390/foods13040623

Xiong, L., Pei, J., Wang, X., Guo, S., Guo, X. and Yan, P., 2022. Effect of lipids in yak muscle under different feeding systems on meat quality based on untargeted lipidomics. *Animals*, **12**: 2814. https://doi.org/10.3390/ani12202814

Zheng, A., Lin, S., Pirzado, S. A., Chen, Z., Chang, W., Cai, H. and Liu, G., 2020. Stress associated with simulated transport, changes serum biochemistry, postmortem muscle metabolism, and meat quality of broilers. *Animals*, **10**: 1442.