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Age, sex, and chilling effects on goat meat

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Abstract

Production and processing factors that affect native goat meat quality are non-existent in the literature. The current study explored age, sex, and chilling effects on 48 goat carcasses cut in half by halal standards and shifting one half immediately to a walk-in chiller at 0–4°C [rapid chilling (RC)] and the other half at 26 ± 2°C [delayed chilling (DC)]. Results showed that Warner Bratzler Shear Force (WBSF) was significantly affected by RC. Cooking loss and color (L*) parameters were significantly higher in young male animals. Chroma values were significantly higher in DC. In conclusion, DC enhances meat quality and tenderness.

Keywords: color, cooking loss, delayed & rapid chilling, tenderness

Introduction

Different types of meat including beef, poultry, and mutton, are consumed worldwide. Consumption of meat varies among different regions of the world as it mainly depends on the culture, cuisine, and eating habits of the population in specific parts of the world. Goat meat is either retailed as capretto or chevon. Capretto is sourced from young goats whose carcass weight is 6–8 kg and its demand is high in America, France, and the Mediterranean region. Meanwhile, Chevon is obtained from adult goats with a carcass weight of 16–22 kg and is mostly preferred in Africa and the Indian subcontinent (Pophiwa *et al*., 2020). Countries have traditions to consume sheep and goat meat and also give preferences with regard to consuming different processed products, for example, in Turkey, Pakistan, and India different varieties of kebabs prepared from lamb (Teixeira *et al*., 2020).

The quality of goat meat is a major concern for farmers, consumers, and researchers (Aldridge *et al*., 2018), as it mainly involves color, water-holding capacity, tenderness, and nutritional profile of meat (Birhanu, 2019). Despite the varying consumption rate of meat from different species, mutton is still considered to be a high-quality protein commodity in most developing countries (Kosum *et al*., 2019). Among the meat quality traits, tenderness is one of the main pillars affecting cooked meat palatability and it has a direct link with end-user satisfaction level (Garmyn, 2020). Moreover, consumers are willing to pay extra money for guaranteed tender meat (Ellies-Oury *et al*., 2019). Tenderness is influenced by both production and processing factors. Understanding different physiological and processing factors affecting meat quality is essential to ensure the best meat for consumers. Major production factors are animal breed, age, sex, slaughtering weight, and feeding management at the farm level

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(Clinquart *et al*., 2022; Pophiwa *et al*., 2020). On the other hand, processing factors include a post-harvest carcass chilling regime of varying rates, temperatures, and durations to enhance tenderness (Ijaz *et al*., 2020). Besides processing factors, animal age at slaughter is a vital factor for meat quality, especially its tenderness (Hossain *et al*., 2021; Purwin *et al*., 2016).

Likewise, meat color is another important parameter that defines the customer's purchasing ability. Consumers usually relate bright red color to freshness and associate brown color with the low freshness of the meat (Henchion *et al*., 2017). Meat color changes continuously during display time and loses its stability with extended storage time (Ijaz *et al*., 2020). The concentration and redox status of myoglobin within the muscle determines the meat color (El Otmani *et al*., 2021), which is affected by animal age (Hwang *et al*., 2019) and carcass chilling regime (Pophiwa *et al*., 2016). Goats are highly susceptible to pre-slaughter stress due to their excitable instinct behavior (Casey and Webb, 2010; Corazzin *et al*., 2019). Among meat quality parameters, color, tenderness, drip loss, and water-holding capacity are affected by stress (Kumar *et al*., 2022). It is also well-recognized that stress limits the acidification pattern of muscle-to-meat conversion (Ponnampalam *et al*., 2017) because, during pre-slaughter stress, the hypothalamus–hypophysis axis involves releases of cortisol and adrenaline which results in the depletion of cellular glycogen. This depletion of glycogen reduces the substrate for glycolysis which ultimately leads to higher meat pH (Corazzin *et al*., 2019). Higher ultimate pH (pHu) is undesirable as it darkens the meat color (Terlouw, 2015) and causes lesser meat tenderization (Nian *et al*., 2018).

Post-slaughter techniques such as the chilling method significantly influence carcass meat quality. Chilling of the carcass is necessary to keep the meat fresh and maintain its shelf life as the rate of microbial and biochemical changes are reduced at low temperatures (Bellés *et al*., 2017; Nastasijević *et al*., 2017). Meat storage and preservation at low temperatures involves chilling the carcass and maintaining a low temperature throughout the display because food safety is of utmost importance in terms of public health especially when considering meat and its products (Gul and Alsayeqh, 2022). In Pakistan, animals slaughtered under commercial conditions are chilled as early as possible to avoid microbial contamination. The most common carcass chilling method, known as rapid chilling (RC), involves shifting carcasses to a chiller operating at 0–4°C immediately after the dressing procedure. Generally, goat carcasses are small, lean, and have a thin subcutaneous fat layer. These feature permits rapid heat dissipation in early postmortem, leading to cold shortening and subsequent meat toughening (Pophiwa *et al*., 2017).

Goat meat has a unique aroma and taste because of which it is considered one of the favorite meats for the Middle Eastern and Indo-Pak natives; however, it is a comparatively expensive protein source due to increased production cost. Due to lack of a modern agricultural system and to reduce the cost of production, goats in Pakistan are reared on green fodder, grasses, and also on agro-industrial by-products as an alternative feed source (Rafique *et al.,* 2022; Sgarro *et al*., 2022). Entirely fattening-based goat farming is non-existance in Pakistan, and most farmers living in rural areas raise goats for their domestic use and subsistence. It is worth mentioning that meat from Pakistani goat breeds has a unique taste; however, it is still not well established. There is also a perception among consumers that younger goats have more tender and juicy meat as compared to older animals and they are willing to pay extra for meat obtained from younger animals. Likewise, male goat meat is more tender and tasty than the meat obtained from female goats. Meat processors are used to chill goat carcasses rapidly due to multiple factors including the schedule of consignments, availability of space in chillers, and also lack of scientific knowledge about the importance of chilling methodology on meat quality. Based on these factors, it was hypothesized that there is a relationship between age groups (milk teeth (MT) and two teeth (TT)), sex (male and female), and chilling methodologies (delayed and rapid) in goat meat. Therefore, these factors need further investigation as age and sex directly correlate with the quality of meat and the recommended age of slaughter for goats with desirable meat traits.

Material and Methods

Experimental design and slaughtering method

In this experiment, 48 goats, 24 male, and 24 non-productive females were procured from the commercial goat fattening farm in the Lahore region. Among the 24 goats of each sex, 12 were 10 months (MT) and the remaining 12 animals were 16 months (TT) of age. The live animals were transported 94 km to the animal shed in Lahore, Pakistan (31.5761°N, 74.2995°E) in approximately 2 h. During transport, the road surface was smooth, and the speed was constant at 45 km/h. The animals' loading and unloading were done with access to a ramp/platform and kept in the lairage for 24 h at an ambient temperature of 25 to 30°C before slaughter. In the meantime, the feed was withdrawn overnight with access to water to minimize the risk of rumen rupture and microbial contamination during the slaughtering procedure. Animal's live weight values were recorded immediately before slaughter (Colonna *et al*., 2020), and after that slaughtering was performed according to the Halal method (Abdullah *et al*., 2019) at the University

experimental slaughtering unit. The process of Halal slaughtering involves proper restraining of the animal, and severing of the trachea, esophagus, both carotid arteries, and jugular veins (Zainalabidin *et al*., 2019).

Chilling treatment

Immediately after the skinning and evisceration procedure, the carcasses were cut into two equal longitudinal halves from the midline with the help of a carcass-splitting saw. One side of the carcass was immediately shifted to a walk-in chiller operating at a temperature of 0–4°C and 1 m/s air velocity for 24 h for RC, while the other side was kept at controlled room temperature, i.e., 26±2°C for 6 h before chilling at 0–4°C until 24 h to ensure delayed chilling (DC). Both the right and left sides of the carcasses were used interchangeably for each trial to ensure the randomized design of the study.

Muscle sampling

After 24 h of post-chilling, both sides of the carcasses were deboned in the deboning hall functioning at 10–15°C. The sirloin muscle (*M. longissimus dorsi*) was obtained from the first rib to the last lumbar vertebrae of both half carcasses as samples. Each sirloin muscle was cut into three steaks with 2 cm thickness and tagged.

Meat quality measurements

Temperature and pH

The pH and temperature were recorded at an interval of 0, 1, 2, 4, 7, and 24 h after splitting of carcasses into halves by inserting a calibrated probe of pH meter (WTW®, pH 3210 SET 2, Germany) and a digital food probe thermometer (TP101®, CixiSinco, China) into different parts of *M. longissimus dorsi* (L.D.) muscles and considered their average as final value. Before each pH measurement, the pH meter was calibrated with buffer solutions of pH 4.0 and 7.0.

Meat color

Following sampling into replicate steaks, samples were placed on a food-grade polystyrene tray and overwrapped with cling film of 250 mm thickness, and placed in a horizontal display chiller operating at 0–4°C for 1-h blooming as adopted by Wyrwisz *et al*. (2016). Meat colorimetric parameters, including L*, a*, b*, C*, and h, were recorded by using a calibrated Chroma meter (Konica Minolta® CR-410, Osaka, Japan) calibrated with a standard white tile prior to measurement. All colorimetric values were the average of the recorded measurements at three different locations of the sample.

Cooking loss

Before cooking, the sirloin samples were weighed using a compact digital weighing balance (SF-400, 7000 g × 1 g). The samples were individually packed in plastic bags and placed in a pre-warmed water bath (Memmert®, WNB 45, Germany) at 80°C for 40–45 min until cooked to the core temperature of 72°C. The core temperature of the samples was measured by inserting a food probe thermometer (TP101®, CixiSinco, China) during cooking. After that, cooked samples were cooled until the samples attained room temperature. The cooking loss was calculated based on the difference between sample weight before and after cooking by the following formula:

$$\text{Cooking Loss (\%)} = \frac{W1(g) - W2(g)}{W1(g)} \times 100$$

W1 = Weight before cooking; W2 = weight after cooking

Instrumental shear force

From each cooked sirloin sample, five strips of approximately 1 × 1 cm were cut alongside the muscle fibers' orientation. For determination of shear force value, strips were placed perpendicularly under the V-Slot® blade of the Warner Bratzler Texture analyzer (TA. X.T. plus®, U.K.). The force required to cut the muscle fibers was in Newton/cm^2.

Statistical analysis

Results were analyzed using the program SPSS Statistics 21.0 (SPSS Inc., Chicago, IL, USA). Data were subjected to multivariate analysis of variance (ANOVA) using the general linear model (GLM) procedure to determine treatment effects. The treatments were analyzed as fixed factors while the carcasses were considered as a random factor to examine the effect of animal age, sex, and post-mortem chilling rate on Warner–Bratzler shear force (WBSF), cooking loss, and color parameters (L*, a*, b*, C* and h) of goats. The significant means were further analyzed to determine the actual differences between means. Duncan's Multiple Range Test was used to determine significant differences among mean values at a level of $P < 0.05$. The results were expressed as means ± standard deviation (SD).

The following mathematical model was used:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijk}$$

where,

Y_{ijk} = observation of dependent variable recorded on ith, jth, and kth treatments;
μ = overall population mean;
α_i = fixed effect of animal age (i = 1, 2);
β_j = fixed effect of sex (j = 1, 2);
γ_k = fixed effect of postmortem chilling rate (k = 1, 2, 3, 4, 5, 6);
$(\alpha\beta\gamma\ D)_{ijk}$ = interactions effects of animal age, sex, and chilling rate; and
ε_{ijk} = residual effect.

Results

The decline in temperature and pH

There was a significant difference in temperature and pH decline profile between treatments (Table 1). An abrupt temperature decline rate and slow pH drop were observed in rapidly chilled carcasses compared to delayed chilled carcasses ($P < 0.05$). The outcome of RC was more pronounced in younger (MT) animals of both sexes. After 2 h of RC, carcasses of MT animals attained a temperature of 10.37°C and pH of 6.32 compared to 11°C and 6.35, for TT animals (Table 1). Comparatively, delayed chilled carcasses exhibited a slower temperature decline and a more rapid pH decline rate than rapidly chilled carcasses. Post-slaughter time in delayed chilled carcasses, the slower fall in temperature of 18.75°C and 20.67°C was recorded, while pH depicted the values of 6.23 and 6.25 in both milk and TT animals, respectively (Table 1).

Furthermore, during RC, young female carcasses (MT) cooled more quickly compared to males, which can be observed 2 h post-slaughter, where females achieved a temperature of 9.99°C and pH of 6.39 in contrast to the males, which were 10.37°C and 6.32°C. However, after 24 h, there was no difference in pH and temperature of both sexes.

Colorimeter analysis

Animal sex had no significant effect on colorimetric parameters (Table 2). The L* values were affected by age, as shown in Table 2. L* values were significantly ($P < 0.05$) higher in MT than in TT animals. However, chilling (delayed and rapid) depicted a nonsignificant effect on lightness, redness, yellowness, and hue angle, while Chroma values were significantly ($P < 0.05$) higher in delayed chilled carcasses than in rapidly chilled carcasses (Table 3). Furthermore, in comparison, the interaction between chilling and age depicted a significant difference ($P < 0.05$) in L*, MT carcasses had greater L* values compared to TT (Table 2). Likewise, the interaction between the chilling regime and sex showed a significant

Table 1. Rate of temperature and pH decline during postmortem delayed chilling (DC) and rapid chilling (RC) of MT and TT animals of male and female goats.

			Post-mortem time (hours)						
Parameters	**Animals**	**Chilling rate**	**0**	**1**	**2**	**4**	**7**	**24**	**SD**
Temperature	MMT	DC	31.91^{Aabc}	22.93^{Ba}	18.75^{Ca}	15.54^{Dab}	5.97^{Ebc}	3.50^{F}	2.56
		RC	30.93^{Ac}	16.00^{Bb}	10.37^{Cb}	6.43^{Dc}	4.54^{Dec}	3.33^{E}	2.84
	MTT	DC	30.96^{Ac}	24.47^{Ba}	20.67^{Ca}	13.38^{Db}	6.93^{Eab}	3.61^{F}	2.04
		RC	31.23^{Abc}	16.78^{Bb}	11.00^{Cb}	7.10^{Dc}	4.50^{Ec}	3.39^{E}	2.12
	FMT	DC	32.90^{Aabc}	25.47^{Ba}	20.69^{Ca}	15.84^{Da}	7.54^{Eab}	3.59^{F}	2.17
		RC	32.42^{Aabc}	15.81^{Bb}	9.99^{Cb}	6.31^{Dc}	4.61^{Dec}	3.38^{E}	2.13
	FTT	DC	33.37^{Aab}	26.46^{Ba}	20.41^{Ca}	14.67^{Dab}	7.88^{Ea}	3.66^{F}	2.59
		RC	33.72^{Aa}	16.91^{Bb}	9.85^{Cb}	7.31^{Dc}	4.65^{Ec}	3.43^{E}	1.97
pH	MMT	DC	6.54^{A}	6.34^{Bab}	6.23^{Cbc}	6.13^{Cbc}	6.02^{Db}	5.85^{Eb}	0.11
		RC	6.60^{A}	6.40^{Bab}	6.32^{Bb}	6.22^{Cab}	6.11^{Da}	6.04^{Da}	0.11
	MTT	DC	6.53^{A}	6.38^{Bab}	6.25^{Bbc}	6.05^{Ccd}	6.00^{Cb}	5.87^{Db}	0.15
		RC	6.65^{A}	6.46^{Bab}	6.35^{Cab}	6.24^{Ca}	6.13^{Da}	6.03^{Da}	0.13
	FMT	DC	6.52^{A}	6.38^{Bab}	6.22^{Cbc}	6.05^{Dcd}	5.94^{DEbc}	5.84^{Eb}	0.14
		RC	6.55^{A}	6.44^{Bab}	6.39^{Ba}	6.26^{Ca}	6.12^{Da}	6.05^{Da}	0.12
	FTT	DC	6.50^{A}	6.33^{Bb}	6.15^{Cc}	6.02^{Dd}	5.92^{Ec}	5.86^{Eb}	0.09
		RC	6.57^{A}	6.49^{Ba}	6.43^{Ba}	6.30^{Ea}	6.17^{Da}	6.06^{Ea}	0.08

Values are expressed as means ± SD (standard deviation). Different capital alphabets A–F (in rows) and small alphabets a–d (in columns) show significant difference at $P < 0.05$. MMT, male with MT; MTT, male with TT; FMT, female with MT; FTT, female with TT; MT, milk teeth; TT, two teeth; DC, delayed chilling; RC, rapid chilling.

Table 2. Effect of DC and RC on color parameters (L*, a*, b*, C*, and h) of MT and TT and male and female goats.

Chilling rate	MT	TT	SD	Male	Female	SD
			L*			
DC	39.09^{A}	37.83^{B}	2.52	38.84	38.08	2.57
RC	39.39^{A}	38.29^{B}	2.96	39.03	38.65	3.01
			a*			
DC	19.86^{a}	19.80	1.32	19.93^{a}	19.74	1.32
RC	19.27^{b}	19.70	1.51	19.21^{Bb}	19.86^{A}	1.48
			b*			
DC	7.99	7.96	1.27	7.97	7.98	1.27
RC	7.68	7.87	1.50	7.49^{B}	8.066^{A}	1.48
			C*			
DC	21.45^{a}	21.37	1.62	21.52^{a}	21.29	1.62
RC	20.78^{b}	21.16	1.89	20.59^{Bb}	21.35^{A}	1.86
			h			
DC	21.85	21.61	2.31	21.68	21.78	2.31
RC	21.47	21.51	2.81	21.01^{B}	21.98^{A}	2.76

Values are expressed as means ± SD (standard deviation). Different capital alphabets A–B (in rows) and small alphabets a–b (in columns) show significant differences at $P < 0.05$. DC, delayed chilling; RC, rapid chilling; MT, milk teeth; TT, two teeth.

difference ($P < 0.05$) in redness, which was comparatively higher in female carcasses than in male carcasses. C* also showed a significant difference ($P < 0.05$) within the treatment and between both sexes (Table 2).

Cooking loss (%)

The cooking loss was significantly ($P < 0.05$) affected by sex (Table 3). Cooking loss values were higher in males compared to female animals. However, animal age did not have a significant effect on cooking loss. Furthermore, the effect of chilling regime also showed a non-significant result.

Instrumental shear force

WBSF values were affected by the chilling regime, and carcasses from males cooled faster and showed significantly higher shear force values than from females. In the case of age, RC showed its adverse effect on shear force values, which were significantly ($P < 0.05$) higher in TT animals (Table 2). On average, in the case of production factor age, either MT or TT animals had a nonsignificant effect on WBSF which are represented as means ± S.D. (standard deviation) in the current study. Moreover, WBSF values were significantly ($P<0.05$) affected by chilling rate and were recorded higher in case of RC as compared to delayed chilled carcasses (Table 3). Furthermore, sex also revealed a non-significant effect on shear force values.

Discussion

Effect of age on meat quality

In ruminants, the evolution of meat quality attributes like color, cooking loss, and textural properties are affected by different production systems (Gonzales-Barron *et al.*, 2021b). In the meat sector, slaughtering age is an important criterion for carcass grading or classification (Belhaj *et al.*, 2021; Dlamini *et al.*, 2020). In the current scenario of the Pakistani meat industry, the overall carcass classification is based on age, sex, weight, and conformation. The effect of physiological age on goat meat quality is not well documented in the literature. Results of the present study showed that age did not have a significant impact on WBSF values. Similarly, Simela *et al.* (2008) reported no difference in consumer acceptability preference between meat obtained from MT and permanent teeth goats, and the consumer panel found no significant difference in tenderness between the goats of two different dentition groups. Although age has shown an effect

Table 3. Effect of animal age, sex, and postmortem chilling rate on WBSF, cooking loss, and color parameters (L*, a*, b*, C*, and h) of goats.

	Animal age			Sex			Chilling rate		
Parameters	MT	TT	SD	Male	Female	SD	DC	RC	SD
WBSF	55.03	55.65	1.71	55.88	54.80	1.69	50.59^{b}	60.09^{a}	1.02
Cooking loss	36.44	35.93	1.68	37.15^{a}	35.21^{b}	1.64	35.63	36.74	1.66
L*	39.25^{a}	38.06^{b}	0.79	38.94	38.37	0.79	38.46	38.84	0.81
a*	19.62	19.76	0.41	19.57	19.80	0.39	19.84	19.54	0.41
b*	7.84	7.92	0.39	7.73	8.02	0.39	7.98	7.78	0.39
C*	21.12	21.27	0.51	21.06	21.33	0.50	21.41^{a}	20.97^{b}	0.50
h	21.67	21.56	0.74	21.35	21.88	0.72	21.73	21.49	0.72

Values are expressed as means ± SD (standard deviation). Different small alphabets a–b (in rows) showing significant difference at $P < 0.05$. MT, milk teeth; TT, two teeth; DC, delayed chilling; RC, rapid chilling; WBSF, Warner Bratzler Shear Force.

on shear force value in other species, at present the difference between age groups (10 months and 16 months) can be considered too small. A possible explanation for this lack of WBSF difference between age groups leads to the hypothesis that cross-linking of collagen, which is one of the main contributors to toughness is not evident before 12 months of age (Payne *et al*., 2020). Lawrence *et al.* (2001) also reported that neither WBSF nor sensory panel tenderness values were different among the five dentition groups (zero, two, four, six, and eight permanent incisors) of beef cattle, and the number of permanent incisors did not affect the WBSF values. The same findings were reported in beef cattle by Schönfeldt and Strydom (2011), who concluded that meat toughness does not increase with the increase in slaughter weight of animals as the intramuscular collagen content remains the same among different age groups (0, 2, and 8 teeth) of animals. However, it is collagen solubility and heat-labile cross-links protein that ultimately determines the tenderness (Schönfeldt and Strydom, 2011) and these vary with the increase in age (Nishimura, 2015).

The colorimetric parameters were similar for both age groups; lightness (L*) decreased while redness (a*) increased with the progression of age. Meat color mainly depends on myoglobin content and its chemical state in muscle (El Otmani *et al*., 2021). As the age of the animal increases, the oxygenation ability of cells is reduced, and therefore, more myoglobin is required to retain oxygen in living cells (Cho *et al*., 2015; De Lima Júnior *et al*., 2016). Hence, myoglobin concentration increases with an increase in age, resulting in reddish meat (Ilavarasan *et al*., 2016). Meat color is one of the most important quality attributes consumers base purchasing decisions upon (Tomasevic *et al*., 2021). Nobre *et al.* (2020) reported a nonsignificant difference in the color parameter among 40 noncastrated male lambs of similar age (~120 days) reared under the same management in agreement with current results.

Effect of sex on meat quality

Results of the current study and prior studies on sheep have shown that sex does not affect shear force values (Klupsaite *et al*., 2022; Santos *et al*., 2015) and color parameters (Sabbioni *et al*., 2019) as both are highly dependent on the pH and temperature decline profiles of the carcass (Santos *et al*., 2007; Simela *et al*., 2004; Yarali *et al*., 2014). Sex results also disclosed insignificant effects on meat colorimetric values of animals; this lack of significant difference in meat color values such as L*, a*, and b* between sexes could be due to the same age of the animals (Njisane and Muchenje, 2013; Santos *et al*., 2015). The results of the present study showed a significant ($P < 0.05$) effect of sex on cooking loss (%) values. Meat from male carcasses lost more weight during cooking than meat from female carcasses, which was also seen in lambs (Klupsaite *et al*., 2022). This occurred mainly due to differences in pHu values which were lower in female lambs, and fatness level which was higher in females, although WBSF values were similarly unaffected by sex (Facciolongo *et al*., 2018). As intramuscular fat content increases, it generally leads to an increase in tenderness but this relationship is weak most of the time (Alvarez *et al*., 2022). The literature related to meat quality effects due to sex is inconsistent, as some authors reported that meat from male carcasses was tougher than female, whereas others claimed no significant difference between them (Gkarane *et al*., 2017). The optimum slaughtering time of small ruminants is sex-related, females are slaughtered earlier than males due to greater fat content, as consumer acceptance of lamb meat depends on the proportion of intramuscular fat (Sabbioni *et al*., 2019).

Effect of chilling regime on meat quality

In the present study, rapidly chilled carcasses revealed higher pHu and lower temperature values as compared to delayed chilled carcasses. Similar results were reported in beef cattle (Li *et al*., 2006, 2012; White *et al*., 2006). These investigations reported that fast chilling delayed the pH decline rate. A possible explanation for this higher pH value is that it might be due to the decreased activity of enzymes involved in glycolytic pathways at a lower temperature (Yan *et al*., 2022). The pHu value is used to evaluate the meat's quality, shelf life, and processing efficiency (Gonzales-Barron *et al*., 2021a). Overall data showed that rapidly chilled carcasses from younger animals of both sexes missed the ideal pH/temperature window, during RC of carcasses; the temperature falls below 15^{o}C while pH is still more than 6, and there are chances of cold shortening (Matarneh *et al*., 2017). The relationship between temperature and pH during the onset process of rigor mortis is critical in determining the degree of cold shortening (Hannula and Puolanne, 2004). When the temperature is too low and pH too high, the sarcoplasmic reticulum cannot function properly and becomes unable to bind calcium leaving an abundant amount of calcium in the sarcoplasm (Van Moeseke *et al*., 2001). Within the myocyte, this calcium, along with the available energy source like Adenosine triphosphate (ATPs), contracts the actin and myosin at their maximum level and eliminates the I-band of the sarcomere. This severe overlapping of myofibrillar proteins causes toughening of meat. The findings of Pophiwa *et al.* (2017) revealed the same result, that DC effectively slows down the carcass temperature decline rate and minimizes the chances of cold shortening from occurring in goat carcasses. Regarding colorimetric parameters, no significant differences were observed in L*, a*, and b* values between rapid and delayed chilled

carcasses, which was similar to the findings of Janz *et al.* (2001) using bison meat. These findings were also supported by Devine *et al.* (2002), who explored the effects of low and high rigor temperatures on sheep meat quality and found that only L* values were greater at high rigor temperature, while a* and b* remained unaffected. This occurred because at higher postmortem temperatures, pHu is greater and is attained more rapidly, and the structure of muscle protein and enzyme modifies, resulting in greater light reflection and less oxygen consumption rate by enzymes. Conversely, another study found pHu only affected L* and a* in lamb, and carcasses having lower pH values displayed a light but brighter red color (Gonzales-Barron *et al.*, 2021b). Similarly, the effect of chilling rate on cooking loss was also not significant within both slaughtering ages (MT and TT). Similar results were reported by Fernandez *et al.* (1994). The outcomes of the current study declared that the chilling regime significantly affects the meat's tenderness. These findings are in line with Liu *et al.* (2015), and according to their conclusions, toughening of meat might be due to the RC of carcasses. In the present study, WBSF values were lower in meat from delayed chilled carcasses because of high temperature and low pH which accelerated the proteolytic activity of the enzymes and hence improved tenderness compared to the rapidly chilled carcasses (Pflanzer *et al.*, 2019).

Conclusion

Overall, goat age did not show a significant effect on shear force values, which denied the misconception that meat from MT animals is more tender or superior compared to meat from TT animals. Similarly, sex also played a non-significant effect on WBSF and colorimetric values except for the cooking loss, which was greater in males as compared to females. It is also noteworthy that chilling had a significant effect on meat quality. RC can lead to cold shortening of meat, making the end product tougher while DC reduces the chances of cold shortening and leads to more tender meat.

References

Abdullah, F.A.A., Borilova, G. and Steinhauserova, I., 2019. Halal criteria versus conventional slaughter technology. Animals 9: 8. https://doi.org/10.3390/ani9080530

Aldridge, M.E., Fearon, J.E., Haynes, B.P., Miller, H.M., Sanford, K.Y., Scott, R.R., Anglin, W.W., Blalock, L.S., Burkes, B.L., Cohn-White, O.L. and Franks, B.R., 2018. Solutions for grand challenges in goat and sheep production. Biotropia 26: 55–64. https://doi.org/10.11598/btb.2019.26.1.944

Alvarez, C., Koolman, L., Whelan, M. and Moloney, A., 2022. Effect of pre-slaughter practices and early post-mortem interventions on sheep meat tenderness and its impact on microbial status. Foods 11: 181. https://doi.org/10.3390/foods11020181

Belhaj, K., Mansouri, F., Tikent, A., Taaifi, Y., Boukharta, M., Serghini, H.C. and Elamrani, A., 2021. Effect of age and breed on carcass and meat quality characteristics of Beni-Guil and Ouled-Djellal sheep breeds. The Scientific World Journal 1–8. https://doi.org/10.1155/2021/5536793

Bellés, M., Alonso, V., Roncales, P. and Beltran, J.A., 2017. A review of fresh lamb chilling and preservation. Small Ruminant Research - 146: 41–47. https://doi.org/10.1016/j.smallrumres.2016.12.003

Birhanu, A.F. 2019. A review on Ethiopian meat production trends, consumption and meat quality parameters. International Journal of Food Science and Agriculture 9: 267–274. https://doi.org/10.26855/ijfsa.2019.10.002

Casey, N.H. and Webb, E.C., 2010. Managing goat production for meat quality. Small Ruminant Research 89: 2–3. https://doi.org/10.1016/j.smallrumres.2009.12.047

Cho, S., Kang, G., Seong, P.N., Park, B. and 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

Clinquart, A., Ellies-Oury, M.P., Hocquette, J.F., Guillier, L., Santé-Lhoutellier, V. and Prache, S., 2022. On-farm and processing factors affecting bovine carcass and meat quality. Animal 100426. https://doi.org/10.1016/j.animal.2021.100426

Colonna, M.A., Rotondi, P., Selvaggi, M., Caputi Jambrenghi, A., Ragni, M. and Tarricone, S., 2020. Sustainable rearing for kid meat production in Southern Italy marginal areas: a comparison among three genotypes. Sustainability 12: 17. https://doi.org/10.3390/su12176922

Corazzin, M., Del Bianco, S., Bovolenta, S. and Piasentier, E., 2019. Carcass characteristics and meat quality of sheep and goat. In Lorenzo, J.M, Munekata, P.E.S (Ed.): More than beef, pork and chicken–the production, processing, and quality traits of other sources of meat for human diet, Springer, Fidel Toldra, pp. 119–165.

De Lima Júnior, D.M., De Carvalho, F.F., Da Silva, F., Rangel, A.H.D.N., Novaes, L.P. and Difante, G.D.S., 2016. Intrinsic factors affecting sheep meat quality: a review. Revista Colombiana de Ciencias Pecuarias 29: 3–15. https://doi.org/10.17533/udea.rccp.v29n1a01

Devine, C.E., Payne, S.R., Peachey, B.M., Lowe, T.E., Ingram, J.R. and 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

Dlamini, B.N., Masarirambi, M.T. and Gadaga, T.H., 2020. A comparative review of the beef carcass classification systems of selected African countries with the red meat classification system found in the European Union. Asian Journal of Advances in Agricultural Research 12: 28–35. https://doi.org/10.9734/ajaar/2020/v12i430090

El Otmani, S., Chebli, Y., Hornick, J.L., Cabaraux, J.F. and Chentouf, M., 2021. Growth performance, carcass characteristics and meat quality of male goat kids supplemented by alternative feed resources: olive cake and cactus cladodes. Animal Feed

Science and Technology 272: 114746. https://doi.org/10.1016/j.anifeedsci.2020.114746

Ellies-Oury, M.P., Lee, A., Jacob, H. and Hocquette, J.F., 2019. Meat consumption–what French consumers feel about the quality of beef? Italian Journal of Animal Science 18: 646–656. https://doi.org/10.1080/1828051X.2018.1551072

Facciolongo, A.M., Lestingi, A., Colonna, M.A., Nicastro, F., De Marzo, D. and Toteda, F., 2018. Effect of diet lipid source (linseed vs. soybean) and gender on performance, meat quality and intramuscular fatty acid composition in fattening lambs. Small Ruminant Research 159: 11–17. https://doi.org/10.1016/j.smallrumres.2017.11.015

Fernandez, X., Forslid, A. and Tornberg, E., 1994. The effect of high postmortem temperature on the development of pale, soft and exudative pork: interaction with ultimate pH. Meat Science 37: 133–147. https://doi.org/10.1016/0309-1740(94)90150-3

Garmyn, A., 2020. Consumer preferences and acceptance of meat products. Foods 9: 708. https://doi.org/10.3390/foods9060708

Gkarane, V., Allen, P., Gravador, R.S., Diskin, M.G., Claffey, N.A., Fahey, A.G., Brunton, N.P., Farmer, L.J., Moloney, A.P. and Monahan, F.J., 2017. Effect of castration and age at slaughter on sensory perception of lamb meat. Small ruminant research 157: 65–74. https://doi.org/10.1016/j.smallrumres.2017.10.011

Gonzales-Barron, U., Popova, T., Piedra, R.B., Tolsdorf, A., Geß, A., Pires, J., Domínguez, R., Chiesa, F., Brugiapaglia, A., Viola, I. and Battaglini, L.M., 2021a. Fatty acid composition of lamb meat from Italian and German local breeds. Small Ruminant Research 200: 106384. https://doi.org/10.1016/j.smallrumres.2021.106354

Gonzales-Barron, U., Santos-Rodrigues, G., Piedra, R.B., Coelho-Fernandes, S., Osoro, K., Celaya, R., Maurício, R.S., Pires, J., Tolsdorf, A., Geß, A. and Chiesa, F., 2021b. Quality attributes of lamb meat from European breeds: effects of intrinsic properties and storage. Small Ruminant Research 198: 106354.

Gul, S.T. and Alsayeqh, A.F., 2022. Probiotics as an alternative approach to antibiotics for safe poultry meat production. Pakistan Veterinary Journal 42(3): 285–291. http://dx.doi.org/10.29261/pakvetj/2022.061

Hannula, T. and Puolanne, E., 2004. The effect of cooling rate on beef tenderness: the significance of pH at 7 C. Meat Science 67: 403–408. https://doi.org/10.1016/j.meatsci.2003.11.012

Henchion, M.M., McCarthy, M. and Resconi, V.C., 2017. Beef quality attributes: a systematic review of consumer perspectives. Meat Science 128: 1–7. https://doi.org/10.1016/j.meatsci.2017.01.006

Hossain, M.A., Rahman, M.M., Rahman, M.W., Hossain, M.M. and Hashem, M.A., 2021. Optimization of slaughter age of Jamuna basin lamb based on carcass traits and meat quality. SAARC Journal of Agriculture 19: 2. https://doi.org/10.3329/sja.v19i2.57686

Hwang, Y.H., Bakhsh, A., Lee, J.G. and Joo, S.T., 2019. Differences in muscle fiber characteristics and meat quality by muscle type and age of Korean native black goat. Food science of animal resources 39: 6. https://doi.org/10.5851/kosfa.2019.e92

Ijaz, M., Jaspal, M.H., Hayat, Z., Yar, M.K., Badar, I.H., Ullah, S., Hussain, Z., Ali, S., Farid, M.U., Farooq, M.Z. and Sardar, A., 2020. Effect of animal age, postmortem chilling rate, and aging time on meat quality attributes of water buffalo and humped cattle bulls. Animal Science Journal 91: e13354. https://doi.org/10.1111/asj.13354

Ilavarasan, R., Abraham, R.J., Rao, V.A., Ruban, S.W. and Ramani, R., 2016. Effect of age on meat quality characteristics and nutritional composition of Toda Buffalo. Buffalo Bulletin 35: 215–224.

Janz, J., Aalhus, J. and Price, M., 2001. Blast chilling and low voltage electrical stimulation influences on bison (Bison bison bison) meat quality. Meat Science 57: 403–411. https://doi.org/10.1016/S0309-1740(00)00118-2

Klupsaite, D., Buckiuniene, V., Bliznikas, S., Sidlauskiene, S., Dauksiene, A., Klementaviciute, J., Jurkevicius, A., Zaborskiene, G. and Bartkiene, E., 2022. Impact of Romanov breed lamb gender on carcass traits and meat quality parameters including biogenic amines and malondialdehyde changes during storage. Food Science & Nutrition 10: 1745–1755. https://doi.org/10.1002/fsn3.2793

Kosum, N., Taşkin, T., Engindeniz, S. and Kandemir, Ç., 2019. Goat meat production and evaluation of its sustainability in Turkey. Ege Üniversitesi Ziraat Fakültesi Dergisi 56: 395–407. https://doi.org/10.20289/zfdergi.520488

Kumar, P., Abubakar, A.A., Ahmed, M.A., Hayat, M.N., Kaka, U., Pateiro, M., Sazili, A.Q., Hoffman, L.C. and Lorenzo, J.M., 2022. Pre-slaughter stress mitigation in goats: prospects and challenges. Meat Science 109010. https://doi.org/10.1016/j.meatsci.2022.109010

Lawrence, T., Whatley, J., Montgomery, T., Perino, L. and 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, C.B., Chen, Y.J., Xu, X.L., Huang, M., Hu, T.J. and Zhou, G.H., 2006. Effects of low-voltage electrical stimulation and rapid chilling on meat quality characteristics of Chinese Yellow cross-bred bulls. Meat Science 72: 9–17. https://doi.org/10.1016/j.meatsci.2005.04.035

Li, K.E., Zhang, Y., Mao, Y., Cornforth, D., Dong, P., Wang, R., Zhu, H. and Luo, X., 2012. Effect of very fast chilling and aging time on ultra-structure and meat quality characteristics of Chinese Yellow cattle M. Longissimus lumborum. Meat Science 92: 4. https://doi.org/10.1016/j.meatsci.2012.07.003

Liu, Y., Mao, Y., Zhang, Y., Liang, R., Wang, R., Zhu, L., Meng, X. and 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

Matarneh, S.K., England, E.M., Scheffler, T.L. and Gerrard, D.E., 2017. Lawrie's meat science. In Woodhead Publishing Series in Food Science Technology and Nutrition (pp. 159–185).

Nastasijević, I., Lakicevic, B. and Petrovic, Z., 2017. Cold chain management in meat storage, distribution and retail: a review. Earth and Environmental Science 85: 1. https://doi.org/10.1088/1755-1315/85/1/012022

Nian, Y., Allen, P., Harrison, S.M. and Kerry, J.P., 2018. Effect of castration and carcass suspension method on the quality and fatty acid profile of beef from male dairy cattle. Journal of the Science of Food and Agriculture 98: 11. https://doi.org/10.1002/jsfa.8960

Nishimura, T., 2015. Role of extracellular matrix in development of skeletal muscle and postmortem aging of meat. Meat Science 109: 48–55. https://doi.org/10.1016/j.meatsci.2015.05.015

Njisane, Y.Z. and Muchenje, V., 2013. Influence of municipal abattoir conditions and animal-related factors on avoidance-related behaviour, bleeding times at slaughter and the quality of lamb meat. Asian-Australasian Journal of Animal Sciences 26: 1496. https://doi.org/10.5713/ajas.2013.13137

Nobre, P.T., Munekata, P.E., Costa, R.G., Carvalho, F.R., Ribeiro, N.L., Queiroga, R.C., Sousa, S., da Silva, A.C.R. and Lorenzo, J.M., 2020. The impact of dietary supplementation with guava (Psidium guajava L.) agro industrial waste on growth performance and meat quality of lambs. Meat Science 164: 108105. https://doi.org/10.1016/j.meatsci.2020.108105

Payne, C.E., Pannier, L., Anderson, F., Pethick, D.W. and Gardner, G.E., 2020. Lamb age has little impact on eating quality Foods 9: 2. https://doi.org/10.3390/foods9020187

Pflanzer, S.B., Gomes, C.L. and Felício, P.E.D., 2019. Delayed carcass chilling improves tenderness of the beef gluteus medius muscle. Pesquisa Agropecuária Brasileira 3(54): 00099. https://doi.org/10.1590/s1678-3921.pab2019.v54.00099

Ponnampalam, E.N., Hopkins, D.L., Bruce, H., Li, D., Baldi, G. and Bekhit, A.E.D., 2017. Causes and contributing factors to "dark cutting" meat: current trends and future directions: a review. Comprehensive Reviews in Food Science and Food Safety 16: 400–430. https://doi.org/10.1111/1541-4337.12258

Pophiwa, P., Webb, E.C. and Frylinck, L., 2016. Meat quality characteristics of two South African goat breeds after applying electrical stimulation or delayed chilling of carcasses. Small ruminant research 145: 107–114. https://doi.org/10.1016/j.smallrumres.2016.10.026

Pophiwa, P., Webb, E.C. and Frylinck, L., 2017. Carcass and meat quality of Boer and indigenous goats of South Africa under delayed chilling conditions. South African Journal of Animal Science 47: 794–803. https://doi.org/10.4314/sajas.v47i6.7

Pophiwa, P., Webb, E.C. and Frylinck, L., 2020. A review of factors affecting goat meat quality and mitigating strategies. Small ruminant research 183: 106035. https://doi.org/10.1016/j.smallrumres.2019.106035

Purwin, C., Wyżlic, I., Nogalski, Z., Sobczuk-Szul, M., Pogorzelska-Przybyłek, P., Lipiński, K., Wierzbowska, J., Starczewski, M. and Michalski, J.P., 2016. The effect of grass silage quality and supplementary concentrate levels on feed intake and fattening performance of crossbred steers. Journal of Elementology 21: 4. https://doi.org/10.5601/jelem.2015.20.4.1061

Rafique. A., Nasir, S., Ashraf, A., Nawaz, Z., Zahid, F.M., Abbas, A. and Masood, S., 2022. Serosurveillance and risk factors analysis of caprine toxoplasmosis in Faisalabad Punjab, Pakistan. Pakistan Veterinary Journal. 42(1): 102–106. http://dx.doi.org/10.29261/pakvetj/2021.020

Sabbioni, A., Beretti, V., Zambini, E.M., Superchi, P. and Ablondi, M., 2019. Allometric coefficients for physical-chemical parameters of meat in a local sheep breed. Small ruminant research 174: 141–147. https://doi.org/10.1016/j.smallrumres.2019.04.001

Santos, V., Silva, S., Mena, E. and Azevedo, J.M.T.D., 2007. Live weight and sex effects on carcass and meat quality of "Borrego terrincho–PDO" suckling lambs. Meat Science 77: 654–661. https://doi.org/10.1016/j.meatsci.2007.05.019

Santos, V.A.C., Cabo, A., Raposo, P., Silva, J.A., Azevedo, J.M.T. and Silva, S.R., 2015. The effect of carcass weight and sex on carcass composition and meat quality of "Cordeiro Mirandês"—protected designation of origin lambs. Small ruminant research 130: 136–140. https://doi.org/10.1016/j.smallrumres.2015.07.008

Schönfeldt, H. and Strydom, P.E., 2011. Effect of age and cut on tenderness of south african beef. Meat Science 87: 206–218. https://doi.org/10.1016/j.meatsci.2010.10.011

Sgarro, M.F., Maggiolino, A., Pateiro, M., Domínguez, R., Iannaccone, F., De Palo, P. and Lorenzo, J.M., 2022. Effects of anthocyanin supplementation and ageing time on the volatile organic compounds and sensory attributes of meat from goat kids. Animals 12: 2. https://doi.org/10.3390/ani12020139

Simela, L., Webb, E.C. and Bosman, M.J.C., 2008. Acceptability of chevon from kids, yearling goats and mature does of indigenous South African goats: a case study. South African journal of animal science 38: 247–259.

Simela, L., Webb, E. and Frylinck, L., 2004. Effect of sex, age, and pre-slaughter conditioning on pH, temperature, tenderness and colour of indigenous South African goats. South African journal of animal science 34: 1–8.

Teixeira, A., Silva, S., Guedes, C. and Rodrigues, S., 2020. Sheep and goat meat processed products quality: a review. Foods 9: 960. https://doi.org/10.3390/foods9070960

Terlouw, C., 2015. Stress reactivity, stress at slaughter and meat quality. CRC Press, Philadelphia, PA.

Tomasevic, I., Djekic, I., Font-i-Furnols, M., Terjung, N. and Lorenzo, J.M., 2021. Recent advances in meat color research. Current Opinion in Food Science 41: 81–87. https://doi.org/10.1016/j.cofs.2021.02.012

Van Moeseke, W., De Smet, S., Claeys, E. and 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

White, A., O'Sullivan, A., O'Neill, E.E. and Troy, D.J., 2006. Manipulation of the pre-rigor phase to investigate the significance of proteolysis and sarcomere length in determining the tenderness of bovine M. longissimus dorsi. Meat Science 73: 2. https://doi.org/10.1016/j.meatsci.2005.11.022

Wyrwisz, J., Moczkowska, M., Kurek, M., Stelmasiak, A., Półtorak, A. and 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

Yan, T., Hou, C., Wang, Z., Li, X., Chen, L., Liang, C., Xu, Y. and Zhang, D., 2022. Effects of chilling rate on progression of rigor mortis in postmortem lamb meat. Food Chemistry 373: 131463. https://doi.org/10.1016/j.foodchem.2021.131463

Yarali, E., Yilmaz, O., Cemal, I., Karaca, O. and Taşkin, T., 2014. Meat quality characteristics in Kıvırcık lambs. Turkish Journal of Veterinary & Animal Sciences 38: 452–458. https://doi.org/10.3906/vet-1309-79

Zainalabidin, F.A., Hassan, F.M., Zin, N.S.M., Azmi, W.N.W. and Ismail, M.I., 2019. Halal system in meat industries. Malaysian Journal of Halal Research 2: 1. https://doi.org/10.2478/mjhr-2019-0001