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Lasalocid-supplemented diets for improving carcass characteristics, meat quality, and fatty acids content of goats

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Abstract

This study investigated the effects of lasalocid supplementation on the diet of goats to improve carcass characteristics, meat quality traits, and fatty acid content. Sixty intact male Ardhi goats were used. The kids were divided into four treatment groups, each with 15 animals, and further subdivided into five subgroups, each with three goats, in a completely randomized design. Data on carcass characteristics, meat quality, and fatty acid profiles were obtained. The LAS treatment significantly affected the chill shrinkage and dressing percentage on the empty body weight. Saturated fatty acids decreased, whereas essential polyunsaturated fatty acids increased with the addition of supplements. In conclusion, including lasalocid in the diets of Ardhi goats enhanced the carcass characteristics of the animals, whereas meat quality traits were not negatively affected by the supplement.

Keywords: Lasalocid, Ardhi goat, Meat quality, Carcass characteristics, Fatty acids

INTRODUCTION

Global consumption of goat meat or chevon has increased substantially because of its nutritional features compared to other red meat sources [1]. Moreover, goat meat is a good dietary protein source with lower total fat, saturated fatty acid, and cholesterol content, making it a healthy product for consumers [1]. The market is driven by the rising health awareness of consumers who usually search for protein-rich food products without hazardous consequences on their overall fitness. In addition, the efforts and activities of many governmental and non-governmental sectors aimed at defeating obesity and other health problems such as diabetes, high cholesterol, hypertension, and heart-related diseases encourage consumers to seek healthier food sources. This directly boosts the goat meat market in Saudi Arabia, although goats, second only to sheep, are the most preferred source of consumed red meat.

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Availability of data and material
Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions
Conceptualization: El-Waziry AM, Basmaeil SM.
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Ethics approval and consent to participate
The research protocol was approved by the institutional research ethics committee (REC) of King Saud University considering all the accepted ethical standards in research involving animals (Reference No.: KSU-SE-21-82).

Lamb consumption and import demand are forecasted to continue increasing in Saudi Arabia, driven by increasing disposable income, urbanization, young populations, and groups of wealthy expats [2]. The total meat consumption in Saudi Arabia was estimated to be 1,921 thousand tons in 2019 and is expected to reach 2,118 thousand tons by 2024 [3]. The self-sufficiency of red meat is estimated to be 43%, indicating an approximately 57% deficiency that needs to be addressed [4]. To bridge the gap in meat demand for consumption between Saudi citizens and other inhabitants, meat production of local species need to increase considerably. Goats are a good source of red meat but are not well utilized yet. The number of goats in Saudi Arabia is estimated to be 6 million [4], but some difficulties with this species impede its maximum expected benefits. These include low growth and decreased daily weight gain rate.

Lasalocid (LAS) is a feed additive widely used as a growth promoter in ruminants and is safe and effective against different livestock species [5]. Including LAS in the diet of lambs significantly increased the final body weight, average daily gain, and hot carcass weight. Therefore, LAS increased the overall growth of lambs [6]. Atrian et al. [7] evaluated the performance of LAS-supplemented Holstein cows. They reported that LAS significantly increased postpartum dry matter intake and milk production and improved the feed conversion ratio, leading to better productivity in dairy cows. Unfortunately, few studies have evaluated the inclusion of LAS in goat feed. Hence, this study aimed to investigate the effect of dietary supplementation with LAS on the carcass and meat quality attributes of goat meat.

MATERIALS AND METHODS

Animal welfare and ethical approval

The Institutional Research Ethics Committee of King Saud University approved the research protocol, considering all accepted ethical standards for research involving animals (Reference No.: KSU-SE-21-82).

Experimental animals, design, housing, and feeding

The experiments were conducted at the Research Station of the Department of Animal Production, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia (24.8051°N, 46.5203°E). Sixty male Ardhi goats were used in this study. The goats were approximately three months old and weighed 17 kg at the beginning of the study. The kids were randomly assigned to four treatment groups, each with 15 animals, subdivided into five subgroups, each with three goats. Before starting the experiment, the animals were ear-tagged, treated for internal and external parasites, and housed in partially shaded pens supplemented with individual feeding and watering troughs. The feeding trial was extended for 84 days, preceded by a 14-day adaptation period, during which animals were gradually fed experimental diets in addition to lucerne (*Medicago sativa*) hay. During the experimental period, the kids received one of the following four treatment diets: group 1 (control, C) was fed a concentrated mixture as a basal diet (BD), comprising barley, yellow corn, wheat bran, soybean meal, and a mixture of vitamins and minerals; group 2 was fed a BD supplemented with 10 ppm LAS; group 3 was fed a BD supplemented with 20 ppm LAS; and group 4 was fed a BD supplemented with 30 ppm LAS (Table 1). The rations were formulated in pellet form to meet the nutrient requirements of the kids in iso-nitrogenous and iso-caloric forms. They were offered food ad libitum twice daily at 08:00 and 15:00. Drinking water and salt licks were provided around the clock.

Table 1. Chemical composition of diet analysis

Ingredients	Treatments			
	Control	LAS 10	LAS 20	LAS 30
CP%	16.24	17.25	17.06	17.44
ADF	12.22	15.46	15.90	17.02
NDF	23.77	27.08	23.56	25.36
Lignin	5.40	5.52	6.09	6.26
NFC	50.93	46.82	50.24	47.94
Fat	1.85	1.96	1.76	1.68
Ash	7.21	6.89	7.38	7.58
Ca	0.89	1.00	0.85	1.06
P	0.38	0.40	0.38	0.38
Mg	0.21	0.23	0.23	0.23
K	1.21	1.36	1.30	1.42
Sulfur	0.21	0.23	0.22	0.24
Na	0.51	0.60	0.53	0.57
Zn (ppm)	91.00	111.00	102.00	112.00
Copper (ppm)	15.00	18.00	14.00	15.00
TDN	88.60	82.10	81.60	80.40
NEL (Mcal/lb)	0.93	0.86	0.86	0.84

Control BD + 0 ppm LAS; LAS 10, BD + 10 ppm LAS; LAS 20 = BD + 20 ppm LAS; LAS 30 = BD + 30 ppm LAS.
LAS, lasalocid; ADF, acid detergent fiber; NDF, neutral detergent fiber; NFC, non-fiber carbohydrate; TDN, total digestible nutrient; NEL, net energy for lactation; BD, basal diet.

Slaughter, carcass, and non-carcass components

At the end of the growth period, eight animals were randomly selected from each treatment group and slaughtered following the Halal meat protocol. The carcass and non-carcass components (NCC) were weighed immediately after slaughter, and the weight of the digestive contents was computed as the difference between the full and empty digestive tracts. Empty body weight (EBW) was calculated as the difference between slaughter and gutfill weights. All carcasses were chilled overnight (at 4℃). The cold carcass weight was measured to determine chill shrinkage (CS). The carcasses were split into two halves from the pelvis to the neck along the vertebral column. The left side was cut between the 12th and 13th ribs to measure the ribeye area (REA), back fat, and body wall thickness. The Longissimus thoracis (LT) muscles from the 9th to 12th thoracic vertebrae on both sides were removed for further analysis.

Physicochemical properties of meat

pH and color measurements: The initial (pHi) and ultimate (pHu) pH values of meat were measured at 1 and 24 h postmortem, respectively, using a portable pH meter (Model pH 211, Hanna Instruments, Woonsocket, RI, USA) on the left LT muscle, caudal to the 12th rib. Moreover, the initial (i) and final (u) color components, lightness (L*), redness (a*), and yellowness (b*), were reported at 1 and 24 h postmortem, respectively. Color measurements were performed using a colorimeter (Konica Minolta, CR-400, Tyoko, Japan; Measuring aperture: 8 mm; Illuminant: CIE D65; Observer angle: CIE 2° Standard Observer). A 30 min blooming period was allowed before measuring the ultimate color components. Three readings were taken on the muscle surface, and the mean value was calculated. Color derivatives, including color saturation (chroma or C), hue angle (H^0), b/a ratio, and color change (ΔE), were calculated using the following equations:

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chroma (C*) = $(a^{*2} + b^{*2})^{1/2}$, H^0 = tan–1 (b/a), and $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ according to Mancini and Hunt [8] and Olfaz et al. [9].

Cooking loss (CL): CL was calculated following the procedure described by Suliman et al. [10]. Samples were placed in an electric commercial stainless-steel grilling oven and cooked at 200℃ to an internal temperature of 70℃. After cooking, the steaks were cooled to room temperature (20℃), the surface dried with filter paper, reweighed, and the CL was expressed as a percentage weight change.

Water-holding capacity (WHC): The WHC was determined following the methodology described by Wilhelm et al. [11]. A meat sample weighing approximately 2 g was analyzed in duplicate. Initially, the sample was placed between two filter papers and left under a 10 kg weight for 5 min. Finally, the WHC was determined as the difference between the initial and final weights of the sample and was expressed as a ratio relative to the original weight.

The myofibril fragmentation index (MFI): The MFI of the muscle samples was calculated according to Culler et al. [12]. Briefly, 4 g of muscle sample was minced using scissors. The sample was then homogenized in a mixer containing 40 mL of cold (2℃) MFI buffer. After that, several washes were performed, and the absorbance of the resultant 0.5 mg/mL solution was read at 540 nm using a spectrophotometer (HACH DR/3000 Spectrophotometer, HACH, Loveland, CO, USA). The MFI of each sample was calculated by multiplying the absorbance at 540 nm by 200.

Textural properties: A 2.5 cm-thick muscle sample (approximately 300 g) was used to perform the test. The sample was placed in an electric commercial stainless-steel grilling oven and cooked at 200℃ to an internal temperature of 70℃. The internal temperature was adjusted by inserting a thermocouple probe (Ecoscan Temp JKT; Eutech Instruments, Keppel Bay, Harbor Front, Singapore) into the center of each steak. The shear force (SF) of the LT was assessed according to Wheeler et al. [13]. Three round cores (1.27 cm in diameter) were removed from each cooked muscle sample parallel to the longitudinal orientation of the muscle fibers. SF was calculated as the maximum force (N/cm^2) perpendicular to the fibers using a TA.HD texture analyzer (Stable Micro Systems, Surrey, UK) equipped with a Warner–Bratzler attachment. The texture profile analysis was conducted using the texture analyzer (TA.HD, Stable Micro Systems, Surrey, UK) fitted with a compression plate attachment. Each sample was subjected to two 80% compression cycles. The components evaluated were hardness, cohesiveness, springiness, and chewiness.

Carcass measurements

Carcass linear measurements

The carcass linear measurements (cm) were recorded after the carcasses were kept at (4℃) for 24 h. These were performed on the left side of the chilled carcasses. The distance from the front end of the pelvic symphysis to the middle of the front side of the first rib was measured to represent internal carcass length. The external carcass length was measured from the shoulder to the ischiatic bone. The carcass width was measured at the fifth thoracic vertebrae and determined as the distance from the fifth thoracic vertebrae to the caudal end of the breastbone from the ventral side. Leg length was measured as the distance from the carpal joint to the front end of the pelvic symphysis. The rump width was measured at the widest part of the leg.

Carcass primal wholesale cuts

On postmortem day two, the carcasses were fabricated into wholesale (primal) cuts: shoulder, rack, loin, leg, foreshank, and breast. Each portion of the primary cut was recorded. Each carcass was divided into fore and hind saddles by cutting between the 12th and 13th ribs. Thin meat was removed from the natural seam between the flanks and leg and forwarded to the last rib midway to

its level of the last rib. The cutting was continued to 1/2 inch above the elbow joint, which separated the shank from the rough breast. The neck was removed where it blended with the shoulders. A cut was made between the fifth and sixth ribs, and the shoulders were removed. The portion left between the 6th and 12th ribs is called the rack and rib. The loin was cut from the hind quarter by sawing before the hipbone between the last two lumbar vertebrae. The remaining portion was the leg. The leg was divided into equal left and right halves by cutting across the pelvic bone. The breasts and shanks were removed from the foresaddles.

Carcass physical separation: The physical separation of the carcass tissues was performed after an overnight keeping of the carcasses at 4℃, then a rack cut (fifth to eighth thoracic vertebrae) was used to separate tissues into muscle, bone, fat, and trimmings using medical scalpels and sharp knives.

REA: The REA was measured by tracing the outer boundary of the longissimus dorsi muscle of the loin cut between the 12th and 13th ribs on transparent paper. The area was then measured using an electronic planimeter (Topcon KP-92N, TOPCON, Pleasanton, CA, USA), and the mean of two readings was recorded.

Backfat and body wall thickness measurements: Backfat thickness was measured over the center of the ribeye, between the 12th and 13th ribs, while body wall thickness was measured at the same site across the lean bone and fat of the lower rib, at a distance of five inches from the midline of the carcass. An electronic stainless-steel digital caliper (Tool Eye Inc - Touch Master, 1825 W Grand St, Springfield, MO, USA) was used to obtain these measurements.

Meat chemical composition

Meat proximate composition: LT muscle was used for this analysis. Before proximate analysis, all external fat and connective tissues were removed to determine moisture, protein, fat, and ash percentages. Frozen samples were thawed overnight at 4℃ before analysis. Each sample was ground using a tabletop grinder to obtain a sample of approximately 200 g. Samples were analyzed following AOAC [14].

Fatty acids analysis: The first step was producing a dried meat sample out of 3 g fresh meat by incubation in a furnace at 130℃ for 5 h. The lipids were then extracted by adding 3 mL of pure n-hexane and shaking for 2 min. The extract was then filtered through a syringe filter (nylon 0.45 μm), and the clear extract was evaporated under a gentle flow of pure nitrogen gas. The initial and final weights of the remaining lipids were measured and calculated. For the gas chromatography-mass spectrometry (GC-MS) analysis, 15 mg of the oil extract was first dissolved in pure n-hexane and vortexed for 2 min. The hexane phase was then separated, moved into a derivatization tube, and dried with gentle nitrogen blowing. Next, 2 mL of 2% NaOH (NaOH in methanol) was added, sealed tightly, heated at 90℃ for 5 min, and allowed to cool. Subsequently, 2 mL of BF3 in methanol was added, sealed tightly, and reheated for 30 min. After cooling, the solution was extracted with 3 mL n-hexane p.a. The n-hexane phase was used for the GC-MS analysis. GC-MS analysis was performed using a 7890B gas chromatograph / 5977 mass selective detector (Agilent Technologies, Santa Clara, CA, USA) with a DB-5ms capillary column (30 m × 0.25 mm × 0.25 μm film thickness) (Agilent Technologies). The injector temperature, ion source, quadrupole, and GC-MS interface were 250℃, 230℃, 150℃, and 280℃, respectively. The helium carrier gas flow rate was maintained at 1 mL/min. A derivatized sample (1 μL) was injected with a 4 min solvent delay time and splitless injection mode. The oven temperature program was initially set at 50℃ and held for 2 min, then increased to 150℃ at a rate of 15℃/min, held for 1 min, and finally increased to 300℃ at a rate of 8℃/min.

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Statistical analysis

Differences in the means of the different treatment groups were tested using analysis of variance in the SPSS software program version 21 (SPSS, Chicago, IL). Separation of the means was performed using Duncan's Multiple Range Test, where means ≤ 0.05 are considered significantly different. Data are expressed as the mean ± SEM.

RESULTS

The carcass data and NCC of Ardhi goats supplemented with LAS are presented in Table 2. The treatments did not show significant differences concerning carcass data, except for CS and dressing percentage (DP) based on EBW. The LAS 10 treatment group showed the highest chill-shrinkage value (2%, $p < 0.05$), followed by LAS 20, LAS 30, and the C. Notably, the LAS 10 group also reported the highest DP value (51.56%, $p < 0.05$) compared to the C and other treatment groups. In contrast, the C group reported the highest CS value (2.30%), followed by LAS 30, whereas the lowest DP on EBW was shown by the LAS 30 group, followed by the LAS 20 group. Including LAS in the diet of goats significantly affected NCC ($p < 0.05$), specifically the head, lungs, liver,

Table 2. Effects of lasalocid supplement on carcass data and non-carcass components (NCC) of Ardhi goats (N = 32)

Parameters	Treatments[1)]				SEM	*p*-value
	Control	LAS 10	LAS 20	LAS 30		
Carcass data						
Slaughter weight (SW, kg)	35.25	35.13	36.13	37.94	0.52	NS
Empty body weight (EBW, kg)	31.36	31.26	32.99	34.22	0.51	NS
Hot carcass weight (kg)	15.88	16.11	16.29	16.41	0.28	NS
Cold carcass weight (kg)	15.52	15.79	15.94	16.03	0.28	NS
Chill shrink (%)	2.30^{a}	2.0^{b}	2.20^{ab}	2.29^{a}	0.04	*
Dressing (%, SW-base)	44.98	45.84	45.04	43.26	0.43	NS
Dressing (%, EBW-base)	50.54^{a}	51.56^{a}	49.33^{ab}	47.94^{b}	0.46	*
CCI (kg/cm)	0.23	0.22	0.22	0.22	0.01	NS
Ribeye area (cm^{2})	12.58	13.76	11.40	12.74	0.37	NS
NCC (%)						
Head (skinned)	3.52^{a}	3.58^{a}	3.43^{a}	3.21^{b}	0.04	*
Heart	0.42	0.40	0.41	0.40	0.01	NS
Lungs	1.03^{a}	1.0^{a}	0.97^{a}	0.83^{b}	0.02	*
Liver	2.10^{bc}	2.22^{ab}	2.04^{c}	2.36^{a}	0.03	*
Spleen	0.17	0.18	0.16	0.16	0.01	NS
kidneys	0.35	0.35	0.36	0.37	0.01	NS
Genitals	1.38	1.47	1.46	1.44	0.04	NS
Skin	7.97	7.53	8.01	7.76	0.17	NS
Empty stomach	3.12^{b}	3.01^{b}	3.24^{b}	4.07^{a}	0.11	*
Empty intestine	2.76^{bc}	2.54c	3.24^{ab}	3.83^{a}	0.13	*
Gutfill	11.01^{a}	11.08^{a}	8.69^{b}	9.81^{ab}	0.36	*
Total NCC percentage	33.82	33.35	32.00	34.24	0.40	NS

[1)] Control, BD + 0 ppm LAS; LAS 10, BD + 10 ppm LAS; LAS 20, BD + 20 ppm LAS; LAS 30, BD + 30 ppm LAS.

LAS, lasalocid; NS, non-significant; CCI, carcass compactness index; BD, Basal diet.

[a–c]Means in the same row with different superscripts are statistically significant (*) at $p \leq 0.05$.

stomach, intestine, and gutfill. Although the total percentage of NCC was not significantly different ($p > 0.05$) between the treatments, LAS 20 and LAS 10 had the lowest values (32.0% and 33.35%, respectively), whereas LAS 30 had the highest percentage (34.24%).

The physicochemical properties of goat meat affected by LAS supplementation are presented in Table 3. The pHi and pHu differed significantly between the treatment groups ($p < 0.05$). Generally, the pHi decreased as the LAS inclusion increased. Group C had the highest pHi value (6.18), whereas LAS 20 had the lowest value (5.89). In contrast, group C had the lowest pHu value (5.78), whereas LAS 30 had the highest value (6.09). LAS supplementation significantly affected CL and MFI ($p < 0.05$). As LAS supplementation increased, CL increased, where LAS 30 displayed the highest CL (36.95%), followed by the LAS 20, LAS 10, and C groups. The same trend of CL was also followed by MFI, with LAS 30 attaining the highest MFI value (103.76), followed by the LAS 20, C, and LAS 10 groups.

Furthermore, the initial lightness (Li*) and yellowness (bi*) color components were significantly affected by the treatment ($p < 0.05$), whereas the redness (ai*) color component showed an insignificant response ($p > 0.05$). Including LAS supplementation increased the initial lightness of meat, with the C group showing the lowest value (37.87) and LAS 30 showing the highest value (42.69), followed by LAS 20 and LAS 10. In contrast, the bi* values increased with the highest rates of LAS inclusion, with LAS 20 and LAS 30 attaining the highest values (7.68), whereas LAS 10 showed the lowest value (5.95). Notably, the LAS 30 group exhibited the highest ($p < 0.05$) ultimate lightness value (46.57). The ultimate redness (au*) value was increased with LAS addition ($p < 0.05$). The highest au* value (15.95) was reported for the LAS 20 group, whereas the lowest value (13.57) was reported for the C group. The treatments did not significantly affect color derivatives;

Table 3. Effects of lasalocid supplement on physicochemical properties of Ardhi goat meat (N = 32)

Parameters	Treatments[1)]				SEM	*p*-value
	Control	LAS 10	LAS 20	LAS 30		
Initial pHi (1 h PM)	6.18^{a}	6.10^{ab}	5.89^{c}	5.96^{bc}	0.04	*
Ultimate pHu (24 h PM)	5.78^{b}	5.79^{b}	5.85^{b}	6.09^{a}	0.03	*
Water-holding capacity (%)	26.0	26.39	25.15	27.85	0.46	NS
Cooking loss (%)	28.10^{b}	31.17^{b}	36.58^{a}	36.95^{a}	0.85	*
MFI	87.95^{bc}	86.50^{c}	98.54^{ab}	103.76^{a}	2.22	*
Initial color components (1 h PM)						
Lightness (Li*)	37.87^{b}	39.58^{ab}	41.11^{a}	42.69^{a}	0.59	*
Redness (ai*)	11.44	12.02	12.74	12.16	0.27	NS
Yellowness (bi*)	6.51^{ab}	5.95^{b}	7.68^{a}	7.68^{a}	0.24	*
Ultimate color components (24 h PM)						
Lightness (Lu*)	45.15^{ab}	45.15^{ab}	43.22^{b}	46.57^{a}	0.47	*
Redness (au*)	13.57^{b}	15.08^{ab}	15.95^{a}	14.61^{ab}	0.36	*
Yellowness (bu*)	15.74	16.0	16.73	15.73	0.27	NS
Color derivatives						
Color change (ΔE)	12.25	12.36	10.30	10.07	0.45	NS
b/a Ratio	1.17	1.07	1.05	1.09	0.02	NS
Chroma (C*)	20.80	22.02	23.12	21.50	0.40	NS
Hue angle (H^{o})	49.40	46.76	46.34	47.28	0.54	NS

[1)] Control, BD + 0 ppm LAS; LAS 10, BD + 10 ppm LAS; LAS 20, BD + 20 ppm LAS; LAS 30, BD + 30 ppm LAS.

[a–c]Means in the same row with different superscripts are statistically significant (*) at $p \leq 0.05$.

LAS, lasalocid; NS, non-significant; MFI, myofibril fragmentation index; BD, basal diet.

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however, the color intensity (C*) increased with LAS supplementation, whereas ΔE decreased as LAS supplementation increased. In contrast, the WHC was not significantly different between treatments.

The results of the linear carcass measurements (cm), primary wholesale cuts (%), physical separation (%), and carcass fat depots are presented in Table 4. Internal and external carcass length and width were significantly increased with LAS inclusion ($p < 0.05$), whereas rump width and leg length were not, although they were numerically increased with LAS addition. In contrast, LAS did not significantly affect primal wholesale cuts except for foreshank and breast (FSB) cuts. The LAS 10 group showed the highest FSHB value (20.55%, $p < 0.05$) compared with the other treatment groups. The loin cut increased) as the LAS inclusion increased ($p > 0.05$. In addition, the meat percentage increased with LAS supplementation ($p < 0.05$), whereas fat, bone, and trimming showed no significant differences. None of the carcass fat depots of Ardhi goats was affected by LAS inclusion ($p > 0.05$), except for back fat. The backfat content of the Ardhi goats increased significantly with LAS supplementation ($p < 0.05$). The highest back fat value (2.14 mm, $p < 0.05$) was attained by the LAS 30 group, followed by the LAS 20, LAS 10, and C groups.

Table 5 displays the chemical composition and textural properties of Ardhi goats fed the LAS

Table 4. Effects of lasalocid supplement on carcass linear measurements (cm), primal wholesale cuts (%), physical separation (%), and carcass fat depots of Ardhi goats (N = 32)

Parameters	Treatments[1)]				SEM	*p*-value
	Control	LAS 10	LAS 20	LAS 30		
Carcass linear measurement (cm)						
Internal carcass length	66.25^{b}	71.88^{a}	73.25^{a}	74.38^{a}	1.0	*
External carcass length	70.0^{b}	73.69^{ab}	73.38^{ab}	75.18^{a}	0.78	*
Carcass width	30.88^{b}	33.50^{a}	33.25^{a}	34.0^{a}	0.36	*
Rump width	35.63	35.75	35.81	36.13	0.28	NS
Leg length	41.13	41.0	41.69	41.56	0.39	NS
Carcass primal wholesale cuts (%)						
Shoulder	31.16	31.56	31.42	31.33	0.33	NS
Rack	8.18	7.86	7.93	8.40	0.14	NS
Loin	12.28	12.19	12.98	12.93	0.29	NS
Leg	28.89	27.85	28.17	28.61	0.38	NS
FSB	19.50^{ab}	20.55^{a}	19.50^{ab}	18.73^{b}	0.22	*
Carcass physical separation (%)						
Fat	7.17	8.15	5.24	6.81	0.52	NS
Meat	54.12^{ab}	54.39^{ab}	57.53^{a}	50.65^{b}	0.97	*
Bone	33.52	31.72	31.89	36.82	0.95	NS
Trimmings	5.19	5.73	5.33	5.72	0.29	NS
Carcass fat depots:						
Omental fat (%)	1.45	2.0	1.93	1.64	0.12	NS
Mesentery fat (%)	1.23	1.36	1.15	1.10	0.05	NS
Pericardial fat (%)	0.24	0.27	0.26	0.22	0.01	NS
KKCF (%)	0.93	1.01	1.23	0.95	0.07	NS
Backfat (mm)	1.75^{b}	1.91^{ab}	2.09^{a}	2.14^{a}	0.05	*
Body wall thickness (mm)	5.26	4.65	4.79	5.32	0.15	NS

[1)] Control, BD + 0 ppm LAS; LAS 10, BD + 10 ppm LAS; LAS 20, BD + 20 ppm LAS; LAS 30, BD + 30 ppm LAS.

[a,b]Means in the same row with different superscripts are statistically significant (*) at $p \leq 0.05$.

LAS, lasalocid; NS, non-significant; FSB, foreshank and breast; KKCF, kidney knob and channel fat; BD, basal diet.

Table 5. Effects of lasalocid supplement on chemical composition and textural properties of Ardhi goat meat (N = 32)

Parameters	Treatments[1)]				SEM	*p*-value
	Control	LAS 10	LAS 20	LAS 30		
Meat chemical composition (%)						
Moisture	71.21	71.88	70.84	71.48	0.28	NS
Crude protein	20.64	20.46	19.72	19.58	0.19	NS
Ether extract	3.63	3.12	4.85	4.42	0.34	NS
Ash	1.02	1.03	1.09	1.02	0.02	NS
Textural properties						
Shearing force (N)	24.64^{ab}	33.82^{a}	18.06^{b}	24.73^{ab}	1.86	*
Hardness (N)	11.80	12.94	10.62	11.08	0.55	NS
Springiness	0.77^{a}	0.75^{a}	0.69^{b}	0.68^{b}	0.01	*
Cohesiveness	0.62^{a}	0.59^{a}	0.55^{b}	0.51^{b}	0.01	*
Chewiness	5.70^{ab}	5.81^{a}	4.06^{bc}	3.91^{c}	0.32	*

[1)] Control, BD + 0 ppm LAS; LAS 10, BD + 10 ppm LAS; LAS 20, BD + 20 ppm LAS; LAS 30, BD + 30 ppm LAS.

[a-c]Means in the same row with different superscripts are statistically significant (*) at p ≤ 0.05.

LAS, lasalocid; NS, non-significant; BD, basal diet.

supplement. LAS supplementation in the diet of goats had no significant effect on the chemical composition of meat. Nevertheless, higher percentages of crude fat were observed with high levels of LAS inclusion ($p > 0.05$), particularly LAS 20 and LAS 30, at 4.84% and 4.42%, respectively. In contrast, LAS inclusion significantly affected SF ($p < 0.05$). Although the results were inconsistent and did not show any trend regarding LAS treatment, the LAS 20 supplement group had the lowest SF value (18.06 N), followed by the C group. Furthermore, all other texture profile properties differed significantly between the treatment groups except for hardness ($p < 0.05$). Notably, increasing the level of LAS supplementation decreased the springiness, cohesiveness, and chewiness.

Table 6. Effects of lasalocid supplement on meat fatty acids composition (%) of Ardhi goats (N = 32)

Fatty acids (%)	Formula	Treatments[1)]				SEM	*p*-value
		Control	LAS 10	LAS 20	LAS 30		
Capric	$C_{10}H_{20}O_2$	0.54	0.69	0.53	0.50	0.06	NS
Lauric	$C_{12}H_{24}O_2$	1.07^{ab}	1.60^{a}	0.76^{b}	0.47^{b}	0.13	*
Myristic	$C_{14}H_{28}O_2$	10.89^{a}	10.55^{a}	5.09^{b}	3.59^{b}	0.92	*
Palmitic	$C_{16}H_{32}O_2$	0.52	2.85	3.42	2.11	0.83	NS
Palmitoleic	$C_{16}H_{30}O_2$	3.97	2.47	1.43	3.62	0.56	NS
Margaric	$C_{17}H_{34}O_2$	2.52	4.60	3.10	3.58	0.95	NS
Linoleic	$C_{18}H_{32}O_2$	4.66	3.74	2.91	6.66	1.21	NS
Oleic	$C_{18}H_{34}O_2$	40.82^{a}	26.87^{b}	22.06^{b}	27.62^{b}	2.32	*
Elaidic	$C_{18}H_{34}O_2$	2.40	1.36	2.45	3.24	0.37	NS
Stearic	$C_{18}H_{36}O_2$	4.60	2.66	2.74	3.33	0.44	NS
Arachidonic	$C_{20}H_{32}O_2$	0.92^{b}	6.27^{ab}	7.99^{a}	4.66^{ab}	1.07	*
Gondoic	$C_{20}H_{38}O_2$	0.04^{b}	0.53^{ab}	0.36^{ab}	0.93^{a}	0.11	*
Eicosapentaenoic (EPA)	$C_{20}H_{30}O_2$	0.03^{b}	0.50^{ab}	0.78^{a}	0.39^{ab}	0.10	*

[1)] Control, BD + 0 ppm LAS; LAS 10, BD + 10 ppm LAS; LAS 20, BD + 20 ppm LAS; LAS 30, BD + 30 ppm LAS.

[a,b]Means in the same row with different superscripts are statistically significant (*).

LAS, lasalocid; BD, basal diet; P, probability; NS, non-significant.

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The lowest values, 0.68, 0.51, and 3.91 of springiness, cohesiveness, and chewiness, respectively, were attained by the LAS 30 group, whereas the highest values, 0.77 and 0.62 of springiness and cohesiveness, respectively, were reported by the C group. The highest chewiness value (5.81) was displayed in the LAS 20 group, followed by the C group (5.70).

The fatty acid composition of Ardhi goats affected by LAS supplementation is presented in Table 6. The treatment groups showed significant differences in the lauric, myristic, oleic, arachidonic, gondoic, and eicosapentaenoic fatty acids ($p < 0.05$). In general, lauric, myristic, and saturated fatty acids decreased with the addition of LAS ($p < 0.05$). The levels of arachidonic and eicosapentaenoic polyunsaturated fatty acids, in addition to gondoic acid, a monounsaturated acid, increased with the inclusion of LAS ($p < 0.05$). Additionally, polyunsaturated oleic acid significantly increased with LAS supplementation compared to the C group ($p < 0.05$). Although linoleic acid did not show significant differences between the treatments, it increased with a higher inclusion of LAS (LAS 30).

DISCUSSION

Many factors affect the quality characteristics of the end products related to the carcasses and meat of livestock. Among these factors are the physical and chemical characteristics of the diet [15]. This study showed no significant impact of LAS inclusion in the diets of goats on final slaughter weight (SW). These findings are in line with that reported by Sadeghi et al. [16], who studied the effects of adding two types of ionophores in diets of lambs on growth performance and carcass characteristics, and Price et al. [17], who tested the effect of dietary ionophores on the feedlot performance of lambs. The results for empty body, hot carcass, and cold carcass weights also agreed with those of Sadeghi et al. [16], in which no significant effects of LAS inclusion were observed between the treatment groups. Furthermore, Crane et al. [18] observed an increase ($p > 0.05$) in the hot carcass weights of lambs fed diets supplemented with LAS compared to non-supplemented groups. The hot carcass weights of the LAS 10, LAS 20, and LAS 30 treatment groups increased compared to the C group but not the DP. This result is also consistent with the conclusion of a meta-analysis that evaluated the effects of adding LAS to beef and dairy cattle [19]. The DP based on SW was not significantly affected by LAS inclusion, the same result as reported by Sadeghi et al. [16] and Crane et al. [18]. In contrast to this conclusion, the DP on EBW was significantly influenced by the addition of LAS. This finding could be attributed to the significant differences in the gutfill content between the treatments. Although the C and LAS 10 groups showed the highest gutfill content, they also reported the highest DP on EBW because of the higher SWs of the LAS 20 and LAS 30 groups. Although the REA showed no significant differences between the treatments, the LAS 10 and LAS 30 groups showed increased REA compared with the C group. Including LAS in the diets of growing goats decreased the total percentage of NCC up to LAS 20, whereas the percentage increased at LAS 30.

The pHi, pHu, CL, and MFI were significantly affected by including LAS in the diets of Ardhi goats, whereas the WHC showed a numerical increase in LAS 10 and LAS 30 but decreased in LAS 20. Notably, including LAS significantly reduced the pHi values, whereas only LAS 30 showed a significant pHu compared to the rest of the treatment groups. The CL results coincided with those of WHC, where higher percentages of WHC indicated a lower capacity to hold water, reflected in a higher water loss during cooking. Contrary to our results, Krelowska-Kulas et al. [20] indicated an improvement in the WHC of the muscles of lambs supplemented with LAS. This discrepancy may be ascribed to the lower rate of LAS inclusion (10–30 ppm) in this study.

Including LAS improved the MFI of the muscles of the animals in the treated groups, especially at higher concentrations (20 and 30 ppm). The influence of ionophore application on the intensity of overall meat color was previously investigated [21–23]. In agreement with these studies, including LAS in the diets of Ardhi goats significantly increased the initial (Li*) and ultimate (Lu*) lightness and initial yellowness of the meat, and a numerical increase in initial redness without a significant impact, but ultimate redness was significantly increased. The overall color intensity of the goat meat increased with the addition of LAS.

All carcass linear measurements responded positively to including LAS in the diet. While internal and external carcass length and width significantly increased with LAS addition, rump width and leg length were not, but also numerically increased with LAS supplement. Carcass primal wholesale cuts also did not reflect any significant effects of LAS supplementation, except for FSB. While physically separated meat differed significantly between treatments, fat, bone, and trimming did not. Generally, including LAS at 10 and 20 ppm resulted in higher meat content; however, LAS 30 resulted in lower meat content than in the C group and the other two treatments. Krelowska-Kulas et al. [20] reported that including LAS in the diets of lambs significantly reduced fat content. This conclusion aligns with our results, in which fat content was numerically reduced by including LAS.

Adding LAS to the diet of goats did not consistently affect carcass fat depots. None of the fat depots showed significant differences between the treatments, except for back fat. The backfat content increased with an increase in LAS supplementation. The lower rate of LAS inclusion in this study may explain the contradictory results reported by Krelowska-Kulas et al. [20], in which adding LAS led to decreased fat content.

No meat chemical composition parameters were significantly affected by LAS addition; however, crude protein and ether extracts were numerically decreased and increased, respectively.

Notably, all textural properties of meat, excluding hardness, responded significantly to including LAS. Generally, meat tenderness increased with high levels of LAS inclusion, which was also true for meat hardness. Springiness, cohesiveness, and chewiness were decreased with LAS supplementation.

Diet and feed additives play major roles in lipid metabolism, fatty acid synthesis, and fat building in tissues. Attention to the alteration of fatty acids in meat has increased because fatty acid composition plays a vital role in determining meat quality [21]. Fortunately, the essential polyunsaturated fatty acids (Omega-6), linoleic, and arachidonic acids increased when including LAS. These fatty acids are unique because the body cannot produce them unless they are available in the diet [22]. This study revealed that the most abundant fatty acids were oleic, myristic, linoleic, and stearic. This result is consistent with that of Simela [23], who studied the meat characteristics and acceptability of chevons from South African indigenous goats. Oleic, linoleic, and palmitic acids represented up to 74.4% of the total fatty acid content in the longissimus lumborum samples. In contrast to a previous study, myristic acid was the second most abundant acid in our study.

In conclusion, this study evaluated LAS supplementation in goat diets to enhance carcass characteristics, meat quality, and fatty acid profiles. Including LAS in the diets of Ardhi goats enhanced the carcass characteristics of the animals concerning weights at slaughter, EBW, and hot carcasses. Supplementation did not negatively affect other carcass or meat quality traits. Adding LAS significantly reduced the percentage of saturated fatty acids, whereas the percentage of essential polyunsaturated acids increased. Further studies should include LAS at higher rates to obtain significant positive changes in other carcass characteristics and meat quality attributes.

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