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Research article

Effects of preslaughter handling approach and aging on carcass and meat quality attributes in goats

Gamaleldin M. Suliman [a,*], Abdullah N. Al-Owaimer [a], Mohsen M. Alobre [a], Ayman A. Swelum [a], Maged A. Algaradi [a], Hani Ba-Awadh [a], Awis-Qurni Sazili [b], Pavan Kumar [c], Ubedullah Kaka [b,d]

[a] Department of Animal Production, College of Food and Agriculture Sciences, King Saud University, 11451 Riyadh, P.O Box 2460, Saudi Arabia
[b] Halal Products Research Institute, Putra Infoport, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[c] Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[d] Department of Companion Animal and Surgery, Faculty of Veterinary Medicine, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

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ABSTRACT

This study aimed to assess the impact of preslaughter handling method and aging on carcass and meat quality traits in goats. Twenty-seven male goats of Ardi breed were assigned into three treatment groups viz., the control (C), ear pulling (EP), and hind-leg pulling (HP). The carcasses were stored for post-mortem aging periods of 1, 7, and 14 days. On day 0 and the respective aging days, samples of the *Longissimus thoracic et lumborum* (LTL) muscles were collected and examined for various meat quality parameters. The preslaughter handling of goats significantly increase the total bacterial count, total Enterobacteriaceae count, and total Clostridium count. It also had a significant effect on the pH of LTL muscle during aging. A significantly lower values for pH were recorded in the treatment groups (EP and HP) as compared to the pH of the C group on day 1 of aging. Notably, both treatment groups were found to increase the shear force, hardness, and chewiness of the meat, ultimately compromising its quality. The proper treatment of meat animals, especially goats, is crucial for enhancing carcass and meat quality. Careful preslaughter handling practices by avoiding ear and hind-leg pulling can minimize negative impacts on the final product. Therefore, the significance of conducting this study lies in its potential to enhance animal welfare, improve meat quality, boost economic benefits for producers, and foster consumer confidence in meat products.

1. Introduction

Goats are excellent small ruminants with the potential to produce red meat in a more sustainable manner. These resilient and prolific animals adapt well to various environments, thriving and reproducing even in harsh conditions with limited resources [1]. They exhibit a strong tolerance to diseases, heat, and various stressors, allowing for meat production with little or no reliance on antibiotics or feed additives. This unique characteristic makes goat meat appealing to a growing number of consumers who seek organic options free from antibiotics and chemicals. The goat carcasses are small and lean, containing less glycogen—the stored form

* Corresponding author.
E-mail address: gsuliman@ksu.edu.sa (G.M. Suliman).

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of glucose made up of linked glucose molecules, which serves as the body's primary energy source. This low glycogen content makes them particularly susceptible to various post-mortem meat quality changes associated with pH fluctuations [2].

During meat production, goats are handled during slaughter, which directly impacts their welfare by causing stress, pain, and fear. This preslaughter handling triggers biochemical, physiological, and behavioral changes due to the activation of the sympathoadrenal (SPA) and hypothalamic-pituitary-adrenal (HPA) systems. The SPA system helps restore balance by regulating adrenal gland activity, while the HPA axis primarily releases cortisol to facilitate the body's short-term stress response. These responses increase energy production to cope with challenging conditions [3]. As a result, there is a reduction in muscle glycogen stores, leading to elevated temperatures and a decrease in pH. These changes adversely affect various meat quality attributes, including drip loss (the leakage of myofibers along with water, iron, and proteins), pH levels, color, and sensory characteristics, which influence the visual appearance, texture, and flavor perception of the meat [4].

Preslaughter handling is a critical factor to consider when evaluating meat quality from a consumer perspective. Goats that are subjected to excessive stress during pre-slaughter handling are more likely to have lower carcass weights, higher incidences of carcass defects (such as bruising and hemorrhages), and lower meat quality, characterized by toughness and darker color [5,6]. Furthermore, meat aging is a process involves the action of microbes and enzymes that break down connective tissue, resulting in more tender meat with a deeper flavor. However, stress can inhibit the activity of these enzymes causing desirable changes in meat quality parameters during aging, thereby slowing down the aging process [7].

Consumers and the general public are now very much concerned about the treatment/ handling of animals during the production of meat, with consumers showing increasing preference and acceptance of meat produced by following animal welfare practices [8]. The improper handling of animals is still prevalent and has been reported in several countries by following practices that are prohibited by World Organization for Animal Health (WOAH) [9–14]. Proper preslaughter handling of animals during the transition from lairage to the slaughter point is essential for ensuring both animal welfare and meat quality. It is crucial to investigate how this handling affects meat quality, as increased awareness and education can help promote better practices among individuals in the meat industry, thereby enhancing animal welfare standards.

Ear and hind-leg pulling of animals before slaughter is a prevalent practice in many slaughterhouses. We hypothesize that these handling methods may induce higher stress levels compared to conventional techniques, potentially compromising meat quality. Thus, the aim of this study was to evaluate the effects of ear and hind-leg pulling, along with aging, on carcass characteristics and meat quality traits in goats.

2. Materials and methods

2.1. Animals and experimental Design

This study was conducted at the Research Station of the Department of Animal Production (24°48′22.1″N 46°31′13.4″E), College of Food and Agricultural Sciences, King Saud University, Saudi Arabia. Twenty-seven (27) intact males of the Ardi goat (age 10 months, average weight of 27 kg) were used for the study. The sample size was determined using G*Power Statistical Software (Release 3.1.9.7, 2020) based on the type of test (ANOVA), power value (0.80), effect size (0.5), and level of significance (alfa), which is 0.05 in our case. The experimental animals were randomly assigned into three groups, each consisting of nine goats, viz., the control group (C); the goats moved from lairage to slaughter point gently, ear-pulling (EP) group; the goats moved from lairage to slaughter point by ear pulling and the last group hind-leg pulling (HP), the goats moved from lairage to slaughter point by hind-leg pulling. To ensure consistency throughout the experiment and to maintain proper control conditions, the research team, which includes both workers and researchers, underwent a comprehensive training period focused on handling experimental animals. Once the experiment commenced, specific personnel was assigned to each treatment group to guarantee uniform handling practices. For additional tasks—such as blood collection, physiological assessments, and evaluations of carcasses and organs— team members were assigned based on their relevant experience and training. The animals had a two-week adaptation period during which they were fed a commercial total mixed ration ad libitum and had free access to clean, fresh tap water and regular veterinary services.

At the start of the experiment, animals in the control group were gently restrained with minimal human contact to ensure adherence to animal welfare principles. The Ear Pulling (EP) goats were moved through the slaughterhouse by staff pulling their ears, while the Hind-Leg Pulling (HP) goats were transported by pulling their hind legs. All groups were moved the same distance and experienced identical floor conditions. After slaughtering [15], the carcasses were dressed manually and aged under chilling conditions at 4±1 °C. The *Longissimus thoracis et lumborum* (LTL) muscle was then removed from both sides of each carcass at four time points: within 1 h of slaughter (0 days), and on days 1, 7, and 14, for meat quality assessment.

2.2. Carcass quality attributes

2.2.1. Slaughter weight, hot carcass weight, and dressing percentage

The quality of the carcasses of slaughtered goats was assessed by measuring slaughter weight, hot carcass weight, and dressing percentage. Hot carcass weight is the weight of the dressed carcass immediately after dressing prior to chilling. The dressing percent was calculated by measuring carcass weight and live weight by using the following formula:

$$\textbf{\textit{Dressing percentage}} = (\textbf{\textit{hot carcass weight}} \,/\, \textbf{\textit{live weight}})\, \textbf{\textit{x}}\, \mathbf{100}$$

2.2.2. Microbial load

The 27 carcasses of Ardi goats of the study were sampled in a slaughterhouse Northern Riyadh, Saudi Arabia (24.7411, 46.5055). Four samples from flank, lateral thorax, breast and brisket were taken from each carcass using viscose sponges-swabbing method. Th samples were collected at the end of the slaughter process by a microbiologist in the research team before sending the carcasses for chilling. The samples were examined for total bacterial count (TBC), in order to calculate the total count of aerobic bacteria, total Enterobacteriaceae count (TEC), and total Clostridium spp. count (TCC). The sampling and microbiological examinations were performed on each group of microorganisms in accordance with The Meat Standard Committee (AS 4696-2002) and Standard Plate Count methods [16–19].

2.3. Meat quality evaluation

2.3.1. pH

Immediately following slaughter and evisceration (approx. 1 h after slaughter), the initial pH (pH0) of the meat was recorded in the LTL muscle between the 12th and 13th ribs. Furthermore, the subsequent pH was also recorded after 1, 7, and 14 days of aging. The measurements of pH were performed using a portable pH meter (Model pH 211, Hanna Instruments, Woonsocket, Rhode Island, USA). The pH meter is regularly calibrated to adjust electrode using 4.01 and 7.01 buffer solutions. Three readings were taken for each sample, and the average values for each parameter were calculated.

2.3.2. Color profile

The color profile of the LTL muscle, including CIE L* (lightness), a* (redness), and b* (yellowness), was measured using a color meter (Konica Minolta CR-400, Japan; Measuring aperture: 8 mm; Illuminant: CIE D65; Observer angle: CIE 2° Standard Observer). The measurements were taken after the samples had oxygenated in air for at least 30 min blooming. Three readings were taken on the muscle surface for each color coordinate, then a mean value was performed. The device was calibrated against white plate (Y = 93.5, x = 0.3158, y = 0.3323) provided by the manufacturer before use. The hue (H°) and chroma (Cab°) values were calculated using the following formulas as reported by Mancini and Hunt [20] and Little [21]:

$$\textbf{\textit{Hue}}\ (\boldsymbol{H^{o}}) = \tan^{-1}(b\,/\,a)$$

$$\text{Chroma}\ (C^{*}) = (a^{*2} + b^{*2})^{1/2}$$

2.3.3. Drip loss (DL)

Water holding capacity (WHC) was assessed through drip loss (DL) using the method outlined by Honikel [22]. This gravimetric technique involves suspending a meat sample in a container to allow gravity to facilitate drip. Specifically, a 100 g meat sample was cut from the carcass along the muscle fiber direction. The sample was then placed in a glass container on a supporting mesh, ensuring no direct contact with the glass sides, and the container was sealed tightly. After storage at refrigeration temperatures (4±1 °C) for periods of 1, 7, and 14 days, the samples were reweighed. For measurement, the sample was promptly removed from the container, gently blotted to remove excess moisture, and weighed. The drip loss was calculated as per the following formula:

$$\textbf{\textit{Drip loss}}\ (\%) = [(\boldsymbol{Wa} - \boldsymbol{Wb})\,/\,\boldsymbol{Wa}]\boldsymbol{x100}$$

Where Wa is the weight before postmortem storage (g), and Wb is the sample weight after postmortem aging (g).

2.3.4. Cooking loss (CL)

A muscle sample weighing approximately 200 g was used to assess cooking loss. The sample was placed in a commercial indoor countertop grill (Aluminum 1600W Electric Grill with adjustable temperature control and nonstick baking cooking surface) and cooked until it reached an internal temperature of 70 °C. A thermocouple thermometer probe (Ecoscan Temp JKT, Eutech Instruments) was inserted into the center of the muscle to monitor the temperature. To calculate the cooking loss percentage, the muscle was weighed before and after cooking, with the cooking loss determined as a percentage of the initial weight [23].

$$\textbf{\textit{CL}}\ (\%) = ((\boldsymbol{wt.before\ cooking} - \boldsymbol{wt.after\ cooking}))/(\boldsymbol{wt.before\ cooking})\ \ \boldsymbol{x\ 100}$$

2.3.5. Shear force (SF)

Shear force is a testing method used in food texture analysis. It involves shearing the product, simulating the way the front incisors act when food is taken into the mouth. It is used to evaluate the tenderness of meat products. To evaluate shear strength, the cooked samples that were previously used for determining cooking loss were repurposed following the methodology outlined by Shackelford et al. [24]. From each muscle sample, five round-cores with a diameter of 1.27 cm were extracted in a direction parallel to the longitudinal orientation of the muscle fibers. These cores were obtained using a handheld coring device. The shear force was measured using a Texture Analyzer (TA-HD-Stable MicroSystems, England) equipped with a Warner-Bratzler attachment. The maximum force exerted perpendicular to the muscle fibers, measured in kilograms, was recorded as the shear force. The crosshead speed of the Texture Analyzer was set at 200 mm/min.

2.3.6. Texture profile analysis

Texture profile analysis (TPA) involves a double mechanical compression test that offers insights into how samples respond when chewed. The texture profile of cooked LTL muscle samples was assessed by measuring the values of hardness (concerning the material's stiffness, determined by monitoring the maximum load achieved during the initial deformation cycle), cohesiveness (pertaining to the material's consistency, which is defined as the ratio of the area under the time/force curve in the second cycle to that in the first cycle), springiness (related to the material's recovery and its viscoelastic characteristics, defined as the ratio of the time required for the material to reach maximum load during the second cycle to the time taken in the first cycle), and chewiness (related to the ease with which a material can be bitten, calculated by multiplying its hardness, cohesiveness, and springiness). The texture profile analysis was carried out in accordance with the methodology outlined by Al-Owaimer et al. [23].The cooked LTL muscle samples were cut into 1 cm $\times$ 1 cm x 2 cm parallel to the longitudinal orientation of the muscle fibers using a portable corer. The TPA test was conducted using a Texture Analyzer (TAHD; Stable Micro Systems) equipped with a compression platen attachment. Each sample underwent two cycles of 80 % compression.

2.4. Statistical analysis

The mean values and standard errors of replicates (n = 9) were analyzed on SPSS-27.0 software packages, IBM Corporation, USA. The normality of the data distribution was assessed using the Kolmogorov–Smirnov test, while the homogeneity of variances was evaluated with Levene's test. The significant difference between means was compared by using analysis of variance (ANOVA) by using Duncan's Multiple Range Test (DMRT). The statistical significance was tested at a 5 % level ($p < 0.05$). One Way Analysis of Variance (ANOVA) was used to analyse the data for slaughter weight, hot carcass weight, and dressing percentage, whereas for pH, drip loss, color, shear force, and texture profile were analyzed by using Two Way ANOVA.

3. Results and discussion

3.1. Carcass quality attributes

3.1.1. Slaughter weight, hot carcass weight, and dressing percentage

The comparison between the C, EP, and HP groups showed that preslaughter handling approach had no significant ($p > 0.05$) influence on slaughter weight, hot carcass weight, and dressing percentage (Fig. 1). However, the dressing percentage of control goats was not significantly higher ($p > 0.05$) that in EP and HP. These non-significant changes in the values could be due to the nature of stress, which was just prior to slaughter and persisted for a short time. Further, stressful conditions in EP and HP groups could result in higher physiological and behavioral responses to supply higher energy to cope with the stressful conditions as mentioned in Ref. [25] who reviewed the pre-slaughter stress mitigation in goats and discussed the prospects and challenges. This causes loss of body weight in stressed animals due to dehydration caused by increased urination and breathing and lower muscle glycogen reserves in these animals as reported in Ref. [26] who reviewed the physiological and behavioral responses of livestock to road transportation stress. This higher catabolic activity could be attributed to the higher dressing percentage and hot carcass weight of the control group as compared to the treatment groups. A similar lower dressing percentage was also recorded in goats under transportation stress [27].

3.1.2. Microbial load

The results of the total microbial contamination on goat carcass surfaces are presented in Table 1. It has been observed that the approach of handling of goat preslaughter have a significant impact on the total bacterial concentration. In the EP and C groups, the total aerobic bacteria contamination ranged from 5.8 to 6.4 log10 CFU/cm^2. However, notable variations were observed in the HP group, with contamination levels reaching 8.5 CFU/cm^2 for total microbial count. Additionally, the total Enterobacteriaceae count exhibited a significant increase in the HP group, reaching 8 log10 CFU/cm^2, compared to 5.45 and 5.7 log10 CFU/cm^2 in the EP and C

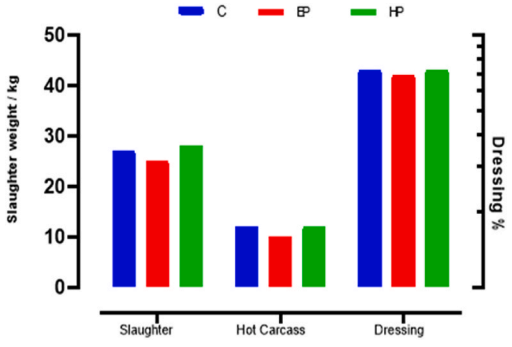

Fig. 1. Slaughter weight, hot carcass weight, and dressing% of goats subjected to different preslaughter handling approach (*n*=9); C: control; EP: ear pulling; HP: hind-leg pulling.

Table 1
The total microbial contamination on goat carcass surfaces as affected by preslaughter handling approach in goats (*n=9*).

Treatments	Microbial Load (log10 CFU*)		
	TBC	TEC	TCC
Control	6.40[a]	5.70[a]	ND[a]
EP	5.80[a]	5.45[a]	ND[a]
HP	8.50[b]	8.0[b]	1.40[b]
SEM	0.37	0.33	–
p value	<0.001	<0.001	<0.001

Means with different superscripts [a, b] within a column differ significantly ($p < 0.05$), Control-goats moved from lairage to slaughter point gently, EP- goats moved from lairage to slaughter point by ear pulling, HP- goats moved from lairage to slaughter point by hind-leg pulling, level of significance $p < 0.05$; TBC = Total bacterial Count; TEC = Total Enterobacteriaceae count; TCC = Total Clostridium count. CFU= Colony forming unit.

groups, respectively. It is worth noting that only Clostridium contamination was found in the HP group. The results obtained here were in accordance with the conclusion reported by Ref. [28] who assessed the impact of preslaughter handling on animal welfare and beef quality some regions of Ethiopia. According to their findings, the poor handling of cattle prior to slaughter has resulted in microbial spoilage, indicating that inadequate handling of cattle immediately before slaughter can have a negative impact on meat quality. The methods of goats handling prior to slaughter have a significant effect on the total count of microorganisms per square centimeter (cm^2). The HP approach of handling of goats before slaughter resulted in an increased total bacterial count, however, there were no significant differences observed in the total count between the C and EP handling groups. The mean results for the fresh goat carcass quality, as determined by total bacterial count (TBC), total Enterobacteriaceae count (TEC), and total Clostridium count (TCC), were found to be influenced by the method of handling of goats preslaughter.

3.2. Meat quality evaluation

3.2.1. Drip loss

The preslaughter handling of goats has a significant ($p < 0.001$) effect on the drip loss on day 7 of aging, with the control sample having significantly higher drip loss than the treatment groups (Table 2). However, on day 1 and day 14 of aging, the drip loss of control and treatment was recorded as comparable. Within the C group, the lowest drip loss was observed at day 14 of aging. Similarly, within the EP group, the lowest drip loss was also recorded at 14 days post-mortem. Further, within the HP group, significant differences in drip loss were observed among samples with the advancement of aging duration. This could be due to increased muscle temperature and lower glycogen and creatine phosphate content in goats due to preslaughter stress as reported in Ref. [29] who studied the effects of pre-slaughter stress and season on the activity of plasma creatine kinase and mutton quality from different sheep breeds. In the conclusion of this study, pre-slaughter stress was found to affect the activity of creatine kinase and mutton quality in general. This resulted in a rapid decline in pH and increased drip loss during aging in the treatment groups. Similar findings of higher decline in drip loss were reported in pigs upon exposure to physiological stress immediately before slaughter [30]. Furthermore, Ding et al. [31] reported that water-holding capacity influences the texture, flavor, nutritional content, and juiciness of meat. Additionally, there is a correlation among water-holding capacity, drip loss, and cooking loss, indicating that lower drip and cooking losses in muscle are associated with higher water-holding capacity and improved mutton quality. In addition, drip loss is also affected by the expression

Table 2
Drip loss and pH values of *Longissimus thoracis et lumborum* muscle during post-mortem aging as affected by preslaughter handling approach in goats (*n=9*).

Treatments	Days of aging				
	0 day	1 day	7 day	14 day	*p* value (group x day)
Drip loss					
Control	–	1.92 ± 0.19^{b}	2.04 ± 0.20^{bB}	0.90 ± 0.15^{a}	<0.001
EP	–	1.49 ± 0.14^{b}	1.21 ± 0.13^{bA}	0.54 ± 0.16^{a}	<0.001
HP	–	1.89 ± 0.17^{c}	1.39 ± 0.09^{bA}	0.84 ± 0.07^{a}	<0.001
p value	–	0.14	0.001	0.15	
pH values					
Control	6.25 ± 0.05^{b}	5.90 ± 0.03^{aB}	5.88 ± 0.05^{aB}	6.60 ± 0.04^{cB}	<0.001
EP	6.37 ± 0.05^{c}	5.73 ± 0.04^{aA}	5.73 ± 0.06^{aA}	6.18 ± 0.05^{bA}	<0.001
HP	6.26 ± 0.03^{b}	5.72 ± 0.04^{aA}	5.81 ± 0.03^{aB}	6.27 ± 0.08^{bB}	<0.001
p value	0.134	0.003	0.085	0.000*	

Values are mean ± standard error with different superscripts small letters, [a, b, c] within a row, and capital letters [A, B, C] within a column differ significantly ($p < 0.05$), Control-goats moved from lairage to slaughter point gently, EP- goats moved from lairage to slaughter point by ear pulling, HP- goats moved from lairage to slaughter point by hind-leg pulling, level of significance $p < 0.05$.

of heat shock proteins (such as β-crystallin and HSP 27) to protect the functional properties of muscle proteins during preslaughter exposure to stress as reported by Ref. [32] who connected between protein oxidation and water holding capacity of meat. They determined that oxidative processes affect proteins' capacity to form hydrogen, electrostatic, and capillary bonds with water molecules. Additionally, the aggregation process may exacerbate this effect by reducing the surface area available for bonding with water. A lower expression of these HSPs is correlated with the higher drip loss and development of pale-soft-exudative condition [33]. The substantial water loss under preslaughter handling approach could be the reason for the lower drip loss in the treatment groups. The EP and HP samples had less leftover muscle water that might be passively released than the C group, which had higher moisture, consequently showing higher drip loss. Our findings are also consistent with the observations reported by Nikbin et al. [27] who studied the influence of pre-slaughter transportation and stocking density on carcass and meat quality characteristics of Boer goats.

3.2.2. pH value

The preslaughter handling approach in goats had a significant effect on the pH of LTL muscle during aging. A significantly ($p = 0.003$) lower values for pH were recorded in the treatment groups (EP and HP) as compared to the pH of the C samples on day 1 of aging (Table 2). Except for day 0, significant differences in pH among the treatment groups were observed on day 1, day 7, and day 14 of aging. At day 7, a lower pH value was indicated by the samples of the EP group, with no significant difference between the C and the HP groups. On day 14, the EP treatment resulted in significantly lower pH values than those of the C and HP groups. Within the C group, pH values declined significantly at days 1 and 7 of aging before significantly increasing at day 14 of aging. Similarly, within the EP and HP treatment groups, when compared to days 0 and 14 of aging, significantly lower pH values were also noted in the samples subjected to days 1 and 7 of aging, with a significant increase in pH observed at day 14 post-mortem. This is likely due to the muscles of EP and HP goats using more energy and releasing more lactate throughout the aging period, which results in a higher muscle pH decrease on day 1 of aging. Muscle cells switch from oxidative phosphorylation to glycolysis for ATP synthesis due to metabolic activation of muscle cells after slaughter and a lack of oxygen in tissues [34]. Preslaughter handling method reduced muscle cells' energy levels, which are needed for post-slaughter enzymatic activity. Further preslaughter stress caused increased glycogen catabolism and muscle temperature under the hormonal (adrenaline) influence, consequently leading to higher pH decline during aging. Similar to our findings of higher pH values in EP and HP groups on day 0, Kadim et al. [35] also reported significantly higher pH in the muscle of goats undergone transportation stress prior to slaughter as compared to that of non-transported goats on day 0 of aging. A significant increase in the pH of all samples on day 14 of aging as compared to day 7 of aging could be attributed to biochemical reactions such as proteolysis caused by bacterial actions and the release of ammonia as reported by Triki et al. [36] who assessed the quality of fresh meat from several species based on free amino acid and biogenic amine contents during chilled storage.

3.2.3. Cooking loss

The effects of preslaughter handling approach on cooking loss are presented in Fig. 2. Both handling methods (EP and HP) groups had significantly lower cooking loss than the C group. However, no significant differences were observed between EP and HP at day 0 post-mortem. In addition, no significant effects were observed between all groups on day 1 of aging. The pH has an impact on water-binding capacity (WBC), which changes from a high WBC at a higher pH to a lower WBC at a lower pH (below 5.6). The reduction in muscle pH might change the structure of myofibrils and accelerate the breakdown of muscle protein. As a result, protein solubility declines, and drip loss increases. Reduced muscle pH has been linked to changes in myofibril structure and an increase in the breakdown of muscle protein [37]. This resulted in decreased protein solubility and increased drip loss. The current study's findings on the impact of stress on cooking loss are consistent with those of Kadim et al. [35], who reported a significant effect of transportation stress on cooking loss in goats. The cooking loss of LTL muscle was significantly ($p < 0.05$) higher on day 0 for all samples as compared to their corresponding day 1 values. It might be due to the pre-rigor state of the LTL muscle on day 0. Similar findings of decreased cooking loss in aged meat were also recorded by Kannan et al. [38] who studied meat quality in goats as influenced by dietary protein and energy levels, and postmortem aging. This decrease in cooking loss is attributed to the structural breakdown of myofibrillar proteins leading to blockage of the channels in skeletal muscle through which water is lost (sponge effect), thereby preventing water release during cooking [39,40].

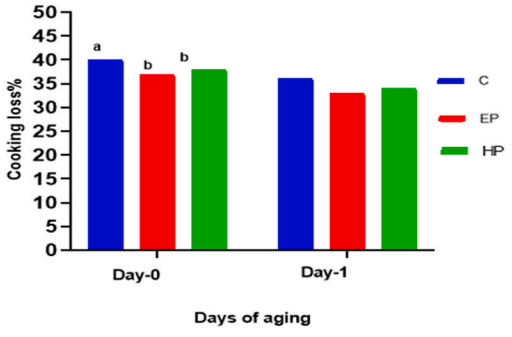

Fig. 2. Meat cooking loss (%) of goats subjected to different preslaughter handling approach and aging periods (n=9). C: control; EP: ear pulling; HP: hind-leg pulling; P = Probability level is significant at $P \leq 0.05$; ^{a,b} Different means represent significantly different treatments.

3.2.4. Color profile

Preslaughter handling method influenced the LTL lightness (L*) and redness (a*) values with increasing lightness and decreasing redness with increasing handling approach ($p < 0.05$) at days 0 and 14 post-mortem (Table 3). The effects of preslaughter handling method on lightness were influenced by the post-mortem aging time, whereby significant differences in lightness values were recorded only at days 0 and 14 post-mortem. Higher significant ($p < 0.05$) changes in lightness values were recorded in samples of EP and HP groups than in the C group. Irrespective of the treatment groups, significant differences in lightness values were consistently observed over the 14 days of aging. As for the redness, the values were not affected by the preslaughter handling approach, regardless of the post-mortem aging time. In general, the higher redness values ($p < 0.05$) were consistently recorded in the samples aged for 1-day post-mortem. Similar to the redness, the yellowness values were not affected by the preslaughter handling method and these were in the case of all post-mortem aging times. Within each treatment group, the differences in yellowness values ($p < 0.05$) over the 14 days post-mortem aging time are of similar trend (day 0 < day 14, day 7 < day 1). Similar to the redness and yellowness values, the total color difference (dE) remained unaffected by the pre-slaughter handling approach. Within the EP and HP groups, significantly higher dE was consistently noted at day 14 post-mortem. Preslaughter handling method did not affect the chroma values at all post-mortem aging times. Within each treatment group, the highest chroma value was consistently recorded in day 1 post-mortem aging samples. The effects of preslaughter handling approach on hue were influenced by the post-mortem aging time, and this was evident by the presence of significant interaction between the two factors. As for the hue, a significant effect of preslaughter handling method was only recorded in day post-mortem aging samples, with the lowest value ($p < 0.05$) indicated by samples of the HP group. The differences in hue value over the days 14 of post-mortem aging were recorded in all treatment groups, with the lowest values indicated by the samples at day 0 post-mortem.

The preslaughter handling stress has an effect on physiological and biochemical responses, leading to various changes in the muscle. The higher rate of post-mortem glycolysis, rapid pH decline, and higher muscle temperature altered the functionality of muscle proteins and their ability to retain water, consequently affecting the color of the muscle. The overall color attributes are affected by the complex interactions between the muscle, the animal's physiological status, age, and preslaughter stress responses. The relative proportions of the redox status of myoglobin (deoxymyoglobin, myoglobin, and oxymyoglobin) on the surface, as well as the amount of myoglobin present on a meat surface, determine the color of the meat surface [35]. In general, the lower glycogen accompanied by

Table 3
Color profile of *Longissimus thoracis et lumborum* muscle during post-mortem aging as affected by preslaughter handling approach in goats (*n=9*).

Treatments	Days of aging				*p* value (group x day)
	0	1	7	14	
Lightness (L*)					
Control	26.68 ± 2.07^{aA}	44.44 ± 1.79^{c}	34.34 ± 1.92^{b}	30.02 ± 0.87^{abA}	<0.001
EP	32.48 ± 2.20^{aB}	44.48 ± 1.28^{b}	37.19 ± 2.07^{b}	37.08 ± 2.56^{bB}	0.003
HP	32.74 ± 0.99^{aB}	44.68 ± 1.58^{c}	38.82 ± 2.75^{b}	39.08 ± 1.49^{bB}	0.001
p value	0.047	0.993	0.384	0.004	
Redness (a*)					
Control	10.13 ± 0.47^{a}	15.68 ± 0.69^{b}	11.83 ± 0.90^{a}	10.70 ± 0.98^{a}	<0.001
EP	8.80 ± 0.43^{a}	13.96 ± 1.40^{b}	9.94 ± 0.87^{a}	7.75 ± 1.61^{a}	0.004
HP	10.21 ± 0.52^{a}	14.91 ± 0.72^{b}	11.11 ± 0.73^{a}	8.56 ± 1.65^{a}	0.001
p value	0.079	0.480	0.290	0.347	
Yellowness (b*)					
Control	5.32 ± 0.28^{a}	14.26 ± 0.54^{d}	11.84 ± 0.92^{c}	8.99 ± 0.67^{b}	<0.001
EP	5.50 ± 0.42^{a}	14.40 ± 1.03^{d}	11.61 ± 0.75^{c}	8.97 ± 1.22^{b}	<0.001
HP	4.64 ± 0.28^{a}	13.72 ± 0.72^{c}	12.10 ± 0.92^{c}	8.38 ± 0.75^{b}	<0.001
p value	0.184	0.817	0.923	0.867	
dE (total color difference)					
Control	–	–	–	–	
EP	7.95 ± 1.62^{a}	8.48 ± 1.12^{a}	8.63 ± 1.12^{a}	13.17 ± 1.43^{b}	0.033
HP	6.65 ± 1.29^{a}	8.05 ± 0.81^{ab}	10.15 ± 1.42^{ab}	12.04 ± 2.49^{b}	0.016
p value	0.541	0.763	0.415	0.701	
Chroma (Cab°)					
Control	11.46 ± 0.49^{a}	21.25 ± 0.66^{c}	16.85 ± 1.09^{b}	13.99 ± 1.17^{a}	<0.001
EP	10.44 ± 0.43^{a}	20.12 ± 1.63^{c}	15.44 ± 0.85^{b}	12.06 ± 1.86^{ab}	<0.001
HP	11.25 ± 0.50^{a}	20.29 ± 0.93^{c}	16.58 ± 0.87^{b}	12.37 ± 1.45^{a}	<0.001
p value	0.290	0.757	0.540	0.636	
Hue (H°)					
Control	27.79 ± 1.29^{aAB}	42.39 ± 1.59^{b}	44.92 ± 2.43^{b}	40.37 ± 0.83^{b}	<0.001
EP	31.97 ± 2.36^{aB}	46.38 ± 1.76^{b}	49.55 ± 2.80^{b}	51.82 ± 3.95^{b}	<0.001
HP	24.66 ± 1.67^{aA}	42.60 ± 1.19^{b}	47.15 ± 2.80^{b}	47.17 ± 5.50^{b}	<0.001
p value	0.031	0.138	0.485	0.140	

Values are mean ± standard error with different superscripts small letters$^{a, b, c}$–within a row and capital letters $^{A, B, C}$ within column differ significantly ($p < 0.05$), Control-goats moved from lairage to slaughter point gently, EP- goats moved from lairage to slaughter point by ear pulling, HP- goats moved from lairage to slaughter point by hind-leg pulling, n = 9, level of significance $p < 0.05$, *- value less than 0.001.

higher pH due to preslaughter stress resulted in lower lightness, thereby developing darker meat [41,42]. Further, in the present study, an increased lightness value for all samples was reported on day 1 compared to the day 0 values. This could be due to the oxygenation of myoglobin leading to the formation of oxymyoglobin, thereby leading to a bright red color. This was also noticed with increased redness (a* value) in the samples. The higher pH recorded in the control samples in the present study (Table 3) could cause higher mitochondrial activity, thereby increasing the tissue oxygen consumption. This resulted in lowering the oxygenation capacity of myoglobin during blooming [43,44]. Further, high ultimate pH was observed to cause darker meat with a low lightness value (L*) [45].

3.2.5. *Shear force and texture profile*

The preslaughter handling effects on shear force and texture profile analysis of LTL muscles of goats at different post-mortem aging periods are presented in Table 4. There is an interaction between the preslaughter handling approach and post-mortem aging time. The effect of preslaughter handling method was only observed at day 0 post-mortem. Compared to the C group, both EP and HP groups demonstrated higher shear force values, suggesting that the EP and HP handling preslaughter have resulted in tougher meat. The effect of 24-h post-mortem aging (day 1), as indicated by lower shear force values, was only seen in the samples of the EP group. As for the hardness, a significant interaction between the pre-slaughter handling method and post-mortem aging time was also recorded. The effect of pre-slaughter handling treatment on hardness was only at 1 day post-mortem aging. Comparing the hardness between 0 and day 1 post-mortem aging, significant differences were only noted within the C and EP groups. In the C group, higher hardness was recorded at day 1 post-mortem, while, in the EP group, significantly lower hardness was noted at day 1 post-mortem aging. In this study, springiness was unaffected by the preslaughter handling approach and post-mortem aging time. Similarly, cohesiveness was also unaffected by the preslaughter handling treatment and post-mortem aging time. A significant interaction was found to be present between preslaughter handling treatment and post-mortem aging time. The effect of preslaughter handling method on chewiness was only found on day 1 of post-mortem aging, with lower ($p < 0.05$) chewiness recorded in both EP and HP samples. At day 0 post-mortem, chewiness remained similar between the preslaughter treatment groups. The effect of post-mortem aging was only present in the C group, with higher chewiness being recorded at day 1 post-mortem aging. The alteration in the shear force value is linked to calpain activity, which increases during the conversion of muscle to meat and aging, thereby improving tenderness and decreasing shear force upon aging [27]. Thus, meat tenderness is affected by proteolysis during aging along with sarcomere length, collagen and cross-linking, marbling, and denaturation of meat proteins [46]. The calpain: calpastatin ratio also has an effect on muscle tenderness. The tenderness of meat declines as pre-slaughter stress in livestock increases, as noted by Ferguson and Warner [47]. In their review,

Table 4
Shear force and texture profile of *Longissimus thoracis et lumborum* muscle during post-mortem aging as affected by preslaughter handling approach in goats (*n*=*9*).

Treatments	Days of aging		*p* value (group x day)
	0 day	1 day	
Shear force (N)			
Control	20.25 ± 3.24^{A}	21.78 ± 3.05	0.736
EP	30.99 ± 4.50^{Bb}	21.35 ± 3.95^{a}	0.013
HP	33.43 ± 3.07^{B}	27.57 ± 4.38	0.290
p value	0.041	0.452	
Hardness (N)			
Control	2.22 ± 0.18^{a}	4.30 ± 0.88^{bB}	0.019
EP	2.74 ± 0.35^{b}	1.95 ± 0.23^{aA}	0.036
HP	2.93 ± 0.20	2.78 ± 0.45^{AB}	0.752
p value	0.141	0.028	
Springiness (ratio)			
Control	0.90 ± 0.09	0.88 ± 0.04	0.864
EP	0.84 ± 0.04	0.85 ± 0.03	0.883
HP	0.87 ± 0.04	0.83 ± 0.04	0.587
p value	0.818	0.663	
Cohesiveness (ratio)			
Control	0.63 ± 0.04	0.62 ± 0.02	0.835
EP	0.61 ± 0.01	0.63 ± 0.02	0.354
HP	0.62 ± 0.03	0.60 ± 0.03	0.734
p value	0.873	0.688	
Chewiness (ratio)			
Control	1.49 ± 0.24^{a}	2.65 ± 0.50^{bB}	0.053
EP	1.18 ± 0.10	1.06 ± 0.08^{A}	0.364
HP	1.67 ± 0.19	1.47 ± 0.22^{A}	0.489
p value	0.187	0.005	

Values are mean ± standard error with different superscripts small letters, $^{a, b, c}$–within a row and capital letters $^{A, B, C}$ within column differ significantly ($p < 0.05$), Control-goats moved from lairage to slaughter point gently, EP- goats moved from lairage to slaughter point by ear pulling, HP- goats moved from lairage to slaughter point by hind-leg pulling, level of significance $p < 0.05$.

they explored the impact of pre-slaughter stress on meat quality in ruminants, finding robust evidence that such stress adversely affects key quality characteristics in both beef and lamb. They also highlighted that a significant reduction in muscle glycogen levels prior to slaughter has a substantial effect on crucial meat quality factors, including ultimate pH and tenderness. Similar findings of increased shear force and lower tenderness due to preslaughter stress were also observed in pigs [34,48]. An increase in the shear force, hardness, and chewiness value of sheep muscle upon preslaughter stress of intermingling of various social groups was also reported by Cam et al. [49]. However, similar to the present findings, Cam et al. [49] who studied the effects of pre-slaughter stress on meat quality characteristics of male lambs of two sheep breeds also reported no significant effect of preslaughter stress on the springiness and cohesiveness of the muscle during aging. The collagen content and its maturation are important determinants of the shear force and hardness of meat; thereby stress influenced collagen-related factors also have a major effect on the shear force and hardness of the meat.

3.2.6. Conclusion

The results obtained in this study demonstrated that both handling approaches prior to slaughter had significant effects on various meat quality aspects. Significantly lower values for pH were recorded in the treatment groups as compared to the pH of the control samples on day 1 of aging. Notably, both handling methods were found to increase the shear force, hardness, and chewiness of the meat, ultimately compromising its quality. Additionally, the manner in which goats are managed and the level of their handling before being slaughtered greatly impact the overall concentration of microorganisms per square centimeter. Based on these findings, it is highly recommended to handle meat animals with utmost care to improve carcass and meat quality. By prioritizing humane and careful handling of meat animals, producers can significantly improve the quality of meat and carcasses, benefiting animal welfare, consumer trust, and economic outcomes. Implementing effective preslaughter practices is not only a matter of ethics but also a strategic approach to enhancing product quality and market competitiveness.

CRediT authorship contribution statement

Gamaleldin M. Suliman: Writing – review & editing, Investigation, Funding acquisition, Conceptualization. **Abdullah N. Al-Owaimer:** Resources, Project administration, Conceptualization. **Mohsen M. Alobre:** Investigation, Data curation. **Ayman A. Swelum:** Writing – review & editing, Methodology, Investigation. **Maged A. Algaradi:** Resources, Methodology. **Hani Ba-Awadh:** Resources, Investigation, Data curation. **Awis-Qurni Sazili:** Writing – review & editing, Supervision, Conceptualization. **Pavan Kumar:** Writing – original draft, Resources, Formal analysis. **Ubedullah Kaka:** Writing – original draft, Formal analysis, Conceptualization.

Data availability

The data presented in this study are available on request from the corresponding author.

Ethics statement

This study was conducted in accordance with the guidelines for experiments involving animals. The research protocol was reviewed and approved by the Research Ethics Committee (REC) of King Saud University, with the approval number (KSU-SE-22-112) dated March 04, 2021.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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