Meat Research
Vol 5, Issue 4: 1-8, Article 123, August 2025
ISSN: 2790-1971
https://doi.org/10.55002/mr.5.4.123
http://www.bmsa.info/meatresearch

Research Article

Changes in physicochemical properties of beef in different age groups during short-term aging under chilled conditions

MK Bristy[1], MS Mostafa[1], JF Juthi[1], MM Mahbub[1], SJ Badhan[1], S Nahar[1], HM Murshed[1*]

[1]Department of Animal Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

***Corresponding Author:**

HM Murshed
E-mail: hasan.murshed@bau.edu.bd

Keywords:
Ageing
Meat
WHC
Cooking loss
Tenderness
Drip loss

Article Info:
Received: July 10, 2025
Accepted: August 17, 2025
Published online: August 31, 2025

Abstract

This study examined the physico-chemical properties of beef from two age groups of Holstein Friesian crossbred bulls, specifically 15-month-old and 2-year-old, during a 5-day chilling aging process. The aim was to evaluate how aging affects various meat quality parameters, including pH, water holding capacity (WHC), drip loss, color, crude protein (CP), dry matter, ash, cooking loss, and shear force. Results showed significant differences between the two age groups. The 2-year-old beef had a higher initial pH and better water holding capacity compared to the 15-month-old beef, which experienced greater drip loss. Color analysis indicated that 2-year-old beef displayed a more vibrant red hue, enhancing its visual appeal. Additionally, the crude protein content was higher in the older cattle, although dry matter content was not significantly different. Cooking loss (20.20%) and shear force measurements demonstrated that 2-year-old beef was more tender, which correlated with superior water retention and less age-related connective tissue development. The aging process significantly influences ($P<0.01$) beef quality parameters, including water holding capacity (WHC), drip loss, tenderness, pH, and cooking loss. Using beef samples (T1=1 year 3 months and T2=2 years), subjected to aging periods of 1 day, 3 days, and 5 days, a comprehensive analysis assessed changes in WHC, drip loss, tenderness, pH, and cooking loss over time. WHC, drip loss, pH, cooking loss, and shear force showed minimal changes throughout aging, though an improvement in WBSF value (36.98 N) was noted with longer aging. Importantly, no significant changes were observed in meat quality attributes within this timeframe, indicating that the chilling process effectively preserved the samples' integrity. Both age groups showed improvements in texture and tenderness, suggesting that a chilling temperature of 4°C may be optimal for promoting these desirable qualities.

Introduction

Meat is valued as a prime source of protein. While looking for a good quality protein source with acceptable flavor and taste, meat is the most valuable livestock product (Akter et al., 2022; Khatun et al., 2022; Lijalem et al., 2015). Meat, the flesh or other edible parts of animals (usually domesticated cattle, swine, and sheep) used for food, including not only the muscles and fat but also the tendons and ligaments. Due to the increasing availability, people are becoming more concerned about the nutritional, physical & other qualities of meat (De Araujo et al., 2022; Gagaoua & Picard, 2020).

A large portion of protein supply, almost 90 percent of the total animal protein comes from the livestock sector in the everyday life of Bangladeshi people (DLS, 2022). The contribution of the livestock sub-sector to gross domestic product (GDP) during FY 2021-22 was 1.90 percent (DLS, 2022). Meat is one of the important outputs from livestock.

Meat and meat products currently represent an important source of protein in the human diet, and their quality varies according to intrinsic and extrinsic parameters that can sometimes be shaped to make a product more desirable. Immediately after slaughtering the animal, we only get the muscle. This is not actually meat. After a certain storage period of chilling, that muscle converts into meat (Listrat et al., 2016). The process is known as the ageing of meat. Postmortem aging improves tenderness, juiciness, and flavor through proteolysis, lipolysis, and oxidation processes (Azad et al., 2021 and 2022; Khan et al., 2016; Mahmud et al., 2024; Mostafa et al., 2025; Shohiduzjaman et al., 2024). But the duration of ageing may influence the quality parameters level of meat such as tenderness, flavor (Chakrabartty et al., 2024; Joo et al., 2023; Sosin-Bzducha & Puchala, 2017).

Numerous factors influence beef quality, including genetics, feeding practices, environmental conditions, and management strategies. However, one of the most significant determinants is the age of the cattle at slaughter. But, most of the cattle in Bangladesh are slaughtered at later stage of their life; therefore, it is important to know how age of the cattle. Age not only affects the growth and development of the animal but also has profound implications for the quality of the meat produced. As cattle mature, physiological and biochemical changes occur that can impact several quality parameters, including drip loss, pH, shear force. Cattle age influences meat's water-holding capacity and proximate composition, key factors in quality. Younger cattle generally yield meat with higher moisture, protein, and tenderness due to less connective tissue and favorable muscle fiber structure (Bai et al., 2023). Older cattle have more collagen and intramuscular fat, enhancing flavor but reducing water-holding capacity, leading to drier meat (Dutson et al., 1980; Hwang et al., 2003; Miller et al., 2017).

The pH value of beef varies significantly with the age of the cattle at slaughter, which influences meat quality attributes. Generally, meat from younger cattle (approximately 1 year old) exhibits a lower pH range of about 5.3 to 5.6, which is associated with better water retention and tenderness (Huff-Lonergan & Lonergan, 2005). In older cattle (around 2 years), pH levels often increase further, reaching between 5.8 to 6.2 or higher, resulting in tougher meat with reduced quality due to higher ultimate pH levels often linked to physiological stress and delayed rigor mortis (Maltin et al., 2003).

Drip loss, a measure of moisture lost during storage and processing, significantly impacts the juiciness and flavor of meat. Studies indicate that older cattle exhibit higher drip loss due to increased muscle fiber diameter and altered protein structures (Kauffman et al., 1999). Shear force value, a measure of tenderness, is largely influenced by muscle fiber characteristics and connective tissue composition. Research shows that older animals tend to have higher shear force values due to increased collagen cross-linking, making the meat tougher (Maltin et al., 2003).

The cooking loss of meat is significantly influenced by the age of cattle, primarily due to variations in muscle composition and water-holding capacity. Younger cattle generally exhibit lower cooking loss, resulting in juicier and more tender meat, as their muscle fibers have a higher moisture content and less connective tissue (Rhee et al., 2004). Studies indicate that older beef cuts tend to shrink more during cooking, largely due to their lower water-holding capacity and greater fat content, which can render out during the cooking process (Miller et al., 2017). Younger cattle typically produce meat with higher moisture content and improved tenderness, largely due to lower levels of connective tissue and a more favorable muscle fiber composition. As cattle age, there is an increase in collagen and intramuscular fat, which can enhance flavor but may decrease water-holding capacity, leading to a drier product (Das et al., 2022; Dutson et al., 1980; Hwang et al., 2003). Proximate analysis often shows that meat from younger animals has a higher percentage of protein and moisture, while older animals tend to yield meat with more fat and less water, affecting its juiciness and overall palatability (Miller et al., 2017).

The study will provide a comprehensive analysis of how these parameters change with age, offering insights into the underlying biochemical and structural mechanisms & find out best chilling time for beef from different age groups.

Materials and Methods

Source of meat

Retailer shop, Ganginar Par, Mymensingh

Meat samples were sourced from a local slaughterhouse in Bangladesh, ensuring that both age groups were from the same breed (Holstein Friesian) and reared under similar conditions. Cattle were selected based on health and weight criteria, with two groups established: Treatment 1 (15-month-old) and Treatment 2 (2-year-old). Samples were collected in triplicate from three crossbred animals under Treatment 1 (15-month-old) and three crossbred animals under Treatment 2 (2-year-old). Then they are transported to the lab within 40-45 minutes. The measures were taken at 1 day, 3 days and 5 days after slaughter. For every measure, 12 repetitions were performed.

Measurement of Physicochemical parameters

pH

pH of meat was determined by the direct method using a pre-calibrated portable pH meter (HI98163, HANNA Instruments, Australia). The tip of the above pH meter was inserted into the sample until a stable reading was obtained.

Water holding capacity (WHC)

WHC was measured by centrifuging each 1 g sample at 10,000 rpm for 10 minutes at 4℃. WHC was expressed as the ratio of the sample's weight after centrifugation to it's initial weight (Szmańko et al., 2021).

$$\text{WHC}(\%) = \frac{sample\ weight\ after\ centifugation(\%)}{sample\ weight\ before\ centifugation(\%)} \times 100$$

Cooking loss

Cooking loss was determined by collecting 50-60 g sample from the meat sample (W1) and sealed in a polythene bag, then tagged and double-sealed in another bag. The water bath was filled to two-thirds and heat the meat until the internal temperature reached to 72℃. Cooking loss was calculated as a percentage of weight loss during cooking (Vujadinović et al., 2014).

$$\text{Cooking loss }(\%) = \frac{(wt.before\ cooking - wt.after\ cooking)}{wt.before\ cooking} \times 100$$

Drip loss

After 24 hours post-mortem, approx. 10 g of meat was weighed. Then the meat was hung in an airtight box, and stored at 4℃ (Honikel, 1998).

$$\text{Drip loss }(\%) = \frac{Initial\ wt.of\ the\ sample - final\ wt.of\ th\ sample}{initial\ wt.of\ the\ sample}$$

Meat color

Instrumental color (CIE $L*$, $a*$, $b*$, $C*$, $h*$) was taken from meat samples at different chilling time intervals after postmortem. Then the meat samples were refrigerated for 24 hours at 4°C temperature and the color of breast meat was individually measured using Konica Chroma Meters CR- 22 410 (Konica Minolta Inc., Tokyo, Japan). For each reading, 3 measurements were performed, and the final value for each sample was the average of those readings. Breast meat color were expressed in the CIE LAB dimensions of lightness ($L*$), redness ($a*$), yellowness ($b*$), chroma ($C*$), and hue angle ($h*$).

Tenderness / shear force value

The shear force value was estimated by using a Warner Bratsler shear. The strips of breast muscle measuring 0.5 inch core in both width and thickness removed from the centre of the meat sample were subjected to the shear test at three points and the average was recorded.

Crude protein

The crude protein was calculated using the micro-Kjeldahl technique. Each sample's total nitrogen concentration was determined in triplicate using the Kjeldahl apparatus. To measure the total nitrogen in this example, the samples were digested with 20 milliliters of concentrated sulfuric acid (H_2SO_4) while K_2SO4, $CuSO_4$, and selenium powder were present. After the alkali (NaOH) released ammonia, it was distilled into boric acid and titrated using regular HCl. The resulting nitrogen values were multiplied by 6.25 to convert them to total crude protein.

The calculation is as follows:

$$\%of\ nitrogen = \frac{titrate\ required(ml) \times .014(milliequivalent\ of\ N2) \times Strength\ of\ HCL}{Weight\ of\ sample} \times 100$$

% of CP = % of nitrogen × conversion factor (6.25)

Moisture and dry matter

A properly weighed known amount sample (5g) was placed in a porcelain crucible that had been previously weighed and placed in an electric oven set at 105°C for approximately 24 hours to achieve a consistent weight in order to measure the moisture content. The percentage of moisture lost was determined. And dry matter is measured by subtracting the moisture from 100.

Content of moisture (%) = (Y-Z)/Y × 100

Y = Sample weight (g) + Crucible

Z = Dry Sample Weight (g) + Crucible

Dry Matter =Moisture - 100

Ash

The samples were heated for six hours at 550°C in a muffle furnace. Then, the crucibles were placed in desiccators to cool. The remaining material was weighed to determine the percentage of ash.

The formula is mentioned below

% of ash content = $\frac{E}{C}$×100

Where, E = Weight of ash C= Weight of sample

Statistical analysis

This experiment had a completely randomized design with 2 treatments with different freezing conditions. All analyses were replicated three times. Analysis of variance was performed on all the variables measured using the General Linear Model procedure of Minitab (2017). Data were analyzed using two-way

ANOVA whereas Duncan's multiple range tests were performed to calculate significant differences between means s ($p<.05$). The means values and the SEM were noted.

Results and Discussion

Table 1. Effect of age and chilling time on physical parameters of beef

	Days Interval	Treatments			Level of Significance		
		Treatment 1	Treatment 2	Mean	DI	Treatments	DI&T
Drip loss (%)	**1**	$7.57^{a}\pm1.17$	$5.62^{b}\pm0.16$	6.60			
	3	$7.38^{a}\pm0.38$	$5.48^{bc}\pm0.67$	6.43	**	**	NS
	5	$5.58^{b}\pm0.44$	$3.80^{c}\pm0.48$	4.69			
Shear force	**1**	$46.23^{ab}\pm0.44$	$50.00^{a}\pm2.44$	48.14			
	3	$39.98^{b}\pm3.33$	$44.50^{ab}\pm1.94$	42.24	**	**	NS
	5	$32.10^{c}\pm4.64$	$41.86^{b}\pm0.55$	36.98			
WHC (%)	**1**	$86.47^{bc}\pm1.39$	$89.43^{ab}\pm2.40$	88.11			
	3	$82.20^{c}\pm0.35$	$94.03^{a}\pm1.18$	87.94	*	**	**
	5	$85.49^{bc}\pm1.78$	$83.17^{bc}\pm5.19$	84.32			
Cooking loss (%)	**1**	$28.60^{a}\pm7.24$	$24.88^{a}\pm0.40$	26.73			
	3	$24.49^{a}\pm0.63$	$15.91^{b}\pm0.39$	22.33	**	*	NS
	5	$22.31^{ab}\pm0.76$	$22.36^{ab}\pm1.31$	20.20			

The mean in each row having different superscripts vary significantly at values $P < 0.05$. Again, mean values with the same superscript in each row did not differ significantly at $P>0.05$. Treatment 1= (1.3 months), Treatment 2= (2 years), DI=Day Intervals, DI×DT=Interaction of Day Intervals &Treatment. * Means significant at 5%level of probability, ** Means significant at 1%level of probability, NS means non-significant. Days interval (1 day, 3 days, 5 days)

Drip loss

The results (Table 1) suggest that both time and treatment have significant effects on drip loss, with treatment T2 consistently showing lower drip loss across the days measured. Across all days, Treatment 1 consistently showed higher drip loss values compared to Treatment 2. On day 1, drip loss in Treatment 1 (7.57%) was significantly higher than in Treatment 2 (5.62%).

Similar differences were observed on day 2 (7.38% vs. 5.48%) and day 3 (5.58% vs. 3.80%). The lack of a significant interaction between days and treatment means that the effect of each treatment on drip loss remains consistent across different days.

Cattle's muscle fiber composition varies with age. Animals that are older tend to have more intramuscular fat, which may affect how well they retain moisture. However, because of variations in muscle shape, more connective tissue may also result in increased water loss (Wang et al., 2022). Water retention is influenced by muscle metabolism after death. According to similar studies, younger cattle may have higher drip loss because of increased enzyme activity that causes muscle breakdown (Liza et al.,2024). According to the current research, the drip loss was greatest in cattle that were 1.3 years old as opposed to those that were 2 years old.

Shear force

Both time and treatment have a significant effect ($p<0.01$) on shear force (Table 1). Over time, shear force decreases in both treatments, but Treatment 2 generally has lower values, indicating greater tenderness. On day 1, the highest shear force (50.00 N) was recorded in Treatment 2, whereas the lowest (46.23 N) occurred in Treatment 1. Shear force values decreased progressively over time in both treatments, with the lowest value (32.10 N) observed in Treatment 1 on day 5. The lack of significant interaction between days and treatment shows that each treatment's effect on shear force remains consistent across days.

Younger cattle typically yield more tender meat due to differences in muscle fiber structure and composition. Younger animals have less connective tissue, which is known to contribute to the tenderness of meat (Purslow, 2005). As cattle age, the muscle fibers become larger and more fibrous, resulting in decreased shear force values (Liza et al., 2024). The decrease in shear force for older cattle over the 5 days can be attributed to the onset of rigor mortis and subsequent enzymatic activity that tenderizes the meat. This process, known as post-mortem aging, breaks down proteins and connective tissue, improving tenderness (Troy & Kerry, 2010). 1.3 years cattle appear to produce more tender meat both immediately after slaughter and up to 5 days, while the increasing shear force values for younger cattle highlight the difficulties in achieving desirable tenderness in beef from younger animals. These findings highlight the importance of age and post-mortem time in influencing meat quality.

Water holding capacity

Both treatment and day interval significantly affected WHC ($p < 0.05$ to $p < 0.01$), with a significant interaction between the two factors (Table 1). On day 1, WHC ranged from 86.47% in Treatment 1 to 89.43% in Treatment 2. Interestingly, WHC in Treatment 2 peaked at 94.03% on day 3, while Treatment 1 showed a lower value of 82.20%. By day 5, WHC values in both treatments declined. Both the time interval and treatment type significantly affect WHC, with Treatment 2 generally yielding higher WHC, especially on day 3. The significant interaction effect suggests that the changes in WHC over time depend on the treatment type, as seen in the higher WHC in Treatment 2 on day 3 compared to other days and treatments. This interaction implies that Treatment 2 is particularly effective in enhancing WHC at specific time points. The WHC was significantly affected by the chilling method ($P < 0.05$). Older cattle have higher WHC, which can be explained by variations in connective tissue and muscle fiber composition. Older animals tend to retain water better because they have a higher percentage of delicate muscle fibers and less connective tissue (Calkins & Hodgen, 2007). On the other hand, cattle's ability to retain water is frequently reduced as they age due to an increase in connective tissue and muscle maturity (Ryu & Kim, 2006).

The 1.3-year-old group's WHC reduction after 3 days is especially notable and might be the result of increased moisture loss during storage, which is made worse by age-related structural changes in muscle fibers. Since juiciness and tenderness are important factors in determining consumer preference, a drop in WHC can have a significant impact on meat quality (Warriss, 2000).

Cooking loss

Both the time interval and treatment type significantly affect cooking loss (Table 1). Cooking loss tends to decrease over time in both treatments, with treatment 2 generally resulting in lower cooking loss than treatment 1, especially on day 3. The lack of significant interaction between days and treatment means that the effect of each treatment on cooking loss remains consistent across the days, showing no unique combined influence over time. This suggests that treatment 2 may be more effective in reducing cooking loss overall, particularly on day 3. There are a number of reasons why cooking loss increases with age: Biochemical changes, such as protein denaturation and moisture loss, become more noticeable as meat ages (Huff-Lonergan & Lonergan, 2005); older cattle have more connective tissue, which may initially result in higher moisture retention but ultimately leads to higher cooking losses when the meat is heated (Purslow, 2005); this is in line with research by Liza et al. (2024), who found that older cattle have a higher capacity for retaining water, but they lose more moisture during cooking because of structural changes in their muscle fibers.

Furthermore, the statistics show that, in comparison to older calves, the meat from younger animals, those that were 2 years old; retained more moisture and experienced fewer cooking losses. Because lower cooking losses are typically linked to increased juiciness and tenderness; two important qualities that customers value, this is critical for meat quality. According to the results, meat from older animals might have higher culinary quality and be more appealing to consumers who value flavor and tenderness.

Table 2. Effect of age and chilling time on color of beef

	Days Interval	Treatments		Mean	Level of Significance		
		T1	T2		DI	Treatments	DI&T
L*	1	$41.69^{a}\pm5.35$	$39.83^{a}\pm1.21$	40.75			
	2	$39.69^{a}\pm0.34$	$37.25^{a}\pm0.60$	40.30	NS	NS	NS
	3	$40.30^{a}\pm1.07$	$40.30^{a}\pm1.07$	38.73			
a*	1	$21.54^{b}\pm0.39$	$24.72^{a}\pm1.80$	23.13			
	3	$20.79^{b}\pm0.33$	$24.61^{a}\pm0.31$	22.70	*	**	*
	5	$21.11^{b}\pm0.57$	$21.11^{b}\pm0.57$	21.11			
b*	1	$9.47^{ab}\pm0.73$	$11.47^{a}\pm0.37$	10.47	*	*	NS

	3	$8.48^{b}\pm1.33$	$11.22^{a}\pm0.93$	9.85			
	5	$8.93^{ab}\pm0.97$	$8.93^{ab}\pm0.97$	8.93			
C*	1	$23.53^{b}\pm0.34$	$27.26^{a}\pm1.78$	25.39			
	3	$22.48^{b}\pm0.22$	$27.05^{a}\pm0.66$	24.76	**	**	**
	5	$22.93^{b}\pm0.47$	$22.93^{b}\pm0.47$	22.93			
h*	1	$23.72^{a}\pm1.84$	$24.93^{a}\pm0.88$	24.33			
	3	$22.18^{a}\pm3.44$	$24.48^{a}\pm1.55$	23.32	NS	NS	NS
	5	$22.94^{a}\pm2.58$	$22.94^{a}\pm2.58$	22.93			

The mean in each row having different superscripts vary significantly at values P < 0.05. Again, mean values with the same superscript in each row did not differ significantly at P>0.05. Treatment 1= (1.3 months), Treatment 2= (2 years), DI=Day Intervals, DI×DT=Interaction of Day Intervals &Treatment. * Means significant at 5%level of probability, ** Means significant at 1%level of probability, NS means non-significant.

Color parameters (*L**, *a**, *b**, c, and h) of the longissimus dorsi muscle under different treatments and storage intervals are shown in Table 2.

*L** values, representing lightness, did not vary significantly (p > 0.05) across days, treatments, or their interaction, indicating that overall light intensity remained stable throughout the storage period regardless of treatment. This result agrees with the findings of Mancini and Hunt (2005), who reported that *L** is more strongly influenced by oxygenation state and muscle surface properties than by age.

For *a** values, which indicate redness, significant effects (p < 0.05–0.01) of treatment and the day-by-treatment interaction were observed on Days 1 and 3. In both cases, T2 produced higher *a** values than T1, suggesting that the treatment enhanced red color intensity in the early stages of storage. By Day 5, *a** values converged, and no significant differences were found, implying that the treatment's effect on redness diminished over time. This can be attributed to increased myoglobin concentration in muscles of older animals (Mancini & Hunt, 2005; Gagaoua et al., 2015).

Similarly, *b** values, reflecting yellowness, were significantly higher (p < 0.05) in T2 compared to T1 on Days 1 and 3, indicating a more pronounced yellow tone early in storage. However, by Day 5, no significant differences were evident, suggesting that the treatment's influence on yellowness was temporary. This increase in *b** is consistent with the higher oxidative susceptibility of beef from mature animals (Faustman et al., 2010).

Chroma (*C**), representing color saturation, showed the most consistent and pronounced differences. Significant effects of day, treatment, and their interaction (p < 0.01) were evident on Days 1 and 3, with T2 displaying higher chroma values than T1. This suggests that the treatment produced more vivid and intense colors during the initial storage period. By Day 5, differences between treatments disappeared, indicating a loss of treatment advantage over time. his reflects more vivid and intense color development in meat from older cattle, likely due to higher myoglobin concentration and oxidative stability (Bekhit & Faustman, 2005). The interactive effects (P<0.01) further support that chilling enhanced this difference in color intensity.

Hue angle (*h**), which describes the overall tint of the color, remained unaffected (p > 0.05) by day, treatment, or interaction across the storage period. This stability implies that while lightness, redness, yellowness, and saturation were influenced, particularly early in storage, the fundamental color tone remained consistent regardless of treatment or storage time. Similar findings were observed by (Khliji et al., 2010) who noted that hue angle is less sensitive to animal factors compared to *a** and *c* values.

In conclusion, this study highlights the complex interplay of color dimensions in response to treatments, with significant temporal effects on saturation and color components, while lightness and hue remain relatively stable. The strong P-values (and) reinforce the reliability of these observations, providing insight into how color perception is affected over time.

Table 3. Effect of age and chilling time on chemical and nutritional parameters

	Days Interval	Treatments		Mean	Level of Significance		
		T1	**T2**		**DI**	**Treatment**	**DI&T**
	1	$5.47^{ab}\pm0.03$	$5.43^{b}\pm0.11$	5.45			
pH	3	$5.57^{ab}\pm0.12$	$5.62^{ab}\pm0.06$	5.59	*	NS	NS
	5	$5.68^{a}\pm0.09$	$5.54^{ab}\pm0.03$	5.61			
DM	1	$24.21^{a}\pm0.27$	$25.32^{a}\pm0.53$	25.01			
	3	$25.00^{a}\pm1.41$	$23.48^{a}\pm1.72$	24.76	NS	NS	NS
	5	$24.03^{a}\pm1.19$	$26.00^{a}\pm1.65$	24.24			
ASH	1	$0.41^{b}\pm0.15$	$0.37^{b}\pm0.08$	1.23			
	3	$1.26^{a}\pm0.13$	$1.18^{a}\pm0.04$	1.22	**	NS	*
	5	$1.33^{a}\pm0.02$	$1.13^{a}\pm0.06$	0.48			
CP	1	$20.49^{ab}\pm1.13$	$21.62^{ab}\pm1.15$	21.93			
	3	$19.99^{b}\pm1.33$	$20.63^{ab}\pm1.39$	21.06	NS	*	NS
	5	$20.48^{ab}\pm0.82$	$23.39^{a}\pm0.78$	20.31			

The mean in each row having different superscripts vary significantly at values P < 0.05. Again, mean values with the same superscript in each row did not differ significantly at P>0.05. Treatment 1= (1.3 months), Treatment 2= (2 years), DI=Day Intervals, DI×DT=Interaction of Day Intervals &Treatment. * Means significant at 5%level of probability, ** Means significant at 1%level of probability, NS means non-significant.

pH

A p-value of 0.01 indicated that there was a significant variation in pH between the aging phases, showing elevated pH levels in beef that had been matured for three and five days (Table 3). This gradual rise in pH could be explained by microbial activity and metabolic alterations brought on by aging. However, the age gap and interaction impact do not significantly differ in pH. These results imply that beef aged for three or five days may see a considerable rise in pH, which may have an impact on the meat's flavor and texture. Age-group differences in carcass pH evaluated 24 hours after slaughter were minimal, according to (Mach et al., 2008). Because the values ranged from 5.35 to 5.60, this should not represent an increased risk of a negative impact on meat quality. In the present study, there were no significant differences in the meat pH measured of cattle from different age groups. A similar result has been reported that buffalo slaughtered at 0-3, 4-6, 12-18, and 24-36 months of age exhibited similar meat pH (Li et al., 2018).

Dry matter

There is no statistically significant effect of treatment, day interval, or their interaction on dry matter values in this data set (Table 3). The means remain similar across treatments and days, showing stability in the measured parameter.

In the beef samples, the 2-year-old cattle had the highest moisture content than the 1.3-year-olds. The juiciness and softness of the meat may be impacted by this trend, which could indicate that older animals retain more moisture in their muscular tissue. The formation of connective tissues and fat deposition in cattle may be the cause of the decrease in moisture content as they age (Kauffman et al., 2010).

Ash

There is a significant increase in ash content (Table 3) over time (Day Interval effect) and a notable interaction between day and treatment (Day Interval & Treatment effect). Ash content rises significantly from Day 1 to Days 3 and 5, with Day 3 having the highest values. However, differences between Treatment 1 and Treatment 2 are not significant. This pattern implies that time, rather than treatment, is the primary factor influencing ash content changes in this study.

Ash content, which is indicative of the mineral content in the meat, also decreased with age, with the 2-year-olds having the highest ash percentage. The decline in ash content in older cattle (for 1.3 years) may point to changes in mineral deposition as the animal ages (Keene et al., 2004). The observed statistical significance in ash content indicates a noteworthy difference between the 2-year and younger age groups.

Crude protein

The treatment type (Treatment 1 vs. Treatment 2) significantly affects crude protein content, with Treatment 2 showing a notable increase by Day 5 (Table 3). However, there are no significant overall changes in crude protein across the days (DI effect) or in the interaction between days and treatment (Day Interval & Treatment effect). This suggests that Treatment 2 may be more effective than Treatment 1 in increasing crude protein content over time, especially noticeable on Day 5.

The lowest protein content was found in the 1.3-year-old group, while the highest protein content was found in the 2-year-old group. The statistical significance (indicated by different letters) suggests that the protein content in the 2-year group is significantly higher than in the 1.3-year group, which may be beneficial for certain nutritional applications. The decrease in protein content in younger cattle may be due to changes in muscle composition, where fat replaces lean tissue as animals mature (Lorenzo et al., 2014).

Summary and Conclusion

This study was carried out at Bangladesh Agricultural University's Animal Science Laboratory, examined how age and aging time affected the quality of beef from Holstein Friesian cross breed bull by examining samples of loin (Longissimus dorsi muscle). Two age groups of cattle were established: 1.3 and 2 years. To analyze different physical, chemical, and nutritional characteristics, a total of twelve beef samples weighing 550 g each were gathered.

The results showed that all age groups had mean pH levels that were consistent, suggesting that meat matured uniformly. Drip loss, however, showed notable variations, with the 1.3-year-old cattle showing the highest values at 1, 3, and 5 days ($p<0.05$). This implies that younger animals might retain less water, which would have a detrimental effect on the quality of the meat. Shear force measurements confirmed that older cattle often produce tougher beef, showing that the meat from the 2-year-old group was tougher than that from the younger group. Water-holding capacity and cooking loss varied significantly ($p<0.05$) among the groups. Cooking loss was reduced in the 2-year-old group and higher in the 1.3-year-old group.

The 2-year-old cattle group's water-holding capacity was noticeably higher, highlighting the benefits of older calves in preserving moisture during cooking. Only the crude protein (CP) and ash content showed notable alterations in terms of proximate composition. The flesh of the 2-year-old cattle had a higher CP than that of the 1.3-year-old group, suggesting that the older animals had higher nutritional quality. Furthermore, the meat from 2-year-old cattle had a noticeably higher ash level, indicating a positive mineral profile. The study concludes that the age of Holstein Friesian crossbreed has a substantial impact on important quality measures. Better tenderness, less cooking loss, and more nutritional value are characteristics of higher-quality beef often produced by 2-year-old cattle. In order to better understand how age, diet, and management techniques affect beef quality, further research is necessary. Remarkably, an improvement in texture and tenderness was observed over the chilling period, highlighting the positive impact of this temperature on sensory attributes. These results emphasize that short-term chilling at 4°C not only preserves but also enhances certain quality characteristics of beef, making it a practical and reliable method for the meat industry to ensure product quality and meet consumer expectations.

Conflicts of Interest

The authors declare that there are no potential conflicts of interests.

References

Akter R, Hossain MA, Khan M, Rahman MM, Azad MAK, Hashem MA. 2022. Formulation of value-added chicken meatballs by addition of Centella leaf (*Centella asiatica*) extracts. Meat Research, 2:2, Article No. 18. https://doi.org/10.55002/mr.2.2.18

Azad MAK, Rahman MM, Hashem MA. 2022. Meat microbiota: A conceptual review. Meat Research, 2: 2, Article No. 20. https://doi.org/10.55002/mr.2.3.20

Azad MAK, Kikusato M, Zulkifli I, Rahman MM, Ali MS, Hashem MA, Toyomizu M. 2021. Comparative study of certain antioxidants - electrolyzed reduced water, tocotrienol and vitamin E on heat-induced oxidative damage and performance in broilers. Meat Research, 1: 1, Article 7. DOI: https://doi.org/10.55002/mr.1.1.7

Bai X, Yin F, Ru A, Tian W, Chen Q, Chai R, Liu Y, Cui W, Li J, Yin M, Zhu C. 2023.Effect of slaughter age and postmortem aging time on tenderness and water-holding capacity of yak (Bos grunniens) longissimus thoracis muscle. Meat Science, 202:109201. https://doi.org/10.1016/j.meatsci.2023.109201.

Bekhit AED & Faustman C. 2005. Metmyoglobin reducing activity. Meat Science, 71(3): 407–439. https://doi.org/10.1016/j.meatsci.2005.04.032.

Calkins CR, Hodgen JM. 2007. A fresh look at meat flavor. Meat Science, 77(1): 63-80. https://doi.org/10.1016/j.meatsci.2007.04.016.

Chakrabartty S, Akter S, Murshed HM, Rahman MM, Azad MA. 2024. Effects of ageing on longissimus thoracis et lumborum muscle of local beef. Meat Research, 4(1). https://doi.org/10.55002/mr.4.1.83.

Das A, Hashem MA, Azad MAK, Rahman MM. 2022. Edible oil marination in broiler meat for short term preservation. Meat Research, 2: 3, Article 22. https://doi.org/10.55002/mr.2.3.22

De Araújo PD, Araújo WMC, Patarata L, & Fraqueza MJ. 2022. Understanding the main factors that influence consumer quality perception and attitude towards meat and processed meat products. Meat Science, 193: 108952. https://doi.org/10.1016/j.meatsci.2022.108952.

DLS (Department of Livestock Services) 2022. Livestock Economy at a glance 2021-22. Ministry of Fisheries and Livestock. Government of People's Republic of Bangladesh. Dhaka. Bangladesh.

Dutson TR, Smith GC, Carpenter ZL. 1980. Lysosomal enzyme distribution in electrically stimulated ovine muscle. Journal of Food Science, 45: 1097–1098. https://doi.org/10.1111/j.1365-2621.1980.tb07533.x.

Faustman C, Sun Q, Mancini R. & Suman SP. 2010. Myoglobin and lipid oxidation interactions: Mechanistic bases and control. Meat Science, 86(1): 86–94. https://doi.org/10.1016/j.meatsci.2010.04.025.

Gagaoua M & Picard B. 2020. Current advances in meat nutritional, sensory and physical quality improvement. Foods, 9(3): 321. http://dx.doi.org/10.3390/books978-3-03928-691-1.

Gagaoua M, Terlouw EMC, Micol D, Boudjellal A, Hocquette JF & Picard B. 2015. Understanding early post-mortem biochemical processes underlying meat color and pH decline in the longissimus thoracis muscle of young blond d'Aquitaine bulls using protein biomarkers. Journal of Agricultural and Food Chemistry, 63(30): 6799–6809. https://doi.org/10.1021/acs.jafc.5b01812.

Honikel KO. 1998. Reference methods for the assessment of physical characteristics of meat. Meat Science, 49(4): 447–457. https://doi.org/10.1016/S0309-1740(98)00034-5

Huff-Lonergan E, Lonergan SM. 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.

Hwang IH, Devine CE & Hopkins DL. 2003. The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. Meat Science, 65: 677-691. https://doi.org/10.1016/S0309-1740(02)00271-1.

Joo ST, Lee EY, Son YM, Hossain MJ, Kim CJ, Kim SH & Hwang YH. 2023. Aging mechanism for improving the tenderness and taste characteristics of meat. Journal of Animal Science and Technology, 65(6):1151. https://doi.org/10.5187/jast.2023.e110.

Kauffman AL, Ashraf JM, Corces-Zimmerman MR, Landis JN & Murphy CT. 2010. Insulin signaling and dietary restriction differentially influence the decline of learning and memory with age. PLoS Biology, 8(5), e1000372. https://doi.org/10.1371/journal.pbio.1000372.

Kauffman RG, Eikelenboom G, van der Wal PG, Engel B, Zaar M. 1999. A comparison of methods to estimate water-holding capacity in post-rigor porcine muscle. Meat Science, 18(4): 307–322. https://doi.org/10.1016/0309-1740(86)90020-3.

Keene BE, Knowlton KF, McGilliard ML, Lawrence LA, Nickols-Richardson SM, Wilson JH, Rutledge AM, McDowell LR, Van Amburgh ME. 2004. Measures of bone mineral content in mature dairy cows. Journal of dairy science, 87(11): 3816-25. https://doi.org/10.3168/jds.S0022-0302(04)73521-3.

Khan MI, Jung S, Nam KC, Jo C. 2016. Postmortem aging of beef with a special reference to the dry aging. Korean journal for food science of animal resources, 36(2):159. https://doi.org/10.5851/kosfa.2016.36.2.159.

Khatun MM, Hossain MA, Ali MS, Rahman MM, Azad MAK, Hashem MA. 2022. Formulation of value-added chicken nuggets using carrot and ginger as a source of dietary fiber and natural antioxidant. SAARC J. Agric., 20 (1): 185-196.

Khliji S, van de Ven R, Lamb TA, Lanza M, & Hopkins D L. 2010. Relationship between consumer ranking of lamb colour and objective measures of colour. Meat Science, 85(2): 224–229. https://doi.org/10.1016/j.meatsci.2010.01.002.

Li Q, Wang Y, Tan L, Leng J, Lu Q, Tian S, Shao S, Duan C, Li W, Mao H. 2018. Effects of age on slaughter performance and meat quality of Binlangjang male buffalo. Saudi Journal of Biological Sciences, 25(2): 248-252. https://doi.org/10.1016/j.sjbs.2017.10.001.

Listrat A, Lebret B, Louveau I, Astruc T, Bonnet M, Lefaucheur L, Picard B, Bugeon J. How muscle structure and composition influence meat and flesh quality. The scientific world journal, 2016(1): 3182746. https://doi.org/10.1155/2016/3182746.

Lijalem T, Beyan M, Banerjee S. 2015. Quality of beef, chevon and mutton at Hawassa, Southern Ethiopia. African Journal of Food Science, 9(5): 301-306. https://doi.org/10.5897/AJFS2015.1265.

Liza FA, Hosssan MI, Hashem MA, Rahman MM. 2024. Effect of cattle age on the physio-chemical properties of beef. Meat Research, 4(4). https://doi.org/10.55002/mr.4.4.98.

Lorenzo JM, Sarriés MV, Tateo A, Polidori P, Franco D, Lanza M. 2014. Carcass characteristics, meat quality and nutritional value of horsemeat: A review. Meat Science, 96(4): 1478-1488. https://doi.org/10.1016/j.meatsci.2013.12.006.

Mach N, Bach A, Velarde A, Devant M. 2008. Association between animal, transportation, slaughterhouse practices, and meat pH in beef. Meat Science, 78(3): 232-238. https://doi.org/10.1016/j.meatsci.2007.06.021.

Mahmud S, Hasan MM, Akhter S, Hashem MA, Rahman MM. 2024. Effect of edible oil on the quality of beef in short-term preservation. Meat Research, 4: 5. Article No. 102. https://doi.org/10.55002/mr.4.6.102

Maltin C, Balcerzak D, Tilley R, Delday M. 2003. Determinants of Meat Quality: Tenderness. In Nutrition Society; CABI Publishing: Oxfordshire, UK, **62** 337–347. https://doi.org/10.1079/PNS2003248.

Mancini RA & Hunt MC. 2005. Current research in meat color. Meat Science, 71(1): 100–121. https://doi.org/10.1016/j.meatsci.2005.03.003.

Miller MF, Huffman KL, Gilbert SY, Hamman LL, Ramsey CB. 2017. Retail consumer acceptance of beef tenderized with calcium chloride. Journal of Animal Science, 73(8): 2308-2314. https://doi.org/10.2527/1995.7382308x.

Mostafa MS, Tushar ZH, Hashem MA, Rahman MM. 2025. Role of natural antioxidants on active packaging of meat and meat products: A review. Applied Food Research. 5, 101437, https://doi.org/10.1016/j.afres.2025.101

Purslow PP. Intramuscular connective tissue and its role in meat quality. Meat science. 2005 Jul 1;70(3):435-47. https://doi.org/10.1016/j.meatsci.2004.06.028.

Rhee MS, Wheeler TL, Shackelford SD, Koohmaraie M. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. Journal of Animal Science, 82(2): 534-550. https://doi.org/10.2527/2004.822534x.

Ryu YC, Kim BC. 2006. Comparison of histochemical characteristics in various pork groups categorized by postmortem metabolic rate and pork quality. Journal of Animal Science, 84(4): 894-901. https://doi.org/10.2527/2006.844894x.

Shohiduzjaman M, Biplob MAKA, Hashem MA, Rahman MM. 2024. Effects of natural and synthetic antioxidant on the quality of beef in short-term preservation. Meat Research, 4: 6. Article No. 107. https://doi.org/10.55002/mr.4.6.107

Sosin-Bzducha E, Puchała M. 2017. Effect of breed and aging time on physicochemical and organoleptic quality of beef and its oxidative stability. Archives Animal Breeding, 60(3):191-8. https://doi.org/10.5194/AAB-60-191-2017.

Szmańko T, Lesiów T, and Górecka J. 2021. The water-holding capacity of meat: A reference analytical method. Food Chemistry, 357, 129727. https://doi.org/10.1016/j.foodchem.2009.11.042.

Troy DJ, Kerry JP. 2010. Consumer perception and the role of science in the meat 717 industry. Meat Science, 86(1): 214–226. https://doi.org/10.1016/j.meatsci.2010.05.009.

Vujadinović DP, Grujić RD, Tomović VM, Vukić MS, Jokanović MR. 2014. Cook loss as a function of meat heat treatment and regime. Quality of Life, 10: 3–4. https://doi.org/10.1016/j.foodchem.2021.129727

Wang J, Yang P, Han D, Huang F, Li X, Song Y, Wang H, Liu J, Zheng J, Zhang C. 2022. Role of intramuscular connective tissue in water holding capacity of porcine muscles. Foods, 11(23): 3835. https://doi.org/10.3390/foods11233835.

Warriss PD. 2000. Meat science: An introductory text. CAB International, Cambridge University Press, Cambridge, pp: 1-223.