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Effect of animal age, postmortem chilling rate, and aging time on meat quality attributes of water buffalo and humped cattle bulls

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Abstract

The study was aimed to investigate the influence of animal age, post-slaughter chilling rate, and aging time on meat quality of *M. longissimus dorsi* (LD) of water buffalo (*Bubalus bubalis*) and humped cattle (*Bos taurus indicus*) bulls. After slaughtering, one side of carcasses was subjected to rapid chilling (RC) (0 ± 2°C) and other side was hanged in controlled room temperature (25 ± 2°C) for 3 hr, then allowed to the chiller (0 ± 2°C). The meat quality traits were analyzed at 1, 7, and 14 days of storage. It was noted that rapidly chilled carcasses from the younger animals of both species missed the ideal pH/temperature window, which affects the toughness of the meat. Buffalo meat presented higher shear force, color L* values, and lower b* value as compared to the cattle meat. Moreover, meat shear force values decreased while all color coordinates and cooking loss values increased with lengthening the storage time in both age groups of cattle and buffalo. In conclusion, the tenderness of cattle meat was superior to that of buffalo and RC adversely affect the shear force values of young cattle and both age groups of buffalo bulls.

KEYWORDS

beef, buffalo meat, cold shortening, meat quality, pH decline

1 | INTRODUCTION

Meat quality is of great interest to producers, consumers, and scientists, as it mainly includes tenderness, color, water-holding capacity, and nutritional value of meat (Hopkins & Geesink, 2009). Tenderness is considered the most critical palatability factor that can affect meat quality (Koohmaraie & Geesink, 2006). Researchers found that inadequate tenderness plays a significant role in consumer dissatisfaction while they are willing to pay extra money on guaranteed tender beef (Feldkamp, Schroeder, & Lusk, 2005). The tenderness is primarily influenced by the production and processing factors. The production factors mainly include animal species, breed, gender, age, weight at slaughter, and nutritional management at the farm. On the other hand, processing factors generally involve postharvest-specific techniques like carcass chilling and aging to enhance the tenderness of beef. Among the production factors, animal age at slaughter has a strong impact on tenderness (Lawrence, Whatley, Montgomery, Perino, & Dikeman, 2001). Most of the studies have consistently concluded that the advancement of animal age leads to a decrease in beef tenderness due to the deposition of heat-stable collagen fibers (Xiong et al., 2007).

Similarly, meat color is another critical criteria for consumers to judge the meat quality and actively contributes to the value of the

product at retail shops (Mancini & Hunt, 2005). The customers associated the bright red color with freshness, while the brown color is considered as an indicator of being stale or spoiled meat. The visible color of meat continuously changes during display and its stability gradually deteriorates as chilled storage is extended. The meat color is mainly determined by the amount and state of myoglobin, which is predominantly affected by the age of the animals (Humada, Sanudo, & Serrano, 2014), postmortem chilling rate (Farouk & Lovatt, 2000), and aging time (Descalzo et al., 2008).

Post-slaughter transformations, such as chilling regimes and aging time, have a crucial impact on meat quality. Carcass chilling is prerequisite to maintain the meat freshness as the rate of biochemical and microbiological changes is reduced at low temperature (Rosenvold & Wiklund, 2011). The management of the chilling rate is a critical aspect of carcass processing, however, in commercial abattoirs, mostly carcasses are chilled rapidly in order to reduce evaporative losses and bacterial proliferation, which may lead to the cold shortening of meat. Furthermore, postmortem storage of meat termed as aging or maturation is commonly accepted to improve tenderness and color of beef (Velotto et al., 2009). The enhancement in tenderness is mainly due to some intrinsic enzymes, which breakdown the structural integrity of muscle cell and cause overall weakening of myofilaments (Camou et al., 2007; Ono et al., 2004). These weakened myofilaments require less strength to shear and eventually results in tender products for consumers. Similarly, tenderization also favors the formation of oxymyoglobin (bright red color), which improves the color of meat.

Meat from water buffalo is an emerging source of red meat and has gained great economic importance for its domestic needs and high export potential. In several South and Southeast Asian countries, buffalo meat is playing an essential role in uplifting the socioeconomic status in rural areas (Kiran et al., 2016; Nanda & Nakao, 2003). Furthermore, buffalo can produce good quality meat, which is by no mean inferior to that of cattle (Lapitan et al., 2008). However, factors that can affect the quality of buffalo meat are rare in the scientific literature. Therefore, an attempt is made in this study to work on both cattle and buffalo bulls. The objective of this study was to evaluate the effect of animal age, chilling methods, and aging times on meat quality of water buffalo and humped cattle bulls.

2 | MATERIALS AND METHODS

2.1 | Experimental design and slaughtering

A total of 48 bulls, 24 each in water buffalo (*Bubalus bubalis*) and humped cattle (*Bos taurus indicus*), were selected from the commercial fattening farm. Among 24 buffalo/cattle bulls, 12 were 18 months and the rest of the animals were 26 months of age. At the farm, animals were intensively housed and raised under the same feeding strategy. The animals were transported 36 km to the animal shed of the University of Veterinary and Animal Sciences, Lahore (31.5761°N, 74.2995°E). During transportation, the road surface was flat and driving speed was constant at 50 km/h. Animals were loaded and unloaded through the ramp and kept on the shed for 1 day, where the temperature was ranged from 25°C to 36°C and relative humidity was 60% to 70%. Meanwhile, ad libitum access to feed and water was given for the first 12 hr, then feed was removed for the rest of the time in order to avoid cross contamination during slaughtering. After reading the live weight values, animals were slaughtered in the morning in the University experimental unit according to the Halal method as described in Pakistan Halal Standards PS3733. This involved exsanguination without electrical stunning.

2.2 | Chilling treatments

Immediately after de-skinning and evisceration on the overhead railing, carcasses were sheared longitudinally into two halves and tagged with the animal number, date of slaughter, and chilling treatment. For rapid chilling (RC), one half of the carcass was shifted immediately into a walk-in chiller at 0 ± 2°C and 1 m/s air velocity for 24 hr. While to ensure delayed chilling (DC), the other half was kept at a controlled room temperature of 25 ± 2°C for 3 hr and then shifted into the same walk-in chiller as adopted by Sorheim et al. (2001). Each time both left and right halves of the carcass were used alternatively for the RC and DC to avoid repetition.

2.3 | Muscle sampling

After 24 hr chilling, both halves of the carcass were shifted into a deboning hall operating at 10 ± 2°C. The strip loin (*M. longissimus thoracis et lumborum*) muscles from the first rib to last lumbar vertebrae of both halves were removed from the carcass and deboned. Every strip loin was cut into nine steaks, each of 200 g with 2.5 cm of thickness, as described by Wyrwisz et al. (2016) and were tagged. Randomly, three steaks from each chilling treatment were processed at 1 day of storage to serve as the control. Other six were weighed and vacuum packed with the help of vacuum packing machine (Multivac® Baseline P100) using plastic bags (SR 150 × 200, PA/PE 90), and stored at 0 ± 2°C for their processing at 7 and 14 days of aging as done by Brewer and Novakofski (2008).

2.4 | Meat quality measurements

2.4.1 | Temperature and pH

The pH of the carcass was measured with a portable pH meter having meat-penetrating probe (pH 3210 SET 2; WTW GmbH) calibrated at pH 4 to 7. While for temperature, a digital food thermometer (TP101; temperature range of −50°C to 300°C) was used. The pH and temperature values were recorded seven times (at 0, 1, 2, 4, 7, 18, and 24 hr of post-slaughter) before the sample processing. For each time, both values were noted from three different sites of *M. longissimus dorsi* (LD) muscles (from the surface, middle, and deeper part of the muscle) and their average was considered the final value.

2.4.2 | Tenderness

For measurement of tenderness, steaks were vacuum packaged, and cooked in water bath (memmert WNB45) adjusted at 80°C. The steaks were drawn out of water bath when they attained a core temperature of 72°C as described by Soares and Areas (1995). After that, samples were cooled down to the room temperature and cut down into strips of 6 cm × 1 cm × 1 cm in a parallel fashion to the orientation of muscle fiber using scalpel-handle blades as done by Neath et al. (2007). The shear force values were recorded by shearing the muscle fiber in the perpendicular direction using the texture analyzer (TA.XT plus® texture analyzer) with V-slot blade. Minimum three shear force values were obtained from each steak and expressed as Newton (N/cm^2).

2.4.3 | Meat color

For the measurement of color values, steaks were placed in polystyrene food grade trays and overwrapped with cling film. For blooming, trays were put in horizontal display chiller (ALVO, Model MD-12, size: 72" × 42" × 48" by Technosight) working at 0–4°C for an hour as followed by Wyrwisz et al. (2016). After that, different parameters of color, i.e., L* (lightness), a* (redness), b* (yellowness), C* (Chroma), and h (hue angle), were measured using chroma meter (Konica Minolta® CR-410). Before color measurement, the colorimeter was calibrated each time using a standard white tile CR-A44 at L* = 94.93, a* = −0.13, b* = 2.55, and C* = 2.55. All the values were the instrumental average of the three independent measurements from different sites across the steaks.

2.4.4 | Purge and cooking losses (%)

For purge loss, samples were weighed by digital compact weighing balance (SF-400, 7,000 g × 1 g), before and after storage of 7 and 14 days. Whereas cooking loss was measured by weighing the steaks before and after cooking. Both purge and cooking losses were calculated as the ratio of the difference between the weights before and after storage or cooking to the weight of steaks before storage or cooking and expressed in percentage.

2.5 | Statistical analyses

The results were expressed as least square means ± standard error of the mean (*SEM*). Statistical analysis was carried out using SAS 9.1 software (SAS Institute Inc.). The mixed model procedure was applied with animal species, slaughter age, aging time, and chilling rate as fixed effects, while animals as random effect, in order to analyze the changes of meat shear forces values, color character (L*, a*, b*, C*, and h), cooking loss, and purge loss percentages. The Tukey-Kramer multiple comparison tests were used to estimate the levels of statistical significance ($p < .05$) among the least square means.

3 | RESULTS

3.1 | Temperature and pH decline

The decline in temperature and pH by time profile was significantly different between treatments (Table 1). The fast decline of temperature and the slow decline of pH were observed during the RC than DC ($p < .05$). The effect of RC was more pronounced in younger animals of both species, like after 4 hr of RC, carcasses of buffalo bulls at 18 months (B18) of age achieved temperature and pH of 5.50°C and 6.15, while buffalo bulls at 26 months (B26) of age attained 7.66°C and 6.09, respectively. At the same postmortem time of DC, B18 and B26 reached the temperature of 11.68°C and 13.31°C, while their pH dropped to 5.82 and 5.88, respectively. Furthermore, during RC, young cattle bulls cooled comparatively quicker as compared to buffalo, like at 2 hr postmortem, the temperature of cattle bulls at 18 months (C18) of age and B18 was 9.37°C and 11.63°C, while pH was 6.30 and 6.26, respectively. Overall, data suggested that RC carcasses from younger animals of both species missed the ideal pH/temperature window, defined as temperature should not below than 10°C before pH reaches 6.2 (Savell, Mueller, & Baird, 2005).

3.2 | Instrumental shear force

As shown in Table 2, shear force values were affected by the species, age, aging time, and chilling rate ($p < .05$). Cattle bulls presented lower shear force values as compared to buffalo bulls. Shear force values of 18-month-old bulls were higher than that of older age bulls, and decreased with the increment of aging time and values at 14 days of storage were lower than the values at 1 and 7 days of storage. Furthermore, RC showed an adverse effect on shear force values ($p < .05$). The interactions effects (presented as *p*-values) of animal age, aging time, and chilling rate are shown in Supplementary Table S1.

On the first day of storage, the shear force values of C18 and C26 were lower as compared to the values of B18 and B26, respectively ($p < .05$, Table 3). However, after 7 days of storage, shear force value of B26 bulls become in parallel with the value of C26 and lower than that of the C18. At the start of storage, the shear force value C26 was higher than the value of C18 ($p < .05$). Shear force was also related to the rate of chilling, and the carcasses of younger (B18 and C18) animals of both species were cooled quickly and subsequently showed significantly higher shear force values. Furthermore, the adverse effect of RC was also observed on the shear force value of older age buffalo bulls (B26). Aging showed a significant ($p < .001$) effect on meat tenderness; the shear force values decreased with the increase of storage time in both age category of cattle and

TABLE 1 Rate of temperature and pH decline during rapid chilling (RC) and delayed chilling (DC) of buffalo bulls at 18 (B18) and 26 months (B26) and of cattle bulls at 18 (C18) and 26 months (C26) of their age at different postmortem time intervals

			Postmortem time (hours)							
Parameters	**Animals**	**Chilling rate**	**0**	**1**	**2**	**4**	**7**	**18**	**24**	***SEM***
Temperature	B18	RC	34.90^{Aa}	15.73^{Cb}	11.63^{Cc}	5.50^{Ed}	4.55^{Ede}	3.51^{Ce}	3.68^{Ce}	0.48
		DC	35.01^{Aa}	28.25^{Bb}	24.16^{Bc}	11.68^{Cd}	6.50^{ABe}	3.90^{ABCf}	3.95^{ABCf}	0.65
	B26	RC	36.71^{Aa}	18.03^{Cb}	12.63^{Cc}	7.66^{Dd}	4.81^{DEe}	3.67^{BCe}	3.77^{ABCe}	0.44
		DC	36.45^{Aa}	31.71^{Ab}	29.24^{Ac}	13.31^{Bd}	6.20^{ABCe}	3.87^{ABCf}	3.91^{ABCf}	0.60
	C18	RC	36.28^{Aa}	15.51^{Cb}	9.37^{Dc}	5.49^{Ec}	4.73^{Ec}	3.63^{BCc}	3.83^{ABCc}	0.45
		DC	36.16^{Aa}	28.93^{Bb}	25.80^{Bc}	15.08^{Ad}	6.84^{Ae}	4.13^{Af}	4.20^{Af}	0.45
	C26	RC	36.11^{Aa}	18.28^{Cb}	13.87^{Cc}	7.52^{Dd}	5.23^{CDEe}	4.02^{ABf}	4.17^{ABef}	0.37
		DC	36.28^{Aa}	32.72^{Ab}	30.82^{Ab}	15.40^{Ac}	5.85^{BCDd}	3.81^{ABCd}	3.74^{BCd}	0.61
pH	B18	RC	6.51^{Aa}	6.36^{ABab}	6.26^{ABbc}	6.15^{Acd}	5.96^{Ad}	5.73^{Ae}	5.75^{Ae}	0.06
		DC	6.52^{Aa}	6.18^{Bb}	6.08^{BCDb}	5.82^{Dc}	5.76^{Cc}	5.68^{Ac}	5.69^{Ac}	0.03
	B26	RC	6.62^{Aa}	6.30^{ABb}	6.16^{ABCbc}	6.09^{ABcd}	5.93^{ABe}	5.73^{Af}	5.72^{Af}	0.05
		DC	6.61^{Aa}	6.23^{ABb}	6.04^{CDc}	5.88^{CDcd}	5.81^{ABCde}	5.70^{Ae}	5.68^{Ae}	0.05
	C18	RC	6.65^{Aa}	6.38^{Ab}	6.30^{Ac}	6.03^{ABCd}	5.88^{ABCe}	5.66^{Af}	5.62^{Af}	0.04
		DC	6.66^{Aa}	6.21^{ABb}	6.08^{BCDc}	5.83^{Dd}	5.80^{BCd}	5.66^{Ae}	5.66^{Ae}	0.04
	C26	RC	6.65^{Aa}	6.31^{ABb}	6.18^{ABCbc}	6.09^{ABc}	5.94^{ABd}	5.76^{Ae}	5.75^{Ae}	0.05
		DC	6.68^{Aa}	6.21^{ABb}	5.98^{Dc}	5.94^{BCDcd}	5.78^{BCde}	5.66^{Ae}	5.73^{Ae}	0.08

Note: Values are expressed as least square means ± *SEM* (standard error of mean). Different capital alphabets ^{A,B,C,D,E} (in columns) and small alphabets ^{a,b,c,d,e,f} (in rows) showing significant difference ($p < .05$).

TABLE 2 Effect of species, age, aging time, and chilling rate on shear force, color parameters (L*, a*, b*, C*, and h), cooking loss (CL), and purge loss (PL) % of buffalo and cattle bulls

Parameters	Species			Age (months)			Aging (days)				Chilling rate			*p*-value			
	Buffalo	Cattle	*SEM*	18	26	*SEM*	1	7	14	*SEM*	RC	DC	*SEM*	Specie	Age	Aging	Chilling
Shear force	29.31^{A}	27.22^{B}	0.16	28.96^{A}	27.96^{B}	0.16	36.15^{A}	25.58^{B}	23.06^{C}	0.22	28.58^{A}	27.94^{B}	0.16	<.0001	.008	<.0001	.004
L*	45.22^{A}	43.81^{B}	0.15	44.65^{A}	44.38^{A}	0.15	42.66^{C}	44.78^{B}	46.11^{A}	0.18	44.26^{A}	44.78^{A}	0.15	<.0001	.196	<.0001	.064
a*	22.75^{A}	22.35^{A}	0.13	22.43^{A}	22.68^{A}	0.13	21.83^{C}	22.57^{B}	23.26^{A}	0.13	22.59^{A}	22.52^{A}	0.13	.090	.096	<.0001	.652
b*	10.31^{B}	11.09^{A}	0.23	10.54^{A}	10.87^{A}	0.23	10.29^{A}	10.85^{A}	10.97^{A}	0.10	10.70^{A}	10.71^{A}	0.23	<.0001	.060	.230	.938
C*	23.51^{A}	23.57^{A}	0.09	23.48^{A}	23.61^{A}	0.09	22.47^{C}	23.74^{B}	24.41^{A}	0.11	23.51^{A}	23.57^{A}	0.09	.636	.301	<.0001	.616
h	24.40^{B}	26.94^{A}	0.13	25.43^{A}	25.91^{A}	0.13	24.52^{B}	26.10^{A}	26.4^{A}	0.16	25.60^{A}	25.75^{A}	0.13	<.0001	.070	.005	.411
CL	32.45^{A}	30.65^{B}	0.13	31.08^{B}	32.02^{A}	0.13	30.23^{C}	31.86^{B}	32.56^{A}	0.16	31.05^{B}	31.85^{A}	0.13	<.0001	<.0001	<.0001	.042
PL	3.22^{A}	3.14^{A}	0.06	3.00^{B}	3.66^{A}	0.06	–	2.44^{B}	3.92^{A}	0.06	3.08^{A}	3.28^{A}	0.06	.326	.041	<.0001	.089

Note: Values are expressed as least square means ± *SEM* (standard error of mean). Different capital alphabets^{A,B,C} (in columns) showing significant difference ($p < .05$).

buffalo bulls. The rate of tenderization was higher during the first 7 days of storage, precisely shear force values were reduced from 36.25 N to 25.37 N and then to 23.08 N during the first and second half of 14 days of storage, respectively.

3.3 | Colorimeter analysis

The L* value was affected by the species and aging time ($p < .05$), shown in Table 2. The L* value was higher in buffalo bull than that of the cattle bull. The L* value was increased with the advancement of aging time. The a* and C* values were affected by the aging time and both color coordinates were increased with the increase of storage time ($p < .05$). Whereas, b* value was significantly affected by the species and was higher in cattle than that of the buffalo bull. The h value was affected by the species and aging time ($p < .05$). The h value was higher in cattle bull than that of the buffalo bull and the h value increased with the increase of aging time.

At the start of storage, L* and a* values were highest in B26 and lowest in C26 ($p < .05$), as shown in Table 4. Whereas, the L* values of B26 were similar to that of C18 but higher as compared to C26 ($p < .05$). Color parameters were also affected by the animal age, in buffalo bulls, color L*, a*, and C* values were higher in B26 than those of the B18, and opposite trend was observed in the case of cattle bulls. Chilling effect the L*, a*, and b* values in C18 and these values were significantly ($p < .05$) higher during DC (Table 4). In B18 and B26 bulls, L* values were significantly affected by chilling and recorded higher during DC ($p < .05$). In both age categories of cattle and buffalo bulls, L*, C*, and h values were significantly ($p < .001$) increased throughout the storage, whereas b* showed a nonsignificant effect of aging.

3.4 | Purge and cooking losses (%)

The cooking loss values were significantly affected by the species, age, aging time, and chilling rate ($p < .05$, Table 2). Cooking loss value was higher in buffalo bulls as compared to the value of cattle bulls. Cooking loss was higher in 26-month-old animals than that of the younger bulls. The cooking loss values were decreased with the increase of aging time. Furthermore, DC presented higher cooking loss value than that of the RC. The purge loss values were significantly affected by animal age and aging time ($p < .05$). Older animals showed higher purge loss values than younger animals. The purge loss values were increased with the increase of aging time.

At the beginning of the storage, maximum cooking loss values were recorded in B26 and minimum in C18, illustrated in Table 5. At 7 and 14 days of aging, cooking loss values were significantly higher in buffalo meat ($p < .05$) as compared to cattle. At 7 days of aging, purge loss values of B18 were similar to C26 but lower than B26 and higher than C18. Chilling showed a significant effect on cooking loss of B26 only and the cooking loss was higher ($p < .05$) during DC, whereas B18 and both age group of cattle remained unaffected.

TABLE 3 Influence of aging time and chilling rate on shear force values of meat of buffalo bulls at 18 (B18) and 26 months (B26) and of cattle bulls at 18 (C18) and 26 months (C26) of their age

	Aging (days)				Chilling rate		
Animals	1	7	14	*SEM*	RC	DC	*SEM*
B18	37.17^{ABa}	27.58^{Ab}	24.91^{Ac}	0.27	38.10^{Aa}	36.20^{Ab}	0.18
B26	37.85^{Aa}	24.42^{Cb}	23.38^{Bc}	0.21	38.32^{Aa}	36.99^{Ab}	0.17
C18	34.19^{Ca}	25.27^{Bb}	22.53^{Bc}	0.29	35.31^{Ba}	33.13^{Bb}	0.21
C26	35.78^{Ba}	24.19^{Cb}	21.51^{Cc}	0.23	36.22^{ABa}	35.33^{Aa}	0.14

Note: Values are expressed as least square means ± *SEM* (standard error of mean). Different capital alphabets ^{A,B,C} (in columns) and small alphabets ^{a,b,c} (in rows) showing significant difference ($p < .05$).

TABLE 4 Impact of aging time and chilling rate on different meat color parameters of buffalo bulls at 18 (B18) and 26 months (B26) and of cattle bulls at 18 (C18) and 26 months (C26) of their age

		Aging (days)				Chilling rate		
Parameters	Animals	1	7	14	*SEM*	RC	DC	*SEM*
L*	B18	42.44^{Bb}	46.09^{Aa}	46.59^{Aa}	0.22	42.03^{Ba}	43.11^{BCa}	0.25
	B26	44.30^{Ac}	45.28^{Bb}	46.94^{Aa}	0.19	43.98^{Aa}	44.76^{Aa}	0.19
	C18	43.22^{Ab}	44.63^{Ba}	44.93^{Ba}	0.21	42.11^{Bb}	44.31^{ABa}	0.26
	C26	40.86^{Cc}	43.35^{Cb}	46.20^{ABa}	0.23	40.27^{Ca}	41.45^{Ca}	0.19
a*	B18	21.44^{Cb}	22.64^{Aba}	22.67^{Aa}	0.12	20.93^{Ba}	21.46^{Ba}	0.17
	B26	23.18^{Aa}	23.27^{Aa}	23.64^{Aa}	0.11	23.33^{Aa}	23.15^{Aa}	0.11
	C18	22.16^{Bb}	22.54^{ABb}	23.36^{Aa}	0.17	21.46^{Bb}	23.09^{Aa}	0.18
	C26	20.74^{Cc}	22.02^{Bb}	23.61^{Aa}	0.21	20.63^{Ba}	20.85^{Ba}	0.09
b*	B18	9.39^{Cb}	10.72^{Aa}	10.08^{Bab}	0.13	9.47^{Ba}	9.34^{Ca}	0.12
	B26	10.12^{Bb}	10.89^{Aa}	11.28^{Aa}	0.14	9.94^{Ba}	10.16^{Ba}	0.16
	C18	11.01^{Ab}	11.14^{Aab}	11.51^{Aa}	0.11	10.84^{Aa}	11.22^{Aa}	0.18
	C26	10.91^{Aa}	11.43^{Aa}	11.37^{Aa}	0.21	10.84^{Aa}	10.97^{ABa}	0.08
C*	B18	22.08^{Bb}	23.58^{Ba}	23.61^{Ba}	0.18	22.10^{Ba}	22.06^{Ba}	0.09
	B26	23.40^{Ab}	24.37^{Aa}	24.35^{ABa}	0.12	23.33^{Aa}	23.41^{Aa}	0.11
	C18	22.95^{Ac}	23.96^{ABb}	25.01^{Aa}	0.26	22.67^{ABa}	23.23^{Aa}	0.18
	C26	21.66^{Bc}	23.27^{Bb}	24.94^{Aa}	0.23	21.69^{Ba}	21.64^{Ba}	0.13
h	B18	23.18^{Cb}	24.94^{Ca}	25.76^{Ca}	0.21	23.19^{Ba}	23.24^{Ba}	0.10
	B26	23.27^{Cc}	25.19^{Ca}	24.34^{Db}	0.17	23.23^{Ba}	23.30^{Ba}	0.14
	C18	25.36^{Bb}	26.63^{Ba}	26.88^{Ba}	0.19	25.27^{Aa}	25.44^{Aa}	0.15
	C26	26.49^{Ab}	27.84^{Aa}	28.82^{Ab}	0.23	26.29^{Aa}	26.68^{Aa}	0.12

Note: Values are expressed as least square means ± *SEM* (standard error of mean). Different capital alphabets ^{A,B,C} (in columns) and small alphabets ^{a,b,c} (in rows) showing significant difference ($p < .05$).

Whereas, aging showed a significant effect on purge and cooking losses of all animals, and increased in parallel with storage time.

4 | DISCUSSION

Buffalo meat was tougher in texture than that of the cattle meat. The same findings were reported by Robertson, Ratcliff, Bouton, Harris, and Shorthose (1986), and concluded that the tenderness of three muscles of cattle was superior as compared to the buffalo. It was hypothesized that it might be due to more collagen contents and its crosslinks in buffalo bulls. The higher color lightness and lower yellowness in buffalo meat were also reported by Lapitan et al. (2008). The yellow color of cattle meat could be due to the deposition of yellow carotenoid pigment in it. The possible reason for more cooking loss in buffalo meat could also be the higher collagen contents, which provide a channel to the water to come out during cooking.

On the first day of aging, shear force values were increased with the increase of animal age, and many mechanisms contributed it (Moholisa, Hugo, Strydom, & Heerden, 2017). These mechanisms mainly include the amount of connective tissue and the degree of muscle shortening when rigor mortis is achieved. At 7 and 14 days

TABLE 5 Effect of aging time and chilling rate on cooking loss (CL) and purge loss (PL) % of meat of buffalo bulls at 18 (B18) and 26 months (B26) and of cattle bulls at 18 (C18) and 26 months (C26) of age

		Aging (days)				Chilling rate		
Parameters	Animals	1	7	14	*SEM*	RC	DC	*SEM*
CL	B18	30.24^{Bc}	32.60^{Ab}	33.51^{Aa}	0.18	29.87^{ABa}	30.62^{Ba}	0.21
	B26	31.82^{Ab}	33.24^{Aa}	33.59^{Aa}	0.17	31.32^{Ab}	32.33^{Aa}	0.15
	C18	28.79^{Cb}	30.37^{Ca}	31.24^{Ba}	0.23	27.94^{Ca}	29.51^{Ba}	0.27
	C26	30.25^{Bb}	31.45^{Ba}	32.15^{Ba}	0.17	29.61^{BCa}	30.88^{ABa}	0.16
PL	B18	–	2.41^{ABb}	3.71^{Aa}	0.09	–	–	–
	B26	–	2.76^{Ab}	4.18^{Aa}	0.11	–	–	–
	C18	–	2.27^{Bb}	3.78^{Aa}	0.14	–	–	–
	C26	–	2.53^{ABb}	4.19^{Aa}	0.12	–	–	–

Note: Values are expressed as least square means ± *SEM* (standard error of mean). Different capital alphabets ^{A,B,C} (in columns) and small alphabets ^{a,b,c} (in rows) showing significant difference ($p < .05$).

of aging, shear force values of older age animals were less than that of younger animals, it could be due to the higher activities of intrinsic enzymes in older animals that breakdown the myofibrillar structure including actomyosin association and involved in tenderization (Moczkowska, Poltorak, & Wierzbicka, 2017). The decrease in color lightness and an increase in redness with the advancement of cattle age are due to the deposition of myoglobin contents as suggested by Cho, Kang, Seong, Park, and Kang (2015). Furthermore, the lower lightness of C26 is also associated with its high $pH_{u,}$ which renders the protein denaturation and light scattering (Ijaz et al., 2020). However, the increased yellowness of B26 than B18 may be attributed to the deposition of some intramuscular pigments with the progression of age (Duarte et al., 2011). The age of both buffalo and cattle bulls also showed a marked influence on cooking loss and increased with the advancement of animal age, it could be due to the increase of collagen crosslinks with advancement of animal age (Roy, Aalhus, Basarab, Larsen, & Bruce, 2015).

In the present study, RC showed a significant effect on shear force values in younger animals of both species, which was consistent with many studies (Liu et al., 2015; Van Moeseke, Smet, Claeys, & Demeyer, 2001). The possible reason may be the less fat covering and weight of muscle of younger animals which make them more prone to miss the ideal temperature/pH window (temperature should not below than 10°C before pH reaches 6.2), described by Savell et al. (2005), and lead to cold shortening. In buffalo bulls, the adverse effect of chilling was also observed in older age bulls, which could be due to less fat covering and muscle weight in buffalo bulls. Furthermore, due to the RC, tenderness values of young cattle bulls (C18) were more affected than buffalo bulls (B18) and it could be due to a higher degree of cold shortening in C18, which was revealed by the fast decline of temperature and slow drop of pH when compared with B18. Chilling also showed a marked influence on L* and a* values of C18 and recorded higher during DC, which was also reported previously (Farouk & Lovatt, 2000; Rees, Trout, & Warner, 2003). The increase in L* could be due to protein denaturation due to the fast decline in pH at a higher temperature, resulting in increased scattering of light.

On the other hand, the increase in redness values of C18 at higher rigor temperature may be due to reduced oxygen consumption rate (OCR) by mitochondrial enzymes (Farouk & Swan, 1998), due to which oxygen get chance to penetrate deeper into the muscles and convert the deoxymyoglobin into oxymyoglobin which is bright red. Whereas, in older animals of both species, all color parameters were not affected by the chilling rate. These results are in partial agreement with the study of Devine et al. (2002). Furthermore, the chilling regime affects the cooking loss values of B26 and it was increased during DC. The increase in cooking loss could be due to more protein denaturation of B26 at a higher temperature, which ultimately decreased the protein capacity to hold the water during cooking; the higher protein denaturation of B26 was also depicted from its higher L* values during DC.

The refrigerated storage of 7 and 14 days of both the age category of buffalo and cattle meat leads to a significant decrease in shear force values, which is in agreement with many studies (Hopkins & Geesink, 2009; Kim, Meyers, Kim, Liceaga, & Lemenager, 2017; Moczkowska et al., 2017). The improvement in tenderness during storage is due to the degradation of myofibrillar and associated proteins. Main proteins which maintain the structural integrity of myofibril are degraded, which primarily includes intermyofibril (vinculin and desmin) and intramyofibrillar (nebulin and titin) links, costameres connections between sarcomere and sarcolemma (dystrophin), and proteins involved in attachment of myocyte to basal lamina (Li et al., 2014; Wu, Farouk, Clerens, & Rosenvold, 2014). Whereas, principle endogenous proteases, which are involved in proteolysis of these proteins, are believed to be the m-, μ-calpains (Herrera-Mendez, Becila, Boudjellal, & Ouali, 2006), calpains 3/p94, and 10 (Ilian, Bekhit, & Bickerstaffe, 2004), cathepsins, multicatalytic proteinase complex (MPC), and caspases (Ouali et al., 2006). Additionally, aging also showed a positive impact on instrumental color parameters (L*, a*, b*, C*, and h), and all color coordinates were increased with the storage of meat of both cattle and buffalo bulls. The increase in L* was also due to the degradations of protein with endogenous proteases, leading to weakening of protein structure, which results in

more light dispersion (Ijaz et al., 2020; MacDougall, 1982). However, the increase in a* values during storage was due to the degradation of mitochondrial enzymes, which decrease the OCR and favor the formation of oxymyoglobin (Beriain, Goni, Indurain, Sarries, & Insausti, 2009). The increase in b* (yellowness) could be due to the meat surface oxidation during aging (Oliete et al., 2006).

Interestingly, it was noted in all animals that the rate of tenderization was higher during the first 7 days of storage and reduced as storage time increased. The results confirm the findings of previous studies (Hou et al., 2014; Mohrhouse, Lonergran, Huff-Lonergran, Underwood, & Weaver, 2012). The reason was explored by Velotto et al. (2009) and proposed that the activity of μ-calpains was higher during the first 7 days than 8 to 15 days of aging of *Longissimus dorsi*, and calpains 3/p94 also become inactive after 7 days of storage. It was important to note that the rate of tenderizing the meat was comparatively faster in buffalo (B26) and after 7 days of storage, shear force values of B26 become comparable to that of cattle (though values were significantly high during the first day of storage). It was due to the higher total protease and calpain activities in older age buffalo than that of the cattle bulls (Neath et al., 2007).

It was also revealed that the cooking and purge loss values were increased in a parallel fashion with the aging of both buffalo and cattle meat (Aroeira et al., 2016; Colle et al., 2015, 2016). The possible reason was proposed by Kim, Warner, and Rosenvold (2014) and Wicklund et al. (2006) that myofibrillar structural disruption during aging reduced the ability of myocytes to retain the water. Johnson (1974) studied the vacuum packaging of chilled beef and reported that 1% to 2% purge loss is tolerable, whereas more than 4% is excessive. In the current study, the purge loss values were recorded more than 4% after 14 days of storage of C26 and B26. This excessive purge could be due to cutting of *M. Longissimus dorsi* into steaks which increased the surface area for the escape of water. Secondly, vacuum packaging may also exert pressure on free water to come out of the muscles.

5 | CONCLUSIONS

Overall, the cattle meat was superior to that of the buffalo meat in terms of tenderness. However, cattle meat showed lower lightness and higher yellowness values as compared to buffalo meat. The rate of tenderization was comparatively rapid in buffalo, and at 7 days of storage, shear force value of older age buffalo becomes similar to the same age category of the cattle bulls. It was also noteworthy that RC increased the shear force values in young cattle and both age categories of buffalo bulls. Furthermore, at the start of aging, shear force values were higher in older animals, whereas at 7 and 14 days of aging, older age animals were tender than younger animals that could be due to a higher rate of tenderization in older animals.

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REFERENCES

Aroeira, C. N., Torres, R. A., Fontes, P. R., Gomide, A. M., Ramos, A. L., Ladeira, M. M., & Ramos, E. M. (2016). Freezing, thawing and aging effects on beef tenderness from *Bos indicus* and *Bos taurus* cattle. *Meat Science*, *116*, 118–125. https://doi.org/10.1016/j.meatsci.2016.02.006

Beriain, M., Goni, M., Indurain, G., Sarries, M., & Insausti, K. (2009). Predicting *Longissimus dorsi* myoglobin oxidation in aged beef based on early post-mortem color measurements on the carcass as a color stability index. *Meat Science*, *81*, 439–445. https://doi.org/10.1016/j.meatsci.2008.09.009

Brewer, S., & Novakofski, J. (2008). Consumer sensory evaluations of aging effects on beef quality. *Journal of Food Science*, *73*, 78–82. https://doi.org/10.1111/j.1750-3841.2007.00575.x

Camou, J. P., Mares, S. W., Marchello, J. A., Vazquez, R., Taylor, M., Thompson, V. F., & Goll, D. E. (2007). Isolation and characterization of μ-calpain, m-calpain, and calpastatin from postmortem muscle. Initial steps. *Journal of Animal Science*, *85*, 3400–3414. https://doi.org/10.2527/jas.2007-0356

Cho, S., Kang, G., Seong, P. N., Park, B., & Kang, S. M. (2015). Effect of slaughter age on the antioxidant enzyme activity, color, and oxidative stability of Korean Hanwoo (*Bos taurus coreanae*) cow beef. *Meat Science*, *108*, 44–49. https://doi.org/10.1016/j.meatsci.2015.05.018

Colle, M. J., Richard, R. P., Killinger, K. M., Bohlscheid, J. C., Gray, A. R., Loucks, W. I., … Doumit, M. E. (2015). Influence of extended aging on beef quality characteristics and sensory perception of steaks from the gluteus medius and *Longissimus lumborum*. *Meat Science*, *110*, 32–39. https://doi.org/10.1016/j.meatsci.2015.06.013

Colle, M. J., Richard, R. P., Killinger, K. M., Bohlscheid, J. C., Gray, A. R., Loucks, W. I., … Doumit, M. E. (2016). Influence of extended aging on beef quality characteristics and sensory perception of steaks from the biceps femoris and semimembranosus. *Meat Science*, *119*, 110–117. https://doi.org/10.1016/j.meatsci.2016.04.028

Descalzo, A. M., Rossetti, L., Sancho, A. M., Garcia, P. T., Biolatto, A., Carduza, F., & Grigioni, G. M. (2008). Antioxidant consumption and development of oxidation during ageing of buffalo meat produced in Argentina. *Meat Science*, *79*, 582–588. https://doi.org/10.1016/j.meatsci.2007.10.020

Devine, C. E., Payne, S. R., Peachey, B. M., Lowe, T. E., Ingram, J. R., & Cook, C. J. (2002). High and low rigor temperature effects on sheep meat tenderness and ageing. *Meat Science*, *60*, 141–146. https://doi.org/10.1016/S0309-1740(01)00115-2

Duarte, M. S., Paulino, P., Fonseca, M. A., Diniz, L. L., Cavali, J., Serão, N., … Cox, R. B. (2011). Influence of dental carcass maturity on carcass traits and meat quality of Nellore bulls. *Meat Science*, *88*, 441–446. https://doi.org/10.1016/j.meatsci.2011.01.024

Farouk, M., & Lovatt, S. (2000). Initial chilling rate of pre-rigor beef muscles as an indicator of color of thawed meat. *Meat Science*, *56*, 139–144. https://doi.org/10.1016/S0309-1740(00)00031-0

Farouk, M., & Swan, J. (1998). Effect of rigor temperature and frozen storage on functional properties of hot-boned manufacturing beef. *Meat Science*, *49*, 233–247. https://doi.org/10.1016/S0309-1740(97)00134-4

Feldkamp, T., Schroeder, T., & Lusk, J. (2005). Determining consumer valuation of differentiated beef steak quality attributes. *Journal of Muscle Foods*, *16*, 1–15. https://doi.org/10.1111/j.1745-4573.2004.05303.x

Herrera-Mendez, C. H., Becila, S., Boudjellal, A., & Ouali, A. (2006). Meat ageing: Reconsideration of the current concept. *Trends in Food Science & Technology*, *17*, 394–405. https://doi.org/10.1016/j.tifs.2006.01.011

Hopkins, D. L., & Geesink, G. H. (2009). Protein degradation post mortem and tenderisation. In M. Du & R. J. McCormick (Eds.), *Applied Muscle Biology and Meat Science* (pp. 149–173). Boca Raton, FL: CRC Press, Taylor & Francis Group Publisher.

Hou, X. U., Liang, R., Mao, Y., Zhang, Y., Niu, L., Wang, R., … Luo, X. (2014). Effect of suspension method and aging time on meat quality of Chinese fattened cattle *M. Longissimus dorsi*. *Meat Science*, *96*, 640–645. https://doi.org/10.1016/j.meatsci.2013.08.026

Humada, M., Sanudo, C., & Serrano, E. (2014). Chemical composition, vitamin E content, lipid oxidation, color and cooking losses in meat from Tudanca bulls finished on semi-extensive or intensive systems and slaughtered at 12 or 14 months. *Meat Science*, *96*, 908–915. https://doi.org/10.1016/j.meatsci.2013.10.004

Ijaz, M., Li, X., Zhang, D., Hussain, Z., Ren, C., Bai, Y., & Zheng, X. (2020). Association between meat color of DFD beef and other quality attributes. *Meat Science*, *161*, 107954. https://doi.org/10.1016/j.meatsci.2019.107954

Ilian, M. A., Bekhit, A. E., & Bickerstaffe, R. (2004). The relationship between meat tenderization, myofibril fragmentation and autolysis of calpain 3 during post-mortem aging. *Meat Science*, *66*, 387–397. https://doi.org/10.1016/S0309-1740(03)00125-6

Johnson, B. (1974). Chilled vacuum-packed beef. *CSIRO Food Research Quarterly*, *34*, 14–20.

Kim, Y., Meyers, B., Kim, H. W., Liceaga, A. M., & Lemenager, R. P. (2017). Effects of stepwise dry/wet-aging and freezing on meat quality of beef loins. *Meat Science*, *123*, 57–63. https://doi.org/10.1016/j.meatsci.2016.09.002

Kim, Y., Warner, R., & Rosenvold, K. (2014). Influence of high pre-rigor temperature and fast pH fall on muscle proteins and meat quality: A review. *Animal Production Science*, *54*, 375–395. https://doi.org/10.1071/AN13329

Kiran, M., Naveena, B. M., Reddy, K. S., Shahikumar, M., Reddy, V. R., Kulkarni, V. V., … More, T. H. (2016). Understanding tenderness variability and ageing changes in buffalo meat: Biochemical, ultrastructural and proteome characterization. *Animal*, *10*, 1007–1015. https://doi.org/10.1017/S1751731115002931

Koohmaraie, M., & Geesink, G. (2006). Contribution of postmortem muscle biochemistry to the delivery of consistent meat quality with particular focus on the calpain system. *Meat Science*, *74*, 34–43. https://doi.org/10.1016/j.meatsci.2006.04.025

Lapitan, R. M., Del barrio, A. N., Katsube, O., Ban-tokuda, T., Orden, E. A., Robles, A. Y., … Fujihara, T. (2008). Comparison of carcass and meat characteristics of Brahman grade cattle (Bos indicus) and crossbred water buffalo (*Bubalus bubalis*) fed on high roughage diet. *Animal Science Journal*, *79*, 210–217. https://doi.org/10.1111/j.1740-0929.2008.00519.x

Lawrence, T., Whatley, J., Montgomery, T., Perino, L., & Dikeman, M. (2001). Influence of dental carcass maturity classification on carcass traits and tenderness of longissimus steaks from commercially fed cattle. *Journal of Animal Science*, *79*, 2092–2096. https://doi.org/10.2527/2001.7982092x

Li, P., Wang, T., Mao, Y., Zhang, Y., Niu, L., Liang, R., … Luo, X. (2014). Effect of ultimate pH on postmortem myofibrillar protein degradation and meat quality characteristics of Chinese yellow crossbreed cattle. *The Scientific World Journal*, *14*, 278–286. https://doi.org/10.1155/2014/174253

Liu, Y., Mao, Y., Zhang, Y., Liang, R., Wang, R., Zhu, L., … Luo, X. (2015). Pre-rigor temperature control of Chinese yellow cattle carcasses to 12–18°C during chilling improves beef tenderness. *Meat Science*, *100*, 139–144. https://doi.org/10.1016/j.meatsci.2014.09.006

MacDougall, D. (1982). Changes in the color and opacity of meat. *Food Chemistry*, *9*, 75–88. https://doi.org/10.1016/0308-8146(82)90070-X

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

Moczkowska, M., Poltorak, A., & Wierzbicka, A. (2017). The effect of ageing on changes in myofibrillar protein in selected muscles in relation to the tenderness of meat obtained from cross-breed heifers. *International Journal of Food Science & Technology*, *52*, 1375–1382. https://doi.org/10.1111/ijfs.13436

Moholisa, E., Hugo, A., Strydom, P. E., & Heerden, I. (2017). The effects of animal age, feeding regime, and a dietary beta-agonist on tenderness of three beef muscles. *Journal of the Science of Food and Agriculture*, *97*, 2375–2381. https://doi.org/10.1002/jsfa.8049

Mohrhouse, D., Lonergran, S., Huff-Lonergran, E., Underwood, K., & Weaver, A. (2012). Investigation of protease activity in early postmortem muscle subjected to alternative chilling conditions. South Dakota Beef Report, USA. South Dakota State University Publisher. Retrieved from https://openprairie.sdstate.edu/sd_beefreport_2012/9

Nanda, A. S., & Nakao, T. (2003). Role of buffalo in the socioeconomic development of rural Asia: Current status and future prospectus. *Animal Science Journal*, *74*, 443–455. https://doi.org/10.1046/j.1344-3941.2003.00138.x

Neath, K. E., Del Barrio, A. N., Lapitan, R. M., Herrera, J., Cruz, L. C., Fujihara, T., … Kanai, Y. (2007). Difference in tenderness and pH decline between water buffalo meat and beef during postmortem aging. *Meat Science*, *75*, 499–505. https://doi.org/10.1016/j.meatsci.2006.08.016

Oliete, B., Carballo, J., Varela, A., Moreno, T., Monserrat, L., & Sanchez, L. (2006). Effect of weaning status and storage time under vacuum upon physical characteristics of meat of the Rubia Gallega breed. *Meat Science*, *73*, 102–108. https://doi.org/10.1016/j.meatsci.2005.11.004

Ono, Y., Kakinuma, K., Torii, F., Irie, A., Nakagawa, K., Labeit, S., … Sorimachi, H. (2004). Possible regulation of the conventional calpain system by skeletal muscle-specific calpain, p94/calpain 3. *Journal of Biological Chemistry*, *279*, 2761–2771. https://doi.org/10.1074/jbc.M308789200

Ouali, A., Herrera-Mendez, C. H., Coulis, G., Becila, S., Boudjellal, A., Aubry, L., & Sentandreu, M. A. (2006). Revisiting the conversion of muscle into meat and the underlying mechanisms. *Meat Science*, *74*, 44–58. https://doi.org/10.1016/j.meatsci.2006.05.010

Rees, M. P., Trout, G. R., & Warner, R. D. (2003). The influence of the rate of pH decline on the rate of ageing for pork. II: Interaction with chilling temperature. *Meat Science*, *65*, 805–818. https://doi.org/10.1016/S0309-1740(02)00285-1

Robertson, J., Ratcliff, D., Bouton, P. E., Harris, P. V., & Shorthose, W. R. (1986). A comparison of some properties of meat from young buffalo (*Bubalus bubalis*) and cattle. *Journal of Food Science*, *51*, 47–50. https://doi.org/10.1111/j.1365-2621.1986.tb10832.x

Rosenvold, K., & Wiklund, E. (2011). Retail color display life of chilled lamb as affected by processing conditions and storage temperature. *Meat Science*, *88*, 354–360. https://doi.org/10.1016/j.meatsci.2011.01.006

Roy, B., Aalhus, J., Basarab, J., Larsen, I., & Bruce, H. (2015). Relationship between meat quality and collagen crosslink concentrations in beef from calf-fed, yearling-fed and mature cattle. *Meat Science*, *99*, 142. https://doi.org/10.1016/j.meatsci.2014.07.017

Savell, J. W., Mueller, S. L., & Baird, B. E. (2005). The chilling of carcasses. *Meat Science*, *70*, 449–459. https://doi.org/10.1016/j.meatsci.2004.06.027

Soares, G., & Areas, J. (1995). Effect of electrical stimulation on post mortem biochemical characteristics and quality of *Longissimus dorsi thoracis* muscle from buffalo (*Bubalus bubalis*). *Meat Science*, *41*, 369–379. https://doi.org/10.1016/0309-1740(94)00058-F

Sorheim, O., Idland, J., Halvorsen, E., Froystein, T., Lea, P., & Hildrum, K. (2001). Influence of beef carcass stretching and chilling rate on tenderness of m. longissimus dorsi. *Meat Science*, *57*, 79–85. https://doi.org/10.1016/S0309-1740(00)00079-6

Van Moeseke, W., De Smet, S., Claeys, E., & Demeyer, D. (2001). Very fast chilling of beef: Effects on meat quality. *Meat Science*, *59*, 31–37. https://doi.org/10.1016/S0309-1740(01)00049-3

Velotto, S., Pagano, F., Barone, C., Esposito, M., Civale, G., & Crasto, A. (2009). Effect of aging technologies on some qualitative characteristics of Longissimus dorsi muscle of Marchigiana beef. *Agronomy Research*, *13*, 1143–1151.

Wicklund, S., Homco, R. C., Ryan, K., McKeith, F., Mcfarlane, B., & Brewer, M. (2006). Aging and enhancement effects on quality characteristics of beef strip steaks. *Journal of Food Science*, *70*, 242–248. https://doi.org/10.1111/j.1365-2621.2005.tb07164.x

Wu, G., Farouk, M., Clerens, S., & Rosenvold, K. (2014). Effect of beef ultimate pH and large structural protein changes with aging on meat tenderness. *Meat Science*, *98*, 637–645. https://doi.org/10.1016/j.meatsci.2014.06.010

Wyrwisz, J., Moczkowska, M., Kurek, M., Stelmasiak, A., Poltorak, A., & Wierzbicka, A. (2016). Influence of 21 days of vacuum-aging on color, bloom development, and WBSF of beef semimembranosus. *Meat Science*, *122*, 48–54. https://doi.org/10.1016/j.meatsci.2016.07.018

Xiong, Y. L., Mullins, O. E., Stika, J. F., Chen, J., Blanchard, S. P., & Moody, W. G. (2007). Tenderness and oxidative stability of post-mortem muscles from mature cows of various ages. *Meat Science*, *77*, 105–113. https://doi.org/10.1016/j.meatsci.2007.04.012

SUPPORTING INFORMATION

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