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Research article

Carcass and meat quality characteristics of Black goats slaughtered at different body weights

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Abstract: In this study, we evaluated the carcass characteristics and meat quality of Black goat kids slaughtered at four weight classes: 15, 20, 30, and 40 kg (n=40). Dressing percentage, linear measurements, and tissue components increased significantly (P<0.0001) with slaughter weight. While the muscle-to-bone ratio improved, the muscle-to-fat ratio decreased (P<0.0001) at higher weights, reflecting advanced maturity and fat deposition. Meat quality parameters, including pH, cooking loss, and expressed juice, were significantly influenced by slaughter weight and muscle type. Analysis of seven distinct muscles revealed that while lightness (L*) decreased, redness (a*) increased as animals matured (P<0.01). Chemically, crude protein and ether extract percentages rose significantly (P<0.0001) with weight, enhancing the nutritional profile. We identified the 30–40 kg range as the optimal slaughter window, maximizing meat yield while maintaining superior tenderness and palatability. These findings confirm that Black goats can be slaughtered at higher weights to optimize production efficiency without compromising essential meat quality attributes.

Keywords: Black goats; slaughter weight; carcass composition; meat quality; muscle-specific attributes; Intramuscular fat; tenderness

1. Introduction

Goat meat (chevon) is highly valued for its favorable nutritional profile, characterized by low levels of fat, cholesterol, and saturated fatty acids, while being a rich source of high-quality protein and polyunsaturated fatty acids [1]. Furthermore, chevon is recognized as a biologically complete product and a rich source of essential micronutrients, particularly potassium (up to 4125 mg/kg), sodium, magnesium, calcium, and iron [2]. It also provides a significant supply of B-complex vitamins, including B3, B5, and B6, which are crucial for human health and rational nutrition [1,2]. However, the high concentration of myoglobin and the specific fatty acid profile of goat meat, characterized by a significant proportion of polyunsaturated fatty acids (PUFA), make it particularly susceptible to lipid and protein oxidation during processing and storage [3]. Such oxidative processes are not only responsible for the deterioration of sensory attributes such as color and flavor but also lead to the formation of secondary compounds that may impact the nutritional safety of the final product [3]. Therefore, defining the optimal slaughter weight is not merely a matter of yield, but a critical factor in ensuring the oxidative stability and shelf-life of the meat, aligning with modern meat science's focus on metabolic balance. Goat meat accounts for approximately 15% of total red meat production in Jordan (approximately 4862 tons). According to the Jordanian Ministry of Agriculture (MOA) [4], the total goat population in Jordan is nearly one million heads. Goat meat is an essential component of the local diet, and Black goat meat is the most favored by consumers and commands the highest market prices in Jordan. This species is a significant source of red meat, especially in developing countries [1]. In the Mediterranean, kids are slaughtered at different live body weights: suckling kids (10–12 kg), light kids (20–22 kg), early fattening kids (30–32 kg), and late fattening kids (40–42 kg) [5]. This is not justified based on meat quality in local and worldwide markets. In light of this, the meat quality of carcasses across slaughter weights should be studied to determine how slaughter weight differences affect meat quality characteristics. Other determinants of goat meat quality include age, breed, sex, body weight, nutrition, species, and pre-slaughter condition [5]. Goat meat offers an attractive alternative to other red meats [6]. This is because goat meat has a lower content of subcutaneous fat and cholesterol than other red meats, and it contains more lean meat than sheep of similar age [7]. It is also a good source of some desirable polyunsaturated fatty acids [8]. Furthermore, studies in the livestock sector have demonstrated that enhancing metabolic efficiency does not merely impact growth performance; it is also a decisive factor in improving meat quality attributes, including tenderness and water-holding capacity. Based on this scientific evidence, which confirms the strong correlation between feed efficiency and final product quality, there is an urgent need to apply these concepts to indigenous goat breeds. Determining the optimal slaughter weight remains a significant challenge that must balance economic profitability with international standards of meat quality [9].

Local Jordanian consumers strongly prefer Black goat meat over sheep or beef. Specifically, consumers prefer meat from young animals under 1 year of age, weighing 10–36 kg live. This preference reflects regional traditions and individual consumer views, which may not align with objective scientific meat quality characteristics. Modern goat meat science emphasizes the need for standardized grading systems to ensure consistency in eating quality. Research indicates that factors such as pre-slaughter nutrition and muscle-specific metabolism are critical in determining tenderness and pH decline [10]. This highlights the importance of scientifically identifying the optimal slaughter weight to balance producer profitability with consumer expectations for meat palatability. To date, no researchers has assessed the influence of different slaughter weights on the carcass and meat characteristics of the indigenous Black goat breed. Given that consumers are increasingly diet-conscious and concerned with meat palatability, providing scientific data on the optimal slaughter point for Black goats is critical.

2. Materials and methods

2.1. Animals and experimental design

The study was conducted at the Agricultural Center for Research and Production (ACRP) at Jordan University of Science and Technology (JUST). All experimental procedures adhered to the guidelines of the Institutional Animal Care and Use Committee (IACUC) at JUST. A total of 40 male Black goat kids were randomly selected from a single, large commercial flock (comprising hundreds of dams and selected sires). The kids were born during the autumn-winter period of 2018. Each kid was reared with its own dam, and all were weaned at 90 days of age (weaning weight between 12 and 15 kg) before having gradual ad libitum access to a mixed ration (14% crude protein and 11.60 MJ ME/kg DM) using an open feeding system. The feed was formulated according to the National Research Council recommendations [11]. The kids selected for slaughtering were randomly chosen from the weaned kids in the flock when they reached their previously determined slaughter weights of 15, 20, 30, or 40 kg (90 to 270 days of age).

2.2. Slaughter procedures

Kids were fasted for approximately 8 hours before slaughter, with free access to water. Slaughtering occurred when the animals reached their target weights (15, 20, 30, or 40 kg). Slaughter and dressing methods followed routine commercial procedures, as described by Abdullah et al. [1]. Live body weight was recorded for each kid before slaughter. Internal organs were removed post-slaughtering. The dressed carcass composed of the body and neck. All non-carcass components were weighed and recorded immediately after the removal of the heart, liver, kidneys, lungs, trachea, spleen, mesenteric, and kidney fat. Empty body weights were recorded and hot carcass weights were recorded within one h of slaughtering. The dressed carcasses were weighed again (cold carcass weight) after a 24 h chilling period at 4°C.

2.3. Carcass linear and area measurements

After a 24-hour postmortem chilling period, cold carcass weights were recorded. Detailed linear measurements were performed on the hanging carcasses using calipers and a metal ruler, following the procedures validated by Abdullah et al. [1]. Body length was measured from the insertion point of the gambrel to the anterior point of the humerus. Leg length was measured from the distal end of the tarsus to the tibial tuberosity. Gigot width was measured from the gambrel across the length of the carcass to the level of the femoral trochanter. The maximum shoulder width was measured between the two lateral surfaces of the two scapulae. The width behind the shoulder was measured as the minimum width behind the scapula. Shoulder fat depth was measured as the depth of subcutaneous fat over *Musculus latissimus* dorsi. Leg fat depth was measured on the ventral edge of *Musculus gluteus* medius. Fat depth was measured as the depth of subcutaneous fat over *Musculus longissimus* at right angles to the skin. Rib fat depth was measured as the depth of subcutaneous fat over the external abdominal oblique. Tissue depth was measured as the depth of tissue over the surface of the rib at a point 110 mm from the midline. *M. longissimus* width was the maximum width across the surface of the *M. longissimus*, while *M. longissimus* depth was measured as the maximum depth at right angles to the width measurement. The eye muscle area was measured as the *M. longissimus* muscle area by using a plastic grid on the caudal part of the rack. Each carcass was divided into four major cuts and a fat tail [12]. The shoulders were separated from the racks. Racks were separated from loins by cutting against the caudal edge of the 12th rib, the ventral edge of the costal cartilages, and through the cartilage disc, separating the 12th and 13th thoracic vertebrae. Legs were separated by cutting through between the last and second-to-last lumbar vertebrae. Each major cut was separated into right and left sides using an electrical saw. These linear and area measurements were selected to capture the allometric shifts in muscle and fat deposition that characterize the developmental maturity of the Black goat breed, enabling a standardized comparison between locomotion and support muscle groups.

2.4. Cutting and dissection procedure and sample preparation

The chilled carcasses were cut into four major cuts (shoulders, racks, loins, and legs) [12]. The shoulders were separated from the racks by first cutting with a knife along a line against the caudal edge of the 7th rib on each side, and the vertebra was sawn through. Racks were separated from the loins by cutting against the caudal edge of the 12th rib, the ventral edge of the costal cartilage, and through the cartilage disc, separating the 12th and 13th thoracic vertebrae. Legs were separated by cutting through between the last and second-to-last lumbar vertebrae. Each major cut was divided into right- and left-hand sides using an electric saw. The right side of each cut was sealed in plastic bags and frozen at approximately -20ºC until dissected. *M. longissimus* was excised from the loin cuts and vacuum packaged in plastic bags until meat quality and chemical composition were determined. Before dissection, each cut was thawed overnight in a cooler at approximately 4ºC while in a plastic bag. Each cut was dissected into its components (subcutaneous fat, intermuscular fat, muscle, bone, and scrap (other)).

2.5. Meat quality measurements

2.5.1. Cooking Loss and Tenderness (Warner-Bratzler Shear Force)

For Warner-Bratzler shear values and cooking loss determination, duplicate 25-mm slices were cut from each muscle and weighed prior to cooking to determine cooking loss. The slices were placed in plastic bags and immersed in a water bath at 75°C for 90 minutes [12]. Cooking loss was calculated by re-weighing the samples after cooking and drying excess surface moisture with a paper towel, as follows:

$$\text{Cooking loss \%} = 100 \times \frac{(\text{Weight before cookin} - \text{Weight after cooking})}{\text{Weight before cooking}} \quad [13]$$

Cooked slices were stored overnight at 4°C. On the following day, 6 to 12 cores of similar size were cut and sheared perpendicular to the muscle fiber direction using a Werner-Bratzler (WB) shear blade mounted on a Salter Model 235 (G-R Manufacturing Co., Manhattan, Kansas, 66502, USA) to determine the peak force (kg) required for shearing [13].

2.5.2. Water Holding Capacity (Expressed Juice, EJ)

Expressed Juice (EJ %) was measured using the method described by Purchas and Aungsupakorn [14] to assess water loss under applied pressure. Approximately 5 g of raw meat (initial weight) was cut into small pieces, covered with two filter papers and two thin quartz plates, and pressed with a 2,500 g weight for 5 minutes. The sample was re-weighed (final weight). Water holding capacity was reported as the expressed juice percentage, calculated as:

$$\text{Expressed juice (\%)} = \text{initial weight (initial weight} - \text{final weight)} \times 100$$

2.5.3. Meat pH

Meat pH was measured after thawing using a pH Spear meter. The meter was calibrated using buffer standards at pH 4, 7, and 10.

2.5.4. Muscle color

Muscle color was measured 24 h post-thawing. Samples were placed on polystyrene trays, covered with oxygen-permeable film, and allowed to bloom for 3 h at 2°C [15]. Color coordinates were measured using a chromometer (Minolta CR 400). The standards reported by CIE [16] were applied, using D65 as the light source. The colorimeter measured CIELAB brightness ($L*$), redness ($a*$), and yellowness ($b*$) [17]. The chromometer was calibrated using a standard white plate (Y=93.8, x=0.316, y=0.3323). Color measurements were taken on eight 2-cm thick cuts at four time points post-cutting: initial, 1 h, 24 h, and 5 days. Samples were stored at 4°C under continuous white light (750 lx) between measurements.
Chroma ($C*$) and Hue Angle ($h\circ$) were calculated using the standard formulas:
Chroma $C^* = (a^{*2} + b^{*2})$ and hue $h° = \tan^{-1}(b^*/a^*)$ [13].

2.5.5. Proximate Chemical Analysis

Samples from *M. longissimus* were taken for chemical analysis. Samples were dried at 100°C to a constant weight, equilibrated, and ground using a Wiley mill to pass a 1 mm screen (Barbender OHG Duisdurg, type 880845, Nr. 958084, Germany). Proximate analysis was performed on the raw meat according to AOAC [18] for the following:

- Dry Matter (DM): (100°C for 24 h; method 967.03).
- Ash: (550°C for 8 h; method 942).
- Crude Protein (CP): (Kjeldahl procedure; method 976.06).
- Total Lipid: (Ether extraction/Soxhlet procedure; method 920.29).

2.6. Statistical analysis

The collected data were analyzed using the General Linear Model (GLM) procedure of SAS (Version 9.4; SAS Institute, Cary, NC, USA) [19]. Data for growth performance and carcass composition were analyzed as a completely randomized design (CRD), with slaughter weight as the main fixed effect. For meat quality characteristics, the statistical model included slaughter weight and muscle type as the major effects, along with their interactions. Interactions were retained in the final model only when significant ($P<0.05$). Normality of residuals and homogeneity of variance were verified using the Shapiro-Wilk and Levene's tests, respectively, prior to further analysis. Least-squares means (LSM) were calculated for all measured variables. Following the reviewers' recommendations, the Tukey-Kramer Honestly Significant Difference (HSD) test was used for multiple comparisons of means to ensure robust statistical inference. Significance was declared at $P<0.05$. The model used to study the effect of slaughter weight on carcass composition was:

$Y_{ij} = \mu + W_i + e_{ij}$

where

Y_{ij} = is the observation in the $_i$th slaughter weight.

μ = the overall mean.

W_i = the effect of slaughter weight.

e_{ij} = random error.

3. Results and discussion

3.1. Final and empty live weights, hot and cold carcass weights, dressing-out percentage, and dripping loss

The effect of slaughter weight of Black goats on final and empty live weight, hot and cold carcass weights, dressing-out percentage, and dripping loss is reported and presented in Table 1.

Empty live weight increased with increasing slaughter weight, from 15 kg to 40kg ($P<0.001$). These results agree with those of Mahgoub and Lodge [20], who reported that empty body weight and carcass components increased with increasing slaughter weight from 18 to 38 kg in Omani sheep. It is expected that all weights will increase as the animal's live weight increases. Bone, lean, fat, and offal increase in weight as the animal approaches its mature weight. This pattern reflects the allometric growth of tissues, where the proportion of carcass tissues shifts from bone to muscle and eventually to fat as the animal progresses towards physiological maturity. The significant increase in carcass weight and dressing percentage observed at 40 kg suggests that the Black goat reaches a point of accelerated fat deposition, which is typical of semi-arid adapted breeds optimizing energy reserves.

Table 1. Least-squares means for final and empty live weights, hot and cold carcass weights, dressing-out % and dripping losses, and non-carcass component percentages of Black goat male kids slaughtered at different live weights.

Item	15kg (n=10)	20kg (n=10)	30kg (n=10)	40kg (n=10)	SE	P-value
	Slaughter weight categories					
	kg					
Final live weight	16.10^{d}	22.50^{c}	32.70^{b}	39.90^{a}	0.48	<.0001
Empty body weight	15.10^{d}	21.50^{c}	31.70^{b}	38.90^{a}	0.48	<.0001
Hot carcass weight	6.20^{d}	9.20^{c}	14.70^{b}	18.80^{a}	0.32	<.0001
Cold carcass weight	6.00^{d}	9.00^{c}	14.40^{b}	18.40^{a}	0.32	<.0001
Dressing-out % [1]	41.20^{b}	42.70^{b}	46.50^{a}	48.30^{a}	0.72	<.0001
Dripping losses[2]	3.60^{b}	2.30^{b}	2.40^{b}	2.10^{a}	0.28	0.0044
	% of Empty body weight					
Lungs & trachea	1.70^{a}	1.50^{a}	1.21^{b}	1.10^{b}	0.07	<.0001
Heart	0.46	0.51	0.52	0.50	0.02	0.3894
Liver	2.13	2.41	2.24	2.31	0.12	0.3618
Spleen	0.22	0.25	0.22	0.20	0.02	0.1305
Kidney	0.42^{a}	0.41^{a}	0.34^{b}	0.35^{b}	0.02	0.0085
Kidney fat	0.24^{c}	0.60^{b}	0.79^{ab}	1.02^{a}	0.09	<.0001
Mesenteric fat	0.51^{c}	0.91^{b}	1.40^{a}	1.60^{a}	0.12	<.0001
Testes	0.12^{c}	0.17^{c}	0.40^{b}	0.57^{a}	0.04	<.0001
Total offal[3]	5.81^{c}	6.76^{b}	7.10^{ab}	7.71^{a}	0.24	<.0001

[1]Dressing % = (Hot carcass weight/empty live weight) *100

[2]Dripping losses = (Hot carcass weight/cold carcass weight) *100

[3]Total offals include heart, spleen, liver, lungs and trachea, mesenteric fat, kidney fat, kidneys and testes weights.

[a,b,c,d] Means within the same row with different subscripts differ according to the indicated level of significant.

The hot and cold carcass weights increased with increasing slaughter weight (P<0.001), and the hot carcass weight was higher than the cold carcass weight at all slaughter weights due to loss of moisture during overnight chilling. The highest hot and cold carcass weights were at slaughter, with a mean of 40 kg across all slaughter weights of Black goats (P<0.001). Dhanda et al. [21] showed higher hot and cold carcass weights for capretto and chevon when slaughtered at 14–22 kg of live weight, but lower hot and cold carcass weights when slaughtered at 30–40 kg. The highest dressing-out percentage was at 40 kg slaughter weight and decreased at lower slaughter weights ($P<0.001$). The dressing-out percentage was lower (41.2–48.3%) in Black goats based on empty body weight compared with Capretto and Chevon (51–54%) [21]. Obtaining the dressing-out percentage for meat animals was considered an important issue for producers and the meat market, as this characteristic indicated the amount of carcass produced from slaughtering the animals. The dressing-out percentage was higher in heavier male goats. This is consistent with other studies that attributed this to a higher mean slaughter weight [22]. Our data reported either similar or slightly lower dressing-out percentages than those of other breeds. For example, Dhanda et al. [23] reported a dressing percentage between 41 and 47% based on full body weight and a dressing percentage around 50% for Capretto kids, while it ranged from 50 to 55% for Chevon kids based on empty body weight. Pena et al. [24] found that dressing percentages ranged from 49% to 56%. The differences among breeds are due to differences in body size and production type. The relatively lower dressing-out percentage in Black goats compared to specialized meat breeds (e.g., Florida or Dhofari) can be attributed to the breed's lower gastrointestinal tract fill and potentially higher proportion of non-carcass components such as internal fat depots, which are essential for survival in challenging environments but reduce the net carcass yield. Dressing-out percent (based on empty body weight) of three breeds of Omani goats ranged between 53 and 57%, with the Dhofari goats having the highest value [25]. The dripping loss was highest at 15 kg of slaughter weight and decreased at higher slaughter weights. The differences in drip loss percentage between slaughter groups were statistically significant ($P = 0.0044$). This trend is due to the reduced body surface/body weight ratio and thicker subcutaneous fat of the carcasses [22, 26]. Chilling losses decreased significantly from 3.6 to 2.1% with increasing slaughter weight, which agrees with the results of Marichal et al. [26] in the Canary Caprine group breed and of Pena et al. [24] in the Florida breed.

3.2. Non-carcass components

The non-carcass components measured included the lungs and trachea, heart, spleen, liver, testes, kidney, and mesenteric fat, as well as total offal (Table 1). The results indicated that the lung and tracheal weights decreased with increasing slaughter weight ($P<0.0001$). The heart weight increased with increasing slaughter weight from the liver (15–30 kg). Liver weight increased from 15-20 kg to slaughter weight and decreased from 30–40 kg. Spleen weight increased from 15-20kg and decreased at a slaughter weight of 30–40 kg. Kidney weight reduced from 15–30 kg at slaughter weights to 40 kg. The testes were higher at higher weights ($P<0.0001$). Both kidney and mesenteric fat were higher at higher slaughter weights ($P<0.0001$). Among the non-carcass components, the liver, kidney, and mesenteric fats contributed to more than 50% of maintenance energy [27]. Abdominal fat constituted at least 4% of the empty body weight, with estimates reaching 6–7% [28]. The internal fat (kidney fat and mesenteric fat), excluding intermuscular, intramuscular, and subcutaneous fat, was 0.6% at 15 kg body weight and 2.6% at 40 kg body weight. It was previously reported that total internal fat mass accounted for approximately 7% of empty body weight, including all internal fats [29]. The total faeces in this experiment accounted for 5.8% to 7.7% of body weight (Table 1). The factors that mainly affect the non-carcass weight are breed, age, sex, slaughter weight [30], feeding system [31], and supplementation [32]. Forage-fed kids had lighter liver weights, whereas kidney, heart, and lung weights were not affected by the feeding system. Mahgoub et al. [33] and Zervas and Tsiplakou [34] reported that goats tend to accumulate fat in the abdominal cavity rather than in subcutaneous tissues, and that this accumulation occurs early in animal growth. However, Dhanda et al. [21] reported that total internal fat increases with age and body weight. Kadim and Mahgoub [35] estimated the total non-carcass fat by 42-52% of the total body fat in goat. Marichal et al. [26] found differences among body weights for all offal components tested. The percentage contributions of the internal organs (liver, spleen, kidney, lung, trachea, and heart) to live body weight in kids were significantly lower in animals of 6 and 10 kg live body weights compared with animals of higher weights. These results also agree with the results by Pena et al. [24].

3.3. Linear dimension measurements

Linear dimensions and fat measurements were carried out on the carcasses or loin cuts of Black goats. Body length (LB), leg length (T), maximum shoulder width (Wf), width behind shoulder (Wth), and gigot width (G) increased with increasing slaughter weights, $P<0.0001$ (Table 2). Fat depth (C), rib fat depth (J), tissue depth (GR), leg fat depth (L3), shoulder fat depth (S2), eye muscle width (A), eye muscle depth (B), and eye muscle area (cm^2) increased in values significantly ($P<0.0001$) as slaughter body weight increased from 15 to 40 kg (Table 2). The eye muscle area ratio decreased with increased slaughter weight, but the decrease was not statistically significant ($P<0.1163$). The ratio of eye muscle width to eye muscle depth increased from 15–20kg and decreased from 30–40 kg (Table 2).

The increase in fat linear measurements indicated that Black goats were very lean. These measurements have always been used to indicate carcass fatness, especially in sheep and goats. Similarly, linear measurements of eye muscle width, depth, and area were used as indicators of increased muscle tissue within the carcass. The increase in linear measurements with increasing body weight is due to the natural growth of body tissues, including the skeleton. These results agree with those of Pena et al. [24], who showed that increased carcass body weight and linear measurements are due to increased muscle and fat content and decreased bone content with increasing age [23].

Shoulder fat depth, tissue depth, leg fat depth, and rib fat depth increased ($P<0.0001$) with increased slaughter body weights, but body length and fat thickness were higher in this study than the results obtained for capretto and chevon kids [23]. However, lower values (0.28–1.11 mm) were obtained for fat depth compared to what was found by Abdullah et al. [36] (1.8–3.1 mm) in intact and castrated kids fed diets with different energy levels. Additionally, similar lower levels of fat thickness across all carcass areas were measured in Black goat kids of similar slaughter weight reported by Abdullah et al. [37].

Eye muscle depth was high in male goats slaughtered at 40 kg, and the ratio between width and depth of the longissimus muscle decreased ($P<0.0001$) from 20 to 40 kg, meaning that the muscle increased more in width than depth. Eye muscle area, which is considered a measure of muscularity, was ower than that found by Dhanda et al. [23] for capretto (LBS 14–22 kg) and chevon (LBS 30–35 kg) carcasses. Fat depth (C) was lower in Black goats than in capretto and chevon carcasses.

Table 2. Least-squares means for carcass and *M. Longissimus* linear dimensions and fat measurements of Black goat male kids slaughtered at different live weights.

Item	Slaughter weight categories 15kg (n=10)	20kg (n=10)	30kg (n=10)	40kg (n=10)	SE	P-value
	mm					
Body length (LB)	869^{d}	913^{c}	1052^{b}	1136^{a}	8.99	<.0001
Leg length (T)	322^{c}	335^{c}	366^{b}	407^{a}	7.30	<.0001
Maximum shoulder width (Wf)	103^{d}	125^{c}	149^{b}	162^{a}	3.09	<.0001
Width behind shoulder (Wth)	89^{d}	107^{c}	125^{b}	137^{a}	3.59	<.0001
Gigot width (G)	118^{c}	135^{b}	160^{a}	166^{a}	2.30	<.0001
Fat depth (C)	0.28^{c}	0.37^{c}	0.78^{b}	1.11^{a}	0.08	<.0001
Rib fat depth (J)	0.37^{c}	0.59^{c}	1.17^{b}	2.05^{a}	0.14	<.0001
Tissue depth (GR)	5.81^{c}	6.31^{c}	9.33^{b}	11.67^{a}	0.48	<.0001
Leg fat depth (L3)	0.31^{c}	0.47^{c}	1.11^{b}	2.00^{a}	0.15	<.0001
Shoulder fat depth (S2)	0.25^{c}	0.34^{c}	0.78^{b}	1.11^{a}	0.08	<.0001
Eye muscle width (A)	39.62^{b}	41.75^{b}	48.56^{a}	51.33^{a}	0.94	<.0001
Eye muscle depth (B)	11.50^{d}	16.69^{c}	19.94^{b}	21.89^{a}	0.58	<.0001
Eye muscle area (cm^2)	6.39^{c}	8.29^{b}	10.59^{a}	11.65^{a}	0.40	<.0001
Eye muscle area ratio[1]	2.7	2.6	2.4	2.2	0.16	<.1163
A to B ratio	3.49^{a}	2.54^{b}	2.44^{b}	2.33^{b}	0.09	<.0001

[1]Eye muscle area (EMA) ratio = (EMA) ^1.5/Cold Carcass Weight.

[a,b,c,d] Means within the same row with different subscripts differ according to the indicated level of significant.

3.4. Carcass components

Least-squares means for total carcass cut weights and percentages of Black goat male kids slaughtered at different live weights are presented in Table 3.

The cold carcass weight and the four carcass cuts weight (neck and shoulders, racks, loins, and legs), in addition to the tail weight, increased with increasing slaughter weight ($P<0.0001$). The neck and shoulder cuts were the heaviest and therefore represent the highest percentage of carcass cuts, followed by the leg cuts. The rack and the loin cuts weighed almost the same. The proportion of neck and shoulder formed on average 46% of the total carcass weight; legs formed on average 33% of the total carcass weight. Loins were approximately 9.6% of the cold carcass weight ($P = 0.0277$). Racks formed an average about 9.55% of the total carcass weight ($P<0.0001$). These results were similar to those reported by Dhanda et al. [21] and by Liméa et al. [38]. Racks showed the highest percentage of cold carcass at a slaughter weight of 30 kg. Loins were maximum when the slaughter weight was 20 kg. Similar percentages of the cold carcass weight of the neck, the shoulders, and the leg cuts were reported from 15 to 40 kg (Table 3). The same authors reported that all cut weights increased with increasing slaughter body weights, with similar cut percentages of the cold carcass weight. Figure 1 shows the weight change of all cuts in relation to the shift in cold carcass weight and the regression equations calculated for the major carcass cuts against cold carcass weights. Cut weights increased with increasing cold carcass weight for necks and shoulders, racks, loins, and legs. This means the linear model was appropriate for explaining the growth of the major cuts at slaughter weights between 15 and 40 kg.

Table 3. Least-squares means for total carcass cut weights and percentages of Black goat male kids slaughtered at different live weights.

Item	Slaughter weight categories				SE	P-value
	15kg (n=10)	20kg (n=10)	30kg (n=10)	40kg (n=10)		
	Kg					
Cold carcass weight	6.0^{d}	9.0^{c}	14.4^{b}	18.4^{a}	0.32	<.0001
Neck & Shoulders	2.8^{d}	4.1^{c}	6.6^{b}	8.5^{a}	0.17	<.0001
Racks	0.5^{d}	0.8^{c}	1.5^{b}	1.9^{a}	0.04	<.0001
Loins	0.5^{d}	0.9^{c}	1.4^{b}	1.7^{a}	0.03	<.0001
Legs	2.0^{d}	2.9^{c}	4.7^{b}	6.2^{a}	0.11	<.0001
Tail	0.02^{d}	0.03^{c}	0.05^{b}	0.06^{a}	0.002	<.0001
Other	0.09	0.10	0.16	0.08	0.027	0.2226
	% of Cold Carcass					
Neck & Shoulders	46.66	46.00	45.67	46.23	0.35	0.2699
Racks	8.67^{c}	9.30^{b}	10.19^{a}	10.12^{a}	0.17	<.0001
Loins	9.12^{b}	10.37^{a}	9.71^{ab}	9.27^{b}	0.28	0.0277
Legs	33.61	32.92	32.99	33.60	0.38	0.4434
Tail	0.36	0.34	0.35	0.30	0.02	0.1844
Other	1.54^{a}	1.08^{ab}	1.07^{ab}	0.42^{b}	0.25	0.0332

$^{a, b, c, d}$ Means within the same row with different subscripts differ according to the indicated level of significant.

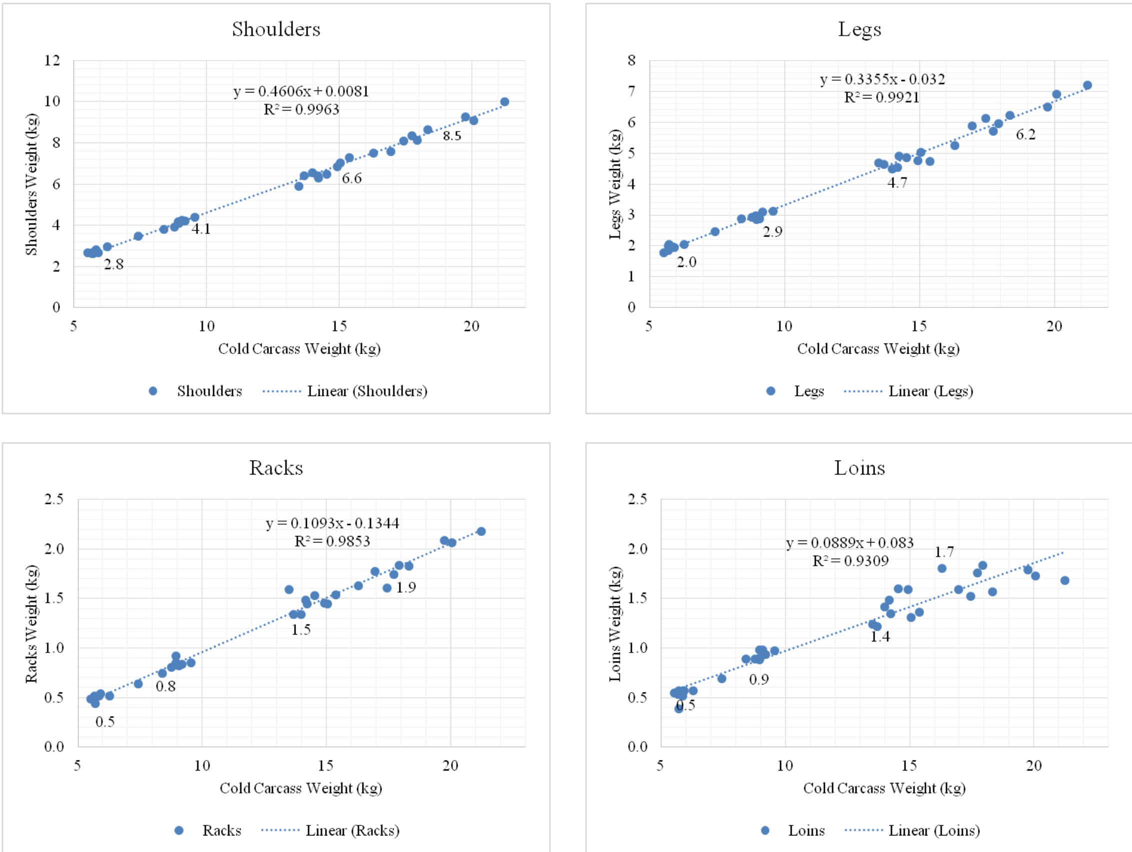

Figure 1. Major cuts weight change in relation to the change in cold carcass weight of Black goat male kids slaughtered at different live weights.

These results agree with those of Abdullah and Qudsieh [5]. Shoulder and leg cut percentages were also similar to those obtained by Obeidat et al. [39], with a lower rack percentage but a higher loin percentage. The breed of goat does not affect the shoulder and leg percentages, as reported by the same authors, who found similar percentages for the shoulder and legs in Black kids and in Shami-Baladi (SB) crossbred kids. The carcasses of all the kids slaughtered were cut into two similar halves, and the cuts on the right side of each kid were thoroughly dissected, and their tissue components were measured and weighted (Table 4). All the weights increased with increasing slaughter body weight ($P<0.0001$). The muscle-to-bone ratio also increased with increasing slaughter weight ($P<0.0001$). The muscle-to-fat ratio decreased significantly with increasing slaughter weight ($P<0.0001$).

The total lean, total fat, and total bone increased significantly from 15 to 40 kg ($p<0.0001$). These tissues are the major components of the carcass; increases in one component affects the others and their ratios. Bone is a highly dynamic tissue, whereas fat is a late-maturing tissue that increases over time with increasing body weight. Carcasses at different slaughter weights showed higher bone weight than total fat content (Table 4). Carcasses showed less total subcutaneous fat tissue compared with total intermuscular fat tissue, regardless of the slaughter weight. This is expected, as goats tend to accumulate less subcutaneous fat tissue and more intermuscular fat tissue [40]. The intermuscular and subcutaneous fat increased from 15 to 40 kg. Total bone decreased with increasing slaughter weight ($P<0.0001$) (Table 4).

Table 4. Least-squares means for total half carcass tissue component weights and percentages of Black goat male kids slaughtered at different live weights.

Item	15kg (n=10)	20kg (n=10)	30kg (n=10)	40kg (n=10)	SE	P-value
	Slaughter weight categories					
	kg					
Total half carcass wt.	2.89[d]	4.42[c]	7.01[b]	9.27[a]	0.17	<.0001
Intermuscular fat wt.	0.09[d]	0.28[c]	0.62[b]	0.83[a]	0.05	<.0001
Subcutaneous fat wt.	0.10[d]	0.21[c]	0.43[b]	0.74[a]	0.03	<.0001
Total fat wt.	0.18[d]	0.48[c]	1.05[b]	1.57[a]	0.07	<.0001
Total lean wt.	1.39[d]	2.31[c]	3.75[b]	5.00[a]	0.08	<.0001
Total bone wt.	1.22[d]	1.47[c]	1.93[b]	2.48[a]	0.06	<.0001
Other wt.	0.09[b]	0.12[b]	0.24[a]	0.28[a]	0.01	<.0001
Meat to bone ratio	1.15[c]	1.57[b]	1.95[a]	1.99[a]	0.05	<.0001
Meat to fat ratio	7.95[a]	5.00[b]	3.64[c]	3.25[c]	0.33	<.0001
	% of half Carcass					
Intermuscular fat	2.93[c]	6.17[b]	8.85[a]	8.93[a]	0.52	<.0001
Subcutaneous fat	3.24[d]	4.65[c]	6.11[b]	7.85[a]	0.34	<.0001
Total fat	6.18[c]	10.82[b]	14.97[a]	16.78[a]	0.72	<.0001
Total lean	47.77[b]	52.39[a]	53.42[a]	52.97[a]	0.90	<0.0005
Total bone	42.13[a]	33.21[b]	27.47[c]	26.71[c]	0.74	<.0001
Other	3.16	2.73	3.42	2.94	0.26	0.3299

[a, b, c, d] Means within the same row with different subscripts differ according to the indicated level of significant.

3.5. Meat quality and chemical composition

The results of least-squares mean for meat quality attributes of different type of muscles from Black goat male kids slaughtered at different live weights are presented in Table 5.

Table 5. Least-squares means for meat quality parameters of seven muscle types from Black goat male kids slaughtered at different live weights.

Item		Muscle Type								
		Semimembranosus	*Semitendinosus*	*Biceps femoris*	*Quadratic*	*M. supraspinatus*	*M. infraspinatus*	*Longissimus*	LSD	P-value
Slaughter Weight										
15 Kg	Muscle Weight (g)	47.3^{Cd}	26.4^{Ed}	56.7^{Bd}	111.3^{Ad}	36.1^{Dd}	33.7^{DEd}	32.0^{Ded}	8.1027	<.0001
20 Kg		89.7^{Cc}	48.1^{Ec}	102.5^{Bc}	157.4^{Ac}	52.7^{Ec}	50.5^{Ec}	72.2^{Dc}	7.3201	<.0001
30 Kg		137.5^{Cb}	72.8^{Fb}	160.6^{Bb}	232.0^{Ab}	88.0^{Eb}	84.3^{Eb}	121.^{Db}	9.4459	<.0001
40 Kg		174.6^{Ca}	94.7^{Ea}	200.6^{Ba}	307.8^{Aa}	111.2^{Ea}	108.7^{Ea}	147.4^{Da}	22.295	<.0001
LSD		11.052	7.0463	15.73	25.021	6.3166	7.6337	11.808		
P-value		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001		
15 Kg	pH^2	5.78^{Cab}	5.87^{CBa}	6.00^{ABa}	5.86^{BCb}	6.02^{Aa}	6.04^{Aa}	5.96^{Aba}	0.1452	0.0049
20 Kg		5.60^{Cb}	5.80^{Ba}	5.76^{Bc}	5.73^{Bc}	5.97^{Aab}	6.00^{Ab}	5.73^{Bb}	0.0923	<.0001
30 Kg		5.79^{Ba}	5.92^{Aa}	5.96^{Aab}	6.00^{Aa}	6.00^{Aab}	6.00^{Ab}	5.75^{Bb}	0.0811	<.0001
40 Kg		5.87^{Aa}	5.93^{Aa}	5.86^{Abc}	5.94^{Aab}	5.85^{Ab}	5.98^{Ab}	5.69^{Bb}	0.1596	0.0187
LSD		0.1815	0.1416	0.1073	0.1021	0.1495	0.0399	0.1151		
P-value		0.0381	0.2315	0.0006	0.0001	0.1377	0.0065	0.0002		
15 Kg	Cooking loss %	40.5^{Aa}	34.6^{BCab}	38.7^{ABa}	39.0^{ABab}	39.7^{Aab}	33.3^{Cb}	39.5^{Aba}	5.0513	0.0371
20 Kg		40.6^{Aba}	37.6^{Ca}	39.7^{Ba}	39.6^{Ba}	41.2^{Aa}	37.8^{Ca}	40.2^{Aba}	1.3375	<.0001
30 Kg		38.3^{Aba}	34.4^{Cab}	38.4^{ABa}	35.7^{BCb}	38.8^{ABbc}	36.6^{BCa}	40.4^{Aa}	3.3857	0.0155
40 Kg		37.6^{BCa}	33.2^{Db}	38.2^{Ba}	35.7^{Cb}	37.6^{BCc}	33.1^{Db}	41.6^{Aa}	2.1947	<.0001
LSD		3.8941	3.6742	4.0058	3.8541	1.8399	2.8365	2.8726		
P-value		0.2877	0.1183	0.8781	0.0797	0.0027	0.0036	0.5140		
15 Kg	EJ %^{3}	34.4^{Aa}	27.4^{Ba}	28.8^{Ba}	28.4^{Ba}	27.9^{Bb}	25.9^{Bb}	29.3^{Ba}	4.019	0.0052
20 Kg		27.5^{BCb}	30.8^{Aba}	27.3^{BCab}	30.2^{ABa}	33.5^{Aa}	25.4^{Cb}	32.0^{Aa}	3.9049	0.0011
30 Kg		29.4^{Bb}	30.9^{Ba}	28.1^{Bab}	27.9^{Ba}	35.5^{Aa}	30.8^{Ba}	29.0^{Ba}	4.3844	0.0196
40 Kg		22.4^{Cc}	28.5^{Ba}	25.4^{BCb}	28.2^{Ba}	34.2^{Aa}	33.2^{Aa}	24.7^{BCb}	4.4891	<.0001
LSD		3.7158	4.1678	3.3817	4.87	5.4773	3.943	4.1002		
P-value		<.0001	0.2573	0.2131	0.7613	0.0401	0.0006	0.0101		
15 Kg	SF(kg/cm^2)^4	6.2^{Ab}	3.9^{Cb}	4.6^{Cb}	6.0^{ABa}	6.4^{Ab}	4.7^{BCb}	4.2^{Ca}	1.3863	0.0013
20 Kg		6.3^{Ab}	6.1^{Aa}	4.3^{Bb}	6.2^{Aa}	6.4^{Ab}	4.7^{Bb}	4.2^{Ba}	1.06.3	<.0001
30 Kg		6.4^{Ab}	6.3^{Aa}	5.6^{ABa}	6.8^{Aa}	6.3^{Ab}	4.8^{BCb}	4.3^{Ca}	1.2043	0.0005
40 Kg		8.2^{Aa}	6.4^{CDa}	6.3^{Da}	7.4^{ABCa}	7.7^{Aba}	7.0^{BCDa}	4.4^{Ea}	1.1602	<.0001
LSD		1.3653	1.4554	1.0002	1.5591	1.0537	1.004	1.0446		
P-value		0.0152	0.0032	0.0014	0.2363	0.0355	<.0001	0.9829		

$^{A, B, C, D}$ Means within the same row with different subscripts differ according to the indicated level of significant.

$^{a, b, c, d}$ Means within the same column with different subscripts differ according to the indicated level of significant.

3.5.1. Muscle weights and distribution

The weights of all examined muscles (*Semimembranosus, Semitendinosus, Biceps femoris, Quadratic, Supraspinatus, Infraspinatus,* and *Longissimus*) increased significantly (*P*<0.0001) as the slaughter body weight (SBW) increased from 15 to 40 kg. Specifically, the *Semimembranosus* muscle weight increased from 47.3 g to 174.6 g, reflecting the overall carcass growth. Across all slaughter weights, the *Quadratic* muscle was consistently the heaviest, while the *Semitendinosus* remained the lightest. This variation highlights the differential growth rates and functional roles of specific muscle groups during the maturation of Black goat kids. This aligns with the observations of Corazzin et al. [41], who noted that major cuts like the leg and shoulder represent the bulk of the carcass weight (50–60%), reinforcing that slaughtering at 30–40 kg optimizes the yield of these major muscle groups.

This differential growth pattern between locomotion and support muscles confirms that slaughter weight acts as a biological regulator, where structural integrity of locomotion muscles is prioritized early in life, while intramuscular fat and protein accretion in support muscles like the *Longissimus* become the major drivers of quality in heavier animals.

3.5.2. Meat quality attributes: pH, cooking loss, and expressed juice

The pH values measured post-thawing were significantly influenced by muscle type and SBW (*P*<0.01). While pH values ranged from 5.69 to 6.04, they generally remained within the acceptable range for goat meat (5.6–5.8). These findings are comparable to those reported by Kadim et al. [25] for Omani goat breeds. The variations in pH among muscles can be attributed to differences in muscle composition, metabolic activity, and functional roles in the live animal. Cooking loss percentage differed significantly between muscle types (*P*<0.01). Interestingly, while cooking loss for the *Longissimus* muscle tended to increase with SBW due to higher fat content, heavier carcasses often exhibit an improved water-holding capacity as moisture is replaced by intramuscular fat; a late-maturing tissue. Similarly, Expressed Juice (EJ%), an indicator of juiciness and tenderness, was significantly affected by muscle type (*P*<0.01). The highest EJ% was observed at 20 kg SBW, consistent with previous reports indicating that juiciness can vary significantly with slaughter weight and intramuscular fat content. The stability of pH and EJ% values in heavier carcasses (30–40 kg) suggests that the animals had reached an appropriate metabolic maturity, thereby avoiding the high-pH issues often associated with pre-slaughter stress in goats, as noted by Casey and Webb [42]. Furthermore, according to Kadim and Mahgoub [43], the concentrated fat deposition around the viscera in goats enables the meat to remain lean yet functional during post-mortem metabolic shifts.

3.5.3. Tenderness (Warner-Bratzler Shear Force)

Tenderness, measured via Warner-Bratzler shear force (SF), increased significantly (*P*<0.001) with SBW in most muscles, except for the *Quadratic* and *Longissimus*. The *Longissimus* muscle was consistently the tenderest across all groups (4.2–4.4 kg/cm^^{2}). This is a critical finding, as goat meat is often perceived as 'tough' or 'stringy' by consumers [42]. The maintenance of tenderness in support muscles (such as *Longissimus*) despite the increase in SBW suggests that at 30–40 kg, the carcasses achieve sufficient mass to mitigate 'cold shortening', a common cause of toughness in lighter carcasses during chilling [42]. The increase in SF at 40 kg SBW is likely due to the increased deposition of connective tissue and collagen as the animal matures. Despite this increase, SF values for Black goats remained within a very acceptable range, confirming the breed's inherent tenderness. The observed SF values, which remained within the acceptable range even as connective tissue cross-linking increased at 40 kg SBW, may be partially explained by the balanced rate of calpain-mediated proteolysis in Black goat myofibrils, which ensures that muscle fiber tenderization keeps pace with structural maturation.

3.5.4. Meat color

Meat color is a primary indicator of quality for consumers. In this study, redness (a*) increased significantly with SBW ($P<0.001$), while brightness (L*) reached its peak at 20 kg. Heavier kids exhibited a darker red color, consistent with the findings of Pena et al. [24], who noted that older animals transition from pale pink to deeper red hues. This trend is desirable in many markets where a darker red color is associated with maturity and rich flavor profiles [41].

3.5.5. Chemical composition

Chemically, the *Longissimus* muscle showed a significant increase in crude protein (from 12.28% to 16.18%) and ether extract (EE%; from 1.66% to 4.60%) as SBW increased from 15 to 40 kg. The increase in EE% reflected the accumulation of intramuscular fat, which is expected as animals' reach maturity. Concurrently, moisture content (DM%) showed an inverse relationship with fat, as water in the muscle tissues is gradually replaced by fat. This accumulation of intramuscular fat (EE% increasing to 4.60%) acts as a structural lubricant, enhancing juiciness and tenderness. As emphasized by Kadim and Mahgoub [43], this lean but high-quality fat profile (rich in polyunsaturated fatty acids) makes the 30–40 kg Black goat an ideal choice for health-conscious consumers seeking a balance between nutritional safety and eating quality. The ash content also increased with weight, which is associated with the overall increase in muscle volume and mineral deposition.

4. Conclusions

This study demonstrates that SBW is a decisive factor influencing the carcass yield and meat quality of Jordanian Black goats. Increasing SBW up to 40 kg significantly enhances meat production and dressing-out percentages, aligning with producer profitability. Scientifically, the 30–40 kg range was identified as the optimal slaughter window, which provides a superior balance between muscle growth and palatability. Specifically, while locomotion muscles showed increased shear force at higher weights, the *Longissimus* muscle maintained exceptional tenderness and ideal pH levels across all groups. Furthermore, the increase in intramuscular fat at 40 kg serves as a critical buffer that improves juiciness and mitigates potential quality defects. These findings establish a scientific baseline for optimizing the production of Black goats, ensuring they remain a resilient and high-quality nutritional source that meets consumer demands and regional food security goals.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

All authors declare no conflict of interest in this paper.

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