Effects of feeding different levels of chromium-methionine in hairy lambs finished with high-energy diets under high ambient heat load: Growth performance, dietary energetics, and carcass traits

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SUMMARY
The aim of this study was to evaluate different levels of chromium methionine (Cr-Met) supplemented in lambs fattening under high ambient heat load. For this reason, 40 Pelibuey × Katahdin castrated male lambs (34.28 ± 3.10 kg initial weight) were daily supplemented with 0.00, 0.60, 1.20 or 1.80 mg Cr/lamb during 56-d for determining treatments effects on growth performance, carcass characteristics, shoulder muscle tissue composition, and visceral mass. The experimental consisted in a randomized complete block design (5-pen blocks, 2 lambs per pen and 5 pens (10 lambs)/ treatment). The feeding program consisted in a total mixed high-energy corn-based finishing diet (87:13 concentrate to forage ratio). Air ambient and the relative humidity during the experiment averaged 29.7 ± 1.4°C and 67.8 ± 5.9%, respectively. This ambient condition resulted in an average of temperature humidity index (THI) of 80.6 which represents a high ambient heat load condition for the lamb productivity. Supplemental Cr-Met did not affect ($P \geq 0.21$) dry matter intake (DMI) but linearly increased ($P<0.01$) average daily gain (ADG), thus increased ($P \leq 0.02$) gain efficiency, dietary net energy, and observed-to-expected dietary net energy ratio. In consistence with the temperature and humidity ambient conditions, the observed to expected dietary NE ratio in the control group was 4% below of the anticipated (0.94) according to the estimated energy based in the ingredient composition in diet, while to 1.20 and 1.80 mg Cr/lamb/day supplemented group, the observed to expected dietary NE was as the expected (1.00), indicating a greater efficiency in energy utilization destined to growth even when they were fattening under high ambient load. There were no effects ($P \geq 0.14$) of Cr-Met on carcass weight, dressing percentage or longissimus muscle area. However, fat thickness ($P=0.04$) and kidney-pelvic-fat ($P=0.01$) were linearly reduced as Cr-Met ingestion was increased. Muscle tissue proportion in shoulder was linearly increased ($P<0.01$) and fat proportion was reduced ($P<0.01$) by Cr-Met supplementation. Whole cuts and visceral organ mass (expressed as g/kg empty body weight) were not affected by Cr-Met ingestion, but visceral fat was linearly reduced ($P=0.04$). It was concluded that ingestion of Cr-Met increased dietary energy utilization in feedlot lambs fattening under high ambient heat load and has a modulating effect on the carcass by reducing fat. Favorable responses on performance, dietary energy, carcass and tissue composition were reached when Cr was supplemented from the dose of 1.20 mg/lamb/day.

KEY WORDS
Chromium methionine, Feedlot lambs, Dietary energetics, Tissue composition, Carcass, Hot climate.

INTRODUCTION

Tropical and subtropical climates are characterized by high ambient heat loads (HAHL), which limit feedlot lamb productivity [1]. As a result of lower feed intake during HAHL, average daily gain and muscle accretion are significantly reduced [2]. However, reductions in feed intake (and thus in energy intake) is not proportional to the reductions in ADG [3]. The above can be explained because metabolic adjustments that domestic animals raised under HAHL entail an extra energy expenditure even in animals well adapted to those conditions [4]. These metabolic adjustments are associated, among others, with lower insulin concentrations, insulin-like growth factor-1 and higher blood cortisol levels which impaired energy and protein utilization [5-7]. Therefore, among the strategies to mitigate the negative effects of HAHL is the use of compounds that reduce these negative metabolic changes for the efficient use of food energy for growth. Chromium (Cr) is an essential trace mineral approved for use as feed additive in ruminants. Cr increases in-

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sulin signaling and consequently, altered glucose and protein metabolism, affecting protein: fat ratio tissue composition [8,9]. In addition, it has been informed that supplementing diets with chromium reduces stress conditions in newly received cattle [10,11]. In ruminants fattening under favorable ambient conditions, supplemental organic Cr (as Cr enriched live yeast) at a dose of 1 to 1.15 mg/kg of diet improved the dietary net energy from 8 to 14% in feedlot cattle [12] and in feedlot lambs [13]. However, separating the effects of the live yeast from the effects of Cr in those experiments is difficult. When Cr is supplemented solely (inorganic or organic forms), the results on growth performance, carcass tissue composition and reduction of stress conditions, have been inconsistent. These inconsistencies have been attributed mainly to dosing (or supplementation level) [13,14], type of Cr (organic vs inorganic) [15], the energy density of the diet [16], and the physiological status of Cr and stress condition [17-18]. Regarding the latter, stressed lambs by transportation that received 0.80 mg of Cr-methionine/kg diet DM, improve 12.5% the feed efficiency (gain-to- feed ratio) when compared to control lambs [19]. In Tan lambs growing in favorable ambient conditions, Jin and Zhou [20] tested different levels of Cr-Met ingestion (0, 0.75 and 1.50 mg/d) in a low-to-moderate energy diet (1.46 and 1.70 Mcal NE_m/kg diet). They reported improvements on digestibility and meat characteristics, but not in growth performance. In feedlot lamb systems in America, lambs were finished with grain corn-based diets containing around 2.05-2.10 Mcal diet NE_m/kg diet, and diets rich in cereals and soluble sugars may promote a greater body Cr elimination increasing its requirements [21]. Furthermore, the tissue composition of gain during finishing is mainly fat; thus, finishing phase, under dietary energy utilization concept, is the less efficient stage since fat accumulation costs 1.65 as much of energy as muscle accretion [22], the lower efficiency in this phase can be aggravated under conditions of high environmental heat load. Therefore, the use of compounds that modulate composition of gain (leaner composition) and reduce the negative effects of heat load can be a strategy to improve dietary energy utilization improving performance and carcass characteristics of lambs finishing with high-energy diets under high ambient heat load conditions. For this reason, the objective of this experiment was to evaluate the effects of feeding different levels of chromium-methionine in hairy lambs finished under high ambient heat load, the variables measured were growth performance, dietary energetics, carcass traits, and visceral mass.

MATERIALS AND METHODS

The experiment was conducted at the Universidad Autónoma de Sinaloa Feedlot Lamb Research Unit, located in Culiacán, México (24°46 13" N and 107°21 14" W). Culiacán is about 55 m above sea level and has a tropical climate. All animal management procedures were conducted within the guidelines of federally and locally approved techniques for animal use and care and approved by the Ethics Committee of the Faculty of Veterinary Medicine and Zootechnics of the Autonomous University of Sinaloa (Protocol #05212023).

Climatic Variables and Temperature Humidity Index (THI) Calculation

Climatic variables (ambient temperature and relative humidity) were obtained every hour from two on-site weather stations (Thermo-hygrometer Avaly, Mod. DTH880, Mofeg S.A., Zapopan, Jalisco, Mexico). The temperature humidity index (THI) was calculated using the formula described by Dikmen and Hansen [23].

Animals, Diet, and Experimental Design

Forty Pelibuey× Katahdin male intact lambs (212±15 d age; 34.28 ± 3.10 kg initial weight) were used in order to evaluate the effects of different levels of chromium methionine (Cr-Met) supplemented in lambs fattening under high ambient heat load ambient on growth performance, dietary energy, carcass traits, muscle tissue composition, and visceral organ mass. Four weeks before the initiation of the experiment, all lambs were treated for parasites (Albendaphorte 10%, Animal Health and Welfare, México City, México), injected with 1×10^6 IU vitamin A (Synt-ADE®, Fort Dodge, Animal Health, México City, México), and vaccinated for Mannheimia haemolytica (One shot Pfizer, México City, Mexico) and were adapted to the basal finishing diet without supplemental Cr-Met (Table 1) and facilities. The basal diet was prepared using a 2.5 m^3 capacity paddle mixer (model 30910-7, Coyoacán, México) Feed sample (~ 50 g) of each batch was taken and stored (4°C) in sealed bags through the experiment, samples were composited previously to submit them to laboratory analysis. Upon initiation of the experiment, all lambs (n=40) were weighed before the morning meal (electronic scale; TORREY TIL/S: 107 2691, TOR REY Electronics Inc., Houston TX, USA), and assigned to one of five weight groupings in 20 pens, with two lambs per pen, and 5

Table 1 - Composition of basal diet offered to lambs and treatments[1].

Item	Basal diet % DM basis
Ingredient composition	
Sudangrass hay	8.00
Alfalfa hay	5.00
Cracked corn	63.50
Soybean meal	10.00
Molasses cane	8.00
Yellow grease	3.00
Trace protein-mineral salt[2]	2.50
Chemical composition [3]	% DM basis
Dry matter content	87.88
Crude protein	14.10
Neutral detergent fiber	17.60
Ca	0.70
P	0.32
Calculated net energy (Mcal/kg) [4]	
Maintenance	2.10
Gain	1.44

[1] All lambs were feeding with the basal diet and receiving daily chromium-methionine (Cr-Met) as follows: 1) chromium-methionine dosed as 0.00 mg/lamb (Control), 2) chromium-methionine dosed as 0.60 mg/lamb (Cr-Met-0.6), 3) chromium-methionine dosed as 1.20 mg/lamb (Cr-Met-1.2), and 4) chromium-methionine dosed as 1.80 mg/lamb (Cr-Met-1.8). The source of chromium-methionine used was Zinpro Microplex® (Zinpro Corp, Eden Prairie, MN, USA). To ensure the concentration of the planned dose, each dose of respective treatment was hand-mixed with 30 g of ground wheat bran and was provided minutes before lambs received the morning feed, thus, a total dose of each treatment was offered once a day. Lambs in the control group received 30 g of ground wheat bran without Cr-Met.

[2] Mineral premix contained: Crude protein 50%, Calcium, 20%; $CoSO_4$, 0.010%; $CuSO_4$, 0.15%; $FeSO_4$, 0.528%; ZnO, 0.111%; $MnSO_4$, 0.160%; KI, 0.007%; and NaCl, 13.7%.

[3] Dry matter, CP, and NDF were determined in our laboratory by analyzing subsamples collected and composited throughout the experiment. Accuracy was ensured by adequate replication with acceptance of mean values that were within 5% of each other.

[4] Based on tabular net energy (NE) and nutrient composition values for individual feed ingredients [26].

replicas per treatment. Pens have 6 m^2 with overhead shade, bucket type waterers and 1 m fence-line feed bunks. All lambs were feeding with the high-energy basal finishing diet (Table 1) and receiving daily chromium-methionine (Cr-Met) as follows: 1) chromium-methionine dosed as 0.00 mg/lamb (Control), 2) chromium-methionine dosed as 0.60 mg/lamb (Cr-Met-0.6), 3) chromium-methionine dosed as 1.20 mg/lamb (Cr-Met-1.2), and 4) chromium-methionine dosed as 1.80 mg/lamb (Cr-Met-1.8). The feeding trial lasted 56 days. The source of chromium-methionine used was Zinpro Microplex (Zinpro Corp, Eden Prairie, MN, USA). To ensure the concentration of the planned dose, each dose of respective treatment was hand-mixed with 30 g of ground wheat bran and was provided minutes before lambs received the morning feed, thus, a total dose of each treatment was offered once a day. Control group received 30 g of ground wheat bran without Cr-Met. Fresh feed was provided twice daily at 0800 and 1400 h. The amount of feed provided in the morning feeding was constant (450 g/lamb), which represented approximately 30% of the total daily feed consumption (as fed basis), whereas the feed offered in the afternoon was adjusted daily, allowing for a feed residual ~50 g/kg daily feed offering. Residual feed of each pen was collected between 0740 and 0750 h each morning, was composited through the experiment and weighed at final of the experiment to determine the feed intake. Feed samples were collected for each elaborated batch. Feed refusal was collected daily and composited weekly for DM analysis (oven drying at 105°C until no further weight loss; method 930.15) [24]. The adjustments to either increase or decrease daily feed delivery were provided in the afternoon feeding. Lambs were individually weighed prior to the morning feeding (0730 h) at experiment initiation and in final day (day 56). Live weights (LW) on day 1 were converted to shrunk body weight (SBW) by multiplying LW by 0.96 to adjust for the gastrointestinal fill. All lambs were fasted (for feed but not for drinking water) for 18 h before recording the final fasted LW.

Chemical Analysis

Feed samples were subjected to the following analyses: DM (oven drying at 105°C until no further weight loss; method 930.15) and CP (N× 6.25, method 984.13) according to AOAC [24]. Neutral detergent fiber (NDF) was determined following procedures described by Van Soest et al. [25].

Calculations

Estimates for determining growth performance (average daily gain (ADG), and feed eficiency), and the calculations to determine the observed dietary energy and the observed-to expected dietary energy ratio was performed following procedures previously described by Estrada-Angulo et al. [27].

Carcass Characteristics, Whole Cuts, LM Tissue Compositon and Visceral Mass Data

After feeding trial was finished, all lambs were harvested on the same day. Lambs were stunned (captive bolt), exsanguinated, and skinned. The gastrointestinal organs were removed and hot carcass weight (HCW) was immediately recorded. Dressing percentage was calculated as HCW/final fasted live weight. After carcasses (with kidneys and internal fat included) were chilled in a cooler at −2 to 1 °C for 24 h, the measurements of fat thickness (FT), longissimus muscle (LM) surface area, kidney, pelvic, and heart fat (KPH) were performed following procedures described by Ramos-Méndez et al. [28]. Each carcass was split into two halves. The left side was fabricated into wholesale cuts, without trimming, according to the North American Meat Processors Association guidelines (NAMP)[29]. Rack, breast, shoulder and foreshank were obtained from the foresaddle, and the loins, flank and leg from the hindsaddle. Weight of each cut was subsequently recorded. The tissue composition of the shoulder was assessed using physical dissection by the procedure described by Luaces et al. [30]. The visceral mass data was registered and calculated following the procedures described by Rivera-Villegas et al. [31].

Statistical Analysis

The number of pen replicates (5) and animals (10) within treatments are enough to determine statistical differences on performance, carcass, and visceral mass variables of feedlot lamb. Based on power analysis and SD for measure, we had a power of 0.905 for detecting a 5% difference. Growth performance data (gain, gain efficiency, and dietary energetics), DM intake, and carcass data were analyzed as a randomized complete block design, with the pen as the experimental unit, using the MIXED procedures of SAS software v. 9 [32], with treatment and block as fixed effects and the experimental unit within treatment as a random effect. Visceral organ mass data was analyzed using the MIXED procedures of SAS software [32], with treatment and pen as fixed effects and interaction between treatment and pen and individual carcasses within pen by treatment subclasses as random effects. Treatment means were separated using the "honestly significant difference test" (Tukey's HSD test). In all cases, the least squares mean and standard error are reported, and contrasts are considered significant when the P value ≤ 0.05.

RESULTS

No mortality was observed, and no lambs were removed from the experiment.

Ambient temperature and relative humidity (RH) during the experiment are shown in Table 2. The THI, calculated based on temperature and RH, ranged between 74.7 and 87.3 averaging 81.0 ± 3.5 during the experiment. Daily maximal THI exceeded 80 for an average of 4:20 h during the 56 days of the experiment. As a result of these environmental conditions, lambs' energy intake and comfort are expected to be compromised, which would affect their growth performance [33].

The supplemental Cr-Met effects on growth performance and dietary energetics are shown in Table 3. Supplemental Cr-Met did not affect ($P \geq 0.21$) daily dry matter intake (DMI) averaging 1.379±0.97 kg, but linearly increased average daily gain (ADG, P=0.01), thus, linearly increased gain to feed ratio (P=0.02), dietary net energy ($P<0.01$), and observed-to-expected dietary net energy ratio ($P<0.01$).

Effects of treatments on carcass, shoulder tissue composition and whole cuts are exposed in Table 4. There were no effects ($P \geq 0.14$) of Cr-Met supplementation on carcass weight, dressing percentage or LM area. However, fat thickness and kidney-pelvic-fat were linearly reduced ($P \leq 0.04$) as Cr-Met ingestion was increased. After 56-d of fattening, muscle proportion in the shoulder tissue was linearly increased and fat proportion was reduced by Cr-Met supplementation. Whole cuts were not af-

Table 2 - Ambient temperature (Ta), mean relative humidity (RH) and mean calculated temperature-humidity index (THI)[1] registered during the experiment.

Week	Mean T_a (°C)	Min T_a (°C)	Max T_a (°C)	Mean RH (%)	Min RH (%)	Max RH (%)	Mean THI	Min THI	Max THI
1	31.0±2.2	27.7±2.8	34.3±1.7	71.3±3.9	64.7±3.9	77.8±2.4	83.4±2.2	77.3±3.4	89.6±1.8
2	30.0±3.4	25.9±2.4	34.1±2.1	78.7±3.0	70.0±5.4	82.7±4.6	82.9±4.0	75.5±4.7	90.4±2.4
3	29.7±2.0	25.7±3.7	33.8±2.8	69.3±4.2	66.1±4.2	72.4±4.2	81.2±2.8	74.7±2.3	87.7±3.2
4	29.5±1.3	26.2±1.8	32.8±1.8	68.2±3.8	60.5±3.7	75.9±2.9	80.9±1.0	74.8±2.2	86.9±2.7
5	30.0±1.1	26.5± 2.4	33.4±2.1	67.3±4.1	57.3±4.4	77.2±4.2	81.5±1.2	74.9±2.7	88.1±3.6
6	28.6±1.2	25.4±1.6	31.9±1.9	62.6±6.6	57.5±7.3	67.6±.6.4	78.7±2.5	73.3±2.7	84.1±3.7
7	28.7±2.4	25.11±1.8	32.3±3.1	58.6±3.8	52.5±3.2	64.7±5.7	78.3±2.1	72.4±2.4	84.3±5.0
Average	29.7±1.9	26.1±2.1	33.2±2.0	67.7±5.9	61.2±6.0	74.2±6.5	81.0±3.5	74.7±2.6	87.3±2.8

[1] THI = 0.81 × ambient temperature + [(relative humidity/100) × (ambient temperature- 14.4)] + 46.4. THI code (Normal THI < 74; Alert >74-79; Danger 79-84 and Emergency > 84).

Table 3 - Treatment effects on growth performance and dietary energy in lambs finishing under high ambient load (average THI =81.0 ± 3.5) supplemented with chromium-methionine.

	Cr-Met ingestion/lamb, mg/d [1]					*P*- value		
Item	0.00	0.60	1.20	1.80	SEM	Linear	Quadratic	Cubic
Days on test	56	56	56	56				
Pen replicates [2]	5	5	5	5				
Live weight, kg [3]								
Initial	34.28	34.41	34.21	34.22	1.214	0.94	0.97	0.93
Final	48.77	49.52	50.55	50.63	1.249	0.23	0.82	0.85
Average daily gain, kg	0.259b	0.270b	0.292a	0.295a	0.011	0.01	0.47	0.24
Dry matter intake, kg	1.340	1.375	1.390	1.410	0.039	0.21	0.86	0.88
Gain to feed, kg/kg	0.194a	0.197ab	0.210b	0.209b	0.004	0.02	0.70	0.26
Observed dietary energy, Mcal/kg								
Maintenance	1.98b	2.00b	2.09a	2.08a	0.014	<0.01	0.27	0.13
Gain	1.33b	1.34b	1.42a	1.41a	0.012	<0.01	0.27	0.13
Observed to expected diet net energy								
Maintenance	0.94b	0.95b	1.00a	0.99a	0.009	<0.01	0.27	0.13
Gain	0.94b	0.95b	1.00a	0.99a	0.010	<0.01	0.27	0.13

Within a row, means without a common letter superscript differ ($p < 0.05$).
[1] Doses of Cr-Met was provided mixed with 30 g of ground wheat bran and was provided minutes before lambs received the morning feed, thus, a total dose/lamb of each treatment was offered once a day. Lambs of control group received 30 g of ground wheat bran without Cr-Met.
[2] Total pens replicate of each treatment represent 10 lambs.
[3] The initial body weight (BW) was reduced by 4% to adjust for the gastrointestinal fill, and all lambs werefasted (food but not drinking water was withdrawing) for 18 h before recording the final BW.

Table 4 - Supplementation of chromium methionine (Cr-Met) effect on carcass characteristics of lambs.

	Cr-Met ingestion/lamb, mg/d [1]					*P*- value		
Item	0.00	0.60	1.20	1.80	SEM	Linear	Quadratic	Cubic
Carcass weight, kg	28.53	28.73	29.62	29.36	0.517	0.16	0.75	0.51
Dressing percentage	58.50	58.03	58.60	57.98	0.698	0.95	0.40	0.28
CCW, kg [1]	27.77	28.50	29.44	29.01	0.707	0.20	0.59	0.76
LM area, cm^{2} [2]	18.26	18.79	19.00	19.32	0.466	0.14	0.82	0.85
Fat thickness, cm	0.404a	0.382ab	0.371ab	0.363b	0.013	0.04	0.56	0.84
KPH, % [3]	2.84a	2.69b	2.22c	2.24c	0.074	0.01	0.27	0.61
Shoulder composition,%								
Muscle	61.04b	62.64a	62.76a	63.43a	0.401	<0.01	0.30	0.28
Fat	19.53b	18.40ab	17.35a	17.04a	0.467	<0.01	0.40	0.76
Muscle to fat ratio	3.12b	3.40ab	3.62a	3.72a	0.142	0.04	0.55	0.82
Whole cuts (% of CCW)								
Forequarter	39.14	39.80	39.33	39.61	0.438	0.63	0.67	0.36
Hindquarter	37.38	37.73	33.55	38.14	0.429	0.30	0.78	0.52
Neck	8.17	7.73	7.93	7.69	0.405	0.50	0.81	0.56
Shoulder IMPS206	7.76	7.98	7.48	7.99	0.360	0.92	0.70	0.31
Shoulder IMPS207	14.78	14.91	14.76	14.69	0.362	0.80	0.78	0.83
Rack IMPS204	6.60	6.29	6.56	7.13	0.368	0.28	0.25	0.86
Breast IMPS209	3.79	3.87	3.99	3.84	0.212	0.76	0.61	0.75
Ribs IMPS209A	6.12	6.47	6.43	6.34	0.184	0.46	0.26	0.69
Loin IMPS231	8.94	9.70	9.09	9.23	0.419	0.89	0.47	0.28
Flank IMPS232	6.06	6.12	6.04	6.99	0.207	0.78	0.81	0.85
Leg IMPS233	22.07	21.52	21.97	22.62	0.449	0.32	0.21	0.70

Within a row, means without a common letter superscript differ ($p < 0.05$).
[1] Cold carcass weight.
[2] Longissimus muscle.
[3] Kidney-pelvic-hearth fat.

Table 5 - Supplementation of chromium methionine (Cr-Met) effect on visceral mass of finishing lambs.

	Cr-Met ingestion/lamb, mg/d [1]					*P*- value		
Item	0.00	0.60	1.20	1.80	SEM	Linear	Quadratic	Cubic
Organs, g/kg empty body weight								
Stomach complex [1]	34.04	34.03	34.38	34.13	1.251	0.91	0.93	0.88
Intestines [2]	40.43	40.08	41.02	41.10	2.175	0.77	0.92	0.83
Hearth + lungs	22.38	23.74	21.44	21.64	1.056	0.37	0.59	0.22
Liver	18.29	19.23	19.20	19.59	1.048	0.86	0.47	0.95
Kidney	2.71	2.75	2.73	2.57	0.121	0.43	0.41	0.88
Omental fat	27.06	26.65	24.32	25.55	1.646	0.37	0.63	0.49
Mesenteric fat	11.17a	10.00ab	9.26ab	8.86b	0.616	0.05	0.66	0.98
Visceral fat	38.23a	36.66ab	33.57b	34.41ab	2.28	0.04	0.41	0.40

Within a row, means without a common letter superscript differ (p < 0.05).
[1] Stomach complex = (rumen + reticulum + omasum + abomasum), without digesta.
[2] Small and large intestines without digesta.

fected by Cr-Met ingestion.
Visceral organ mass (expressed as g/kg empty body weight) was not affected (P≥0.25) by Cr-Met ingestion (Table 5), but visceral fat was linearly reduced (P=0.04) mainly by a linearly reduction of mesenteric fat (P=0.05).

DISCUSSION

According to the average weight registered during the experiment, the average Cr-Met ingestion to the treatments 0.60, 1.2 and 1.8 mg Cr-Met/day corresponds to 0.014, 0.028, and 0.042 mg/kg BW, respectively. Requirements of Cr for ruminants is not yet established. Diets that contain greater amounts of cereal grains, like finishing diets, are relatively poor in Cr (~0.04-0.06 mg/kg DM) [34]. According to current standards [35], the maximum tolerable concentration of Cr in diets is 1 g Cr/kg diet. Therefore, the total ingestion of Cr in the current experiment was within tolerable limits.
The absence of the effect of Cr supplementation on DM intake in fattening ruminants is consistent with previous reports in which Cr was supplemented as enriched Cr yeast [12,13] or as inorganic or organic Cr [20]. Although there are reports that DMI increased when dairy cows and calves have been supplemented with Cr, this effect may had been related to animals that present Cr deficiency when supplemented [21] or presented a short-term high stressful conditions (i.e., weaning, postpartum) that severely affect DM intake [36].
Most of the reports regarding Cr effects on productivity and health have been related to dairy cows and beef calves and to a lesser extent in fattening lambs. Even still, the precise requirements of Cr for growing-finishing ruminants still remains unknown. In this sense, the effects of Cr supplementation on growth performance varied considerably. Consistent with our findings, Valdés-García et al. [12] tested different dosage levels of Cr in finishing heifers. Maximal ADG and feed efficiency was observed in heifers consumed dose of 0.028 Mg Cr/kg BW. Related to finishing lambs, Ahmed and Rahman [37] reported a greater ADG and feed efficiency in Awassi lambs that were fed with a finishing diet supplemented with Cr-yeast at dose of 0.035 mg Cr/kg BW. In the same line, Estrada-Angulo et al. [13] reported linear improvements in ADG and feed efficiency in lambs supplemented with Cr-yeast being maximal response at dosage of 0.026 mg Cr/kg BW, similar to the dose used in the current experiment. Merino crossed lambs that were subjected to HAHL conditions during 63-d and supplemented with Cr-picolinate (~0.029 mg Cr-Pi/kg BW) showed greater ADG compared to non-supplemented lambs [38]. Lashkari et al. [17] report that supra-supplementation of Cr (supra-physiological doses) improves the growth performance of growing and fattening ruminants, which might explain why Cr-Met supplementation at or above of 1.2 mg per day increased the ADG and feed efficiency in the current experiment. In contrast, other studies did not observe effects of supplemental organic Cr in growth performance and feed efficiency of feedlot lambs. The majority of the reports that indicate absence de effects of Cr on growth performance have been made with low doses of Cr (<0.010 mg Cr/kg BW) with low-to-moderate (< 1.8 Mcal NE_m/kg diet) energy diets [39,40], or in lambs fattening under favorable ambient (i.e. THI <78) conditions [18]. For example, in a study performed under favorable ambient conditions by Jin and Zhou [20], in which Tan lambs were fed during 65-d with two diets (1.47 and 1.70 Mcal NE_m/kg) that containing high doses of Cr supplementation (0.026 and 0.051 mg Cr/kg BW) reported only a trend (P=0.09) for improvements in ADG and feed efficiency. The energy of diets and the environmental condition in which these experiment was carried out could have reduced the expected effects of supra-supplementation with Cr.
Just as dose affects the magnitude of response to Cr supplementation, it is well known that better responses to Cr supplementation are in stressed animals [18]. Although Pelibuey lambs and their crosses are better adapted to arid and to tropical ambient [41], when are fed under HAHL conditions (>79 THI) show adaptive changes in dietary intake patterns and energy utilization, that do not always translate into changes in the «stress parameters» such as rectal temperature, blood metabolites, breath rate, among others, but increases requirements of energy for maintenance, which negatively influences growth performance and dietary energy utilization [42,43]. An objective of this experiment was to determine how the supplementing Cr-Met effects can help to alleviate the negative impact on dietary energy utilization and growth of adapted lambs that are fattening under high ambient load. On the basis of observed growth performance and the calculated diet NE by ingredient composition in the basal diet (Table 1), the observed-to-expected ratio of dietary NE can be estimated. This ratio enables effective estimation of dietary energy utilization efficiency. In this manner, differences in energy usage for growth performance can be expressed with greater precision with the observed-to expected energy ratio than those conventional measures of "feed efficiency" [44]. The observed-to-expected dietary NE ratio of

1.00 indicates that the observed ADG is consistent with the expected ADG. If the ratio is below 1.00, the energy that is destined to ADG is utilizing less efficiently, while if the ratio is greater than 1.00, the utilizing energy destined to weight gain is more efficiently. In the case of controls, observed to expected dietary NE ratio was 6% below of the expected (0.94). This indicates that part of energy destined to gain was used to cover the increase of the energy maintenance requirement as a result of HAHL condition. Expressed differently, lambs that were not received supplemental Cr have an increase of 19.7% of maintenance coefficient requirement (MQ) above the specified standard for lambs under favorable ambient conditions of 0.056 Mcal/SBW$^{0.75}$ [45]. This increase in MQ is within range for animals under HAHL conditions specified for NRC [46]. In the case of Cr-Met supplemented lambs, the MQ increase over the specified coefficient (0.056) represented 17.3%, 2.4%, and 4.5% for 0.60, 1.20 and 1.80 mg Cr-Met/day, respectively. Therefore, it can be considered that daily chromium supplementation from 1.20 mg/lamb may reduce the energy requirements of the physiological mechanisms necessary to reestablish homeostasis in sheep subjected to HAHL. This energy saving for maintenance which translates into the improvements on energy efficiency used for gain could be explain by the effects observed of supplemental Cr on some physiological parameters related to energy metabolism in ruminants under HAHL conditions [10,37,38,47,48].

Cr-Met supplementation affected muscle and fat deposition in carcass. Cr is included in the auto amplification system for insulin signaling, enhancing insulin's effects and increasing glucose tolerance [49]. A higher insulin level in insulin-sensitive tissues (such as adipose tissue and muscle) might result in higher carcass quality [10]. The information about the effects of supplemental Cr on carcass characteristics and tissue composition of lambs are limited and inconsistent. Consistent with our results, Sánchez-Mendoza et al. [9], using similar lambs type, diet, and Cr source (doses at 0.016, 0.032, and 0.051 mg/kg BW), did not detect changes on HCW and LM, but noted a significant decrease on fat thickness and KPH, and increases on protein: fat ratio measured in the shoulder. On the other hand, Estrada et al. [13] reported increases on HCW and LM, but without effect on KPH when lams were supplemented at dose of 0.026 mg/kg BW. Reduction in intramuscular fat was observed in Tan lambs when the low to moderate energy diets were supplemented with Cr-Met at dose up to 0.051 mg Cr-Met/kg BW [20]. Supplementation up to 0.025 mg Cr picolinate/kg BW did not affect muscle and fat tissue deposition in Merino crossbred lambs subjected to HAHL conditions [38]. Other studies that were performed under favorable ambient conditions have reported no effects in carcass traits of the lambs when Cr was supplemented at lower levels (~0.13 mg Cr/kg BW) than in the present experiment [39,40]. Several factors can affect the response to Cr supplementation on carcass characteristics, but in a meta-analysis study performed by Hernández-García et al. [50], it was determined that the main effects of Cr supplementation on finishing lambs are increases in HCW, LM, and protein in carcass, and decreases on fat in carcass and fat proportion in meat.

The absence of the effects of Cr on whole cuts is in concordance with previous reports [13,20], similar result was observed for organ mass [13]. There is very limited information regarding Cr supplementation effects on visceral fat of lambs. Nevertheless, Najafpanah et al. [51] identified in goats that Cr downregulates the expression of enzymes that are involved in the synthesis of fatty acids in the visceral adipose tissue. This effect of regulation of gene expression has explained the decrease in abdominal fat in broilers when they are supplemented with Cr [52].

CONCLUSIONS

It was concluded that ingestion of Cr-Met increased dietary energy utilization in lambs fattened under high ambient heat load. Cr-Met supplementation has a modulating effect on the carcass by increasing muscle tissue and reducing body fat. Favorable responses on ADG and dietary energy utilization, and reductions in fat on carcass and in tissue composition were evident when Cr was supplemented from a dose of 1.20 mg/head/day. Cr supplementation can be a tool for alleviating the detrimental effect of HAHL on lamb growth performance and carcass characteristics; however; further research regarding to determine more precisely the Cr requirements of growing-finishing ruminants under HAHL are needed.

Declaration of Competing Interest

Authors declare no conflict of interest

Authors Contributions

Authors who meet authorship criteria are listed as authors, and each author certifies that they have contributed sufficiently to the conception and design of this work, as well as the acquired the experimental data and analysis and its interpretation, as well as the writing of the manuscript, to accept public responsibility. According to the authors, the manuscript represents valid research. Moreover, each author certifies that this material or similar material has not been submitted to or published as a full article anywhere else

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