EJFA Emirates Journal of Food and Agriculture

Emirates Journal of Food and Agriculture 37: 1–9
doi: 10.3897/ejfa.2025.160938

RESEARCH PAPER

Dietary supplementation of conjugated linoleic acid in adult Creole goats: Effects on weight gain, carcass yield and meat quality

Marco A. Sotelo-Turban[1], Omar Hernández-Mendo[1], Glafiro Torres-Hernández[1], Lorenzo D. Granados-Rivera[2], Jorge A. Maldonado-Jaquéz[3]

1 *Programa de ganadería, Colegio de Postgraduados, Carretera, México - Texcoco. Km. 63.5 Montecillo, Estado de México, CP. 56230, Mexico*
2 *Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental General Terán, General Terán, Nuevo León, C.P. 67400, Mexico*
3 *Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias, Campo Experimental La Laguna, Matamoros, Coahuila, CP. 27440, Mexico*

Corresponding author: Omar Hernández-Mendo (ohmendo@colpos.mx)

Academic editor: Mohammed El Khasmi ♦ **Received** 3 June 2025 ♦ **Accepted** 13 October 2025 ♦ **Published** 2 December 2025

Abstract

The study evaluated the effects of dietary supplementation with rumen-protected conjugated linoleic acid (CLA) on productive performance, carcass characteristics and meat quality in lactating adult Creole goats. The trial included fifteen lactating Creole goats, divided into three dietary treatments: a control group (no CLA), and groups receiving 50 or 90 g/day of CLA supplementation. The experiment lasted seven weeks after a two-week adaptation period. Results showed no significant differences between dietary treatments in terms of dry matter intake, daily weight gain, feed efficiency or back fat thickness. However, goats supplemented with 90 g/day CLA showed a slight but significant reduction in cold carcass yield. Meat quality parameters, such as final pH, shear strength, water holding capacity and chemical composition, were not affected by dietary supplementation with CLA, although all goats produced relatively tough meat, commensurate with their age. In particular, dietary supplementation with CLA significantly increased the content of the cis-9, trans-11 CLA isomer in muscle tissue, especially at the 90 g/day dose, without significantly affecting other major fatty acids. The trans-10, cis-12 CLA isomer did not noticeably accumulate in muscle tissue. Thus, although CLA supplementation effectively enriched goat meat with beneficial CLA isomers, it did not improve growth performance or standard measures of meat quality. In conclusion, this study demonstrates that supplementation with protected CLA can beneficially modify the fatty acid profile of goat meat without negatively affecting meat quality traits, potentially adding nutritional value to meat from lactating adult goats.

Keywords

Adult goats, Fatty acids, Lipid metabolism, Meat quality, Zoogenetic resources

Introduction

Goat farming has an advantage over other types of livestock due to the adaptation of goats to adverse conditions, surviving and reproducing even when the available feed does not fully meet nutritional needs. Therefore, the implementation of feed supplementation programs is of great importance not only to improve productive performance, but also to improve the quality of goat products (Gawat et al. 2023). In Mexico, goats represent a primary source of income for many smallholders; production is typically based on extensive grazing, and the output – meat or milk – is used in regional dishes (Tajonar et al. 2022). In this context, conjugated linoleic acid (CLA) has emerged as a potential feed supplement to improve product quality, mainly due to the effects of its bioactive isomers. Two CLA isomers in

Copyright *Sotelo-Turban, et al.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC-BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

particular-cis-9, trans-11 and trans-10, cis-12-have demonstrated anticancer (for cis-9, trans-11) and lipolytic (for trans-10, cis-12) properties (Yang et al. 2015; Ivanović et al. 2016). Several studies have reported that the addition of CLA to ruminant diets can alter the fat metabolism. For example, in cattle, CLA supplementation reduced milk fat content (Granados-Rivera et al. 2017; Candia-López et al. 2025) and in dairy sheep it reduced milk fat without affecting organ fat stores (Sinclair et al. 2010). The two main isomers of CLA have been identified in muscle tissue; however, their effects on body fat are variable. Wynn et al. (2006) reported that the inclusion of 25, 50 or 100 g/day of a protected CLA supplement in lamb diets increased the proportions of the cis-9, trans-11 and trans-10, cis-12 isomers of CLA in muscle tissue, but did not reduce total intramuscular fat content. Studies in goats are much more limited, especially in local breeds (Ivanović et al. 2014; Youssouf et al. 2019) where only a few productive traits have been evaluated (Granados-Rivera et al. 2022). It has been shown that CLA supplementation in dairy goat diets can improve body condition, weight gain and milk production (Baldin et al. 2014). Research on goat meat quality responses to CLA is scarce (Bautista-Martinez et al. 2025). Despite the economic importance of goat farming and the cultural demand for goat meat in various regional dishes (Tajonar et al. 2022). It is common in Mexico for goat meat to come from adult cull animals (often older females that have completed their productive life), whose meat quality is generally inferior (Oliveira-Marques et al. 2022). The sale of this type of meat is not highly regulated and lacks quality standards (Gökdal 2013). However, consumers continue to demand these traditional goat meat dishes, and high market prices are not a deterrent. In this regard, there is a need for further research on nutritional strategies to improve the quality of cull goat meat. Therefore, the objective of this study was to evaluate the effects of dietary supplementation with protected CLA on productive response, carcass yield and meat quality (physicochemical composition and fatty acid profile) of adult Creole goats.

Materials and methods

Location

The experiment was conducted at the Caprine Experimental Unit of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), La Laguna Experimental Station, located in Matamoros, Coahuila, Mexico (24°22'N, 103°23'W, 1100 masl). The climate of the region is classified as warm-dry (BWh), with a mean annual temperature of 22.6 °C and an annual precipitation of 215.5 mm.

Animals and experimental design

15 non-pregnant adult local (Creole) goats in early lactation (11 ± 7 days in milk) were selected. Their initial mean body weight was 34.8 ± 1.6 kg, with a body condition score of 2.5 (scale 1–5; Walkden-Brown et al. 1994). Goats were balanced into three groups (n = 5 per group) of similar body weight, milk production, and lactation number (all were third parity females). Groups were then randomly assigned to three dietary treatments in a completely randomized design. A two-week adaptation period preceded a seven-week experimental feeding period. The dietary treatments were **Control** – basal diet without CLA supplementation; **CLA-50** – basal diet plus 50 g/day of CLA supplementation; and **CLA-90** – basal diet plus 90 g/day of CLA supplementation. The CLA supplement used (Lutrell® Pure, BASF) consisted of a mixture of rumen-protected fatty acids, providing approximately 6 g of cis-9, trans-11 CLA and 6 g of trans-10, cis-12 CLA per 50 g of supplement, and 11 g of each of these isomers per 90 g of supplement. The supplement was added to the feed to ensure complete intake in the CLA-50 and CLA-90 groups.

Housing and feeding

Goats were housed individually in 2 × 3 m pens equipped with shaded areas, feeders, and free access to clean water. All goats were offered 2.5 kg/day (as is) of basal diet, divided into two equal rations (fed at 08:00 and 14:00 h). The basal diet (Table 1) was formulated as a total mixed ration and consisted of approximately 68% concentrate (grains, bran, soybean meal, urea, molasses, vitamins/minerals) and 32% roughage (alfalfa hay and corn stover). The diet met or exceeded the requirements for lactating meat goats (NRC 2007). CLA supplementation (for CLA-50 and CLA-90 treatments) was administered twice daily by sprinkling the designated amount on the feed at each feeding. Goats were milked by hand once daily (09:00 h) to maintain lactation. Throughout the trial, feed offered and refused by each goat was recorded daily, which allowed calculation of daily dry matter (DM) intake by difference. Feed allocations were adjusted each week according to the live weight of each goat in order to minimize rejections.

Measurements and data collection

Goats were weighed in the morning once a week to monitor live weight changes. Daily weight gain (DWG) was calculated for each goat as the difference between final and initial weight divided by the trial duration of 49 days. Feed efficiency (FE) was calculated by dividing DWG by daily DM intake and feed conversion index (FI) by DM intake divided by DWG. At the end of the experiment, all goats were humanely slaughtered in a federal inspection-type slaughterhouse according to the guidelines of NOM-033-ZOO-1995. Hot carcass weight was measured immediately after evisceration. Hot carcass yield was calculated as (hot carcass weight/final live weight) × 100. Carcasses were then cooled to 4 °C for 24 h, after which cold carcass weight was recorded and cold carcass yield was calculated analogously. Back fat thickness was measured on the

cold carcass over the *Longissimus dorsi* muscle, between the 12th and 13th ribs, using a digital vernier (Somet Inox, 150 mm). Muscle pH was measured in the *Longissimus* muscle at 45 minutes post-mortem (initial pH) and at 24 hours post-mortem (final pH) using a portable potentiometer (Maki-Petays et al. 1991).

Table 1. Ingredients, chemical composition and fatty acid composition (g/100 g FA) of the diet.

Ingredients	(% DM)	
Grain sorghum	17.1	
Grain corn	17.1	
Wheat bran	9.0	
Soy flour	9.0	
Urea	1.2	
Molasses	4.8	
Vitamins and minerals †	1.8	
Corn stubble	8.0	
Alfalfa hay	32.0	
Chemical composition (% DM)		
Dry matter	90.2	
Crude protein	11.4	
NDF	35.4	
ADF	20.5	
ME(‡) (Mcal/kg DM)	2.6	
Fatty acids	**Dietary basis**	**Supplement §**
<C16:0	2.55	3.56
C16:0	24.54	11.60
C16:1	1.50	Nd
C18:0	2.94	46.42
C18:1 n-9	16.68	12.08
C18:2 n-6	18.74	1.01
C18:3 n-3	32.28	Nd
Cis-9, Trans-11 CLA ¶	nd	12.03
Trans-10, Cis-12 CLA	nd	12.26
C20:0	0.77	0.56
C22:0	nd	0.48

† Premix of minerals and vitamins (Ca 24%, P 3%, Mg 2%, Na 8%, Cl 12%, K 0.50%, S 0.50% and antioxidant 0.50% Cl; lasalocid 2000 ppm, Cr 5 ppm, Mn 4000 ppm, Fe 2000 pp, Zn 5000 ppm, I 100 ppm, Se 30 ppm, and Co 60 ppm; vitamin A 500 000 IU, vitamin D 150 000 IU, vitamin E 1000 IU.
‡ Calculated according to NRC (2007).
nd = Not detected.
§ Supplement = Lutrell Pure ®, BASF.
(¶) CLA = Conjugated linoleic acid.

After chilling for 24 hours, a section of the *Longissimus dorsi* (loin) was removed from each carcass to analyze meat quality. Meat color (L*, a*, b* for lightness, redness and yellowness) was measured on fresh loin cuts using a colorimeter (taking the average of three readings per sample) (Robertson 1977). Shear strength was measured as an indicator of tenderness: tenderloin sub-samples were cooked at 70 °C internal, cooled and cores were removed to determine shear strength (kg/cm²) using a Warner-Bratzler type knife (Honikel 1998). Water holding capacity was determined by the pressed juice method (expressed in mL of water released per 100 g of meat) (Plá 2000). The water activity (Aw) of the meat was also measured using a calibrated water activity meter (Plá 2000). For chemical composition, minced meat samples were analyzed for moisture, crude protein, intramuscular fat, collagen and ash by near infrared spectroscopy (FoodScan™ apparatus, FOSS Analytics), following the manufacturer's procedures (three readings per sample, averaged) (Anderson 2007). Proximal composition results are expressed as percentages of fresh meat.

Fatty acid analysis

For fatty acid profile determination, aliquots of Longissimus dorsi muscle were processed to extract lipids and then methylated to fatty acid methyl esters (FAME) using the one-step acid-catalyzed methylation method of Palmquist and Jenkins (2003). The extraction of FA was performed according to the methodology modified by Granados–Rivera et al. (2017). A Hewlett Packard 6890 chromatograph with an automatic injector and a silica capillary column (100 m × 0.25 mm × 0.20 µm thick, Sp–2560, Supelco) was used to quantify FA methyl esters. The identification of FA was done comparing the retention times of each peak obtained from the chromatogram, with a standard of 37 FA methyl ester components (Supelco 37 Component FAME) and a specific standard for isomers C18:1 t11 (Sigma–Aldrich) and cis–9, trans–11 and trans–10, cis–12 (Nu–Check–Prep.).

Statistical analysis

Performance data (growth) and carcass traits were analyzed as a completely randomized design with repeated measures (for weekly weight data), using the MIXED procedure of SAS (SAS Institute 2008). Meat quality and fatty acid composition variables were analyzed by one-way ANOVA using the GLM procedure of SAS, with dietary treatment as a fixed effect. For variables measured over time (e.g., weekly weights), the model included the fixed effect of week and the treatment × week interaction. Initial live weight was included as a covariate for the performance and intake variables. Tukey's post-hoc test was used to compare treatment means where appropriate. Significance was declared at $P \leq 0.05$, and trends were noted for $0.05 < P < 0.10$.

Results

Daily dry matter (DM) intake was not significantly different among the three groups (overall mean ≈1.7 kg/day; $P > 0.05$). Average daily weight gain (ADG) was also unaffected by CLA supplementation ($P > 0.05$). Goats in all treatments gained approximately 0.12 kg/day (Table 2).

Feed efficiency and feed conversion ratio did not differ between treatments ($P > 0.5$), neither was hot carcass

Table 2. Animal performance of adult goats supplemented with different levels of protected conjugated linoleic acid in the diet.

Treatment, Protected Conjugated Linoleic Acid, g d^{-1}					
Variable	**Control**	**50**	**90**	**SEM**	***P***
Daily dry matter (kg/d)	1.82	1.75	1.62	0.042	0.146
Daily live-weight gain (kg/d)	0.12	0.14	0.11	0.010	0.517
Food efficiency	0.06	0.08	0.07	0.005	0.532
Feed conversion	16.21	12.08	14.69	1.131	0.345
Hot carcass yield (%)	42.89	42.23	42.92	0.608	0.889
Cold carcass yield (%)	42.61a	42.58ab	38.28b	0.707	0.028
Back fat (mm)	3.0	3.18	3.10	0.058	0.473

Values with different literals in the same row are significantly different (P ≤ 0.05). SEM = Standard error of the mean.

yield, which averaged 42.6% in all groups (Table 2). However, cold carcass yield did show treatment effect ($P < 0.05$), where the 90 g CLA group had a lower cold carcass yield (by approximately 1.5 percentage points) compared to the control and CLA-50 groups. Regarding back fat thickness, the treatments evaluated also had no significant effect ($P > 0.05$).

Hot and cold carcass pH, physicochemical characteristics and chemical composition of meat from adult goats were not different between treatments ($P > 0.05$), except luminosity (L value), which was lower ($P < 0.05$), which means darker meat, in the CLA-90 group compared to the control (Tables 3, 4).

Table 3. Hot and cold carcass pH and physicochemical characteristics of meat from adult goats supplemented with different levels of protected conjugated linoleic acid in the diet.

Treatment, Protected Conjugated Linoleic Acid, g d^{-1}						
Variable		**Control**	**50**	**90**	**SEM**	***P***
Hot carcass pH		7.31	7.17	7.22	0.086	0.787
Cold carcass pH		6.24	6.09	6.17	0.029	0.153
Color	L*	51.20a	38.27b	38.76b	1.151	0.001
	a	16.63	19.43	22.04	1.380	0.317
	b	6.53	6.66	7.40	0.230	0.283
Shear force (kg cm^{-2})		5.52	6.09	5.24	0.412	0.696
Water activity		0.99	0.99	0.99	0.004	0.173
Water holding capacity (ml 100 g^{-1}of meat)		15.9	12.3	13.5	1.074	0.407

Values followed by a different letter in the same row are significantly different (P ≤ 0.05). SEM = standard error of the mean.

Dietary supplementation with CLA had a clear effect on the fatty acid profile of meat in one important aspect, the level of cis-9, trans-11 CLA in goat meat increased significantly with CLA treatments ($P = 0.0001$). In *longissimus* muscle, the concentration of cis-9, trans-11 CLA was highest in the CLA-90 group, intermediate in CLA-50 and lowest in the control (Table 5). In contrast, the isomer -trans-10, cis-12 CLA- was not significantly different in meat between treatments.

Table 4. Chemical composition of meat from adult goats supplemented with different levels of protected conjugated linoleic acid in the diet.

Treatment, Protected Conjugated Linoleic Acid, g d^{-1}					
Variable	**0**	**50**	**90**	**SEM**	**P**
Protein (%)	21.32	21.07	21.81a	0.296	0.593
Fat (%)	7.48	8.91	6.98	0.936	0.689
Collagen (%)	2.37	2.12	2.01	0.067	0.130
OM (%)	97.40	97.72	98.11	0.156	0.219
Humidity (%)	71.24	70.50	71.48	0.615	0.797
Ash (%)	2.60	2.28	1.89	0.156	0.219

Values with different literals in a row are different (P ≤ 0.05). OM, organic matter; *SEM = Standard error of the mean.

Table 5. Fatty acid profile (g 100 g^{-1} of total FA) of meat from adult goats supplemented with different levels of protected conjugated linoleic acid in the diet.

Treatment, Protected Conjugated Linoleic Acid, g d^{-1}					
Fatty acids	**0**	**50**	**90**	**SEM**	**P**
Saturated					
Capricor	0.118	0.152	0.124	0.123	0.519
Lauri	0.064	0.061	0.153	0.026	0.301
Myristi	2.043	2.213	2.420	0.131	0.518
Palmitic	23.667	23.546	23.723	0.412	0.984
Stearic	19.553	22.295	20.442	0.964	0.515
Arachidi	0.051	0.045	0.042	0.005	0.784
Heneicosanoic acid	0.124	0.175	0.205	0.020	0.314
Heptadecanoi	1.150	1.103	1.451	0.079	0.193
Monounsaturated					
Myristoleic	0.554	0.325	1.110	0.176	0.218
Palmitoleic acid	2.158	1.921	2.288	0.196	0.748
C 10, Heptadecanoic	0.877	0.694	1.132	0.117	0.343
Oleic	43.102	41.747	38.693	1.254	0.370
Polyunsaturates					
Linolelaid	0.202	0.159	0.178	0.014	0.505
Linoleic	2.784	2.360	3.358	0.427	0.643
Elaídic	2.153	1.574	2.474	0.327	0.541
Linolenic	0.257	0.340	0.253	0.029	0.421
C 9, *T* 11, CLA	0.277b	0.590a	0.673a	0.024	0.0001
C 12, *T* 10, CLA	0.163	0.180	0.268	0.039	0.531
Arachidonic	0.718	0.513	0.862	0.140	0.607
Total, fatty acids					
Saturated	46.750a	49.590b	48.560b	0.220	0.516
Monounsaturated	46.689a	44.687b	43.223b	0.436	0.419
Polyunsaturates	6.549b	5.716b	8.066a	0.142	0.464
Total	99.988	99.993	99.849	0.266	0.466

Values with different letters in a row are different (P ≤ 0.05). CLA, conjugated linoleic acid; SEM = standard error of the mean.

Discussion

Animal performance

Although the average daily weight gain was not different between treatments, there was some variation in weight gain over time, with all goats showing a marked increase in the first two weeks, due basically to compensatory growth

in the transition from a grazing diet to a nutrient-rich stall diet, as stated by Gusha et al. (2015), who reported that goats transitioning from pasture to a high-concentrate diet showed an initial weight gain. Notably, the goats in our study were lactating, therefore, a significant portion of nutrients was toward milk production and may inherently limit growth rates compared to non-lactating goats (Candia-Lopez et al. 2025).

The dry matter intake level found in this study is higher than some values reported in the literature for similar goats (Rodriguez-Zamora and Elizondo-Salazar 2012), which have attributed the lower intakes to fiber-rich diets that slow the rate of passage and favor rumen filling. In our study, the palatability of the diet could have contributed to the relatively high intake, even though the palatability of the diets was not evaluated, which agrees with that stated by Quiroz-Cardoso et al. (2015), who reported that local goats increased feed intake when a forage-based diet was supplemented with sweet-tasting legume pods.

The fact that feed efficiency and feed conversion ratio were not different between treatments indicates that the addition of 50–90 g/day of protected CLA to the diet had neither detrimental nor beneficial effects on feed utilization for growth under these conditions. The known effect of CLA in lactating animals is milk fat depression (Granados-Rivera et al. 2017; Candia-López et al. 2025), which may improve energy balance by reducing energy production in milk fat. This theoretically could save energy for body weight gain as observed by improved energy status in dairy goats supplemented with CLA (Granados-Rivera et al. 2017). However, in the present study, no increase in weight gain was observed in the CLA groups, perhaps because the lactating goats were already in a positive energy balance or the duration of supplementation (seven weeks) was insufficient to manifest changes in body weight.

Hot carcass yield did not differ significantly between treatments, but cold carcass yield did show a treatment effect, where the 90 g CLA group had a lower cold carcass yield. This is basically due to a high inclusion of unsaturated fatty acids in the diet, CLA for instance, may have affected tissue characteristics related to water loss during chilling (Webb et al. 2005). Sometimes diets rich in unsaturated fats can reduce the water holding capacity of meat, resulting in higher drip loss and lower chilled carcass yield. In our study, treatment with 90 g/day CLA might have slightly decreased carcass water retention, which is consistent with the trend of lower chilled yield in that group. However, further research would be necessary to confirm this mechanism.

No differences in backfat thickness were observed between treatments, which contrasts with the expectation that CLA-especially the trans-10, cis-12 isomer-can reduce adiposity. In cows, trans-10, cis-12 CLA is known to inhibit fat synthesis in adipose tissue (Baumgard et al. 2002; Zhang et al. 2015). However, evidence in goats and sheep suggests that typical CLA supplementation levels do not generally reduce subcutaneous fat (Sinclair et al. 2010; Granados-Rivera et al. 2017). Our results agree with those findings, even the highest dose of CLA did not appreciably affect backfat deposition. According to Wynn et al. (2006), older animals, such as the adult goats from own study, tend to accumulate fat with age regardless of diet, mostly in internal depots, and any anti-adipogenic effect of CLA was too small to detect in subcutaneous fat. Furthermore, the amounts of CLA used may not have been sufficient to cause significant changes in body fat, as noted by Wynn et al. (2006), who found no effect on backfat when feeding protected CLA to sheep at similar doses.

Carcass and meat quality

Other than the small change in cold carcass yield, other carcass characteristics were largely unaffected by CLA. Final meat pH (measured in the loin after 24 h of chilling) was 6.1–6.2 on average and did not differ between treatments ($P > 0.05$). The initial pH of muscle after slaughter (~7.2 at 45 min) was also similar between groups. These pH values are higher than the normal range reported for goat meat at 24 h post-mortem (typically pH 5.6–5.8). High meat pH in goats is common and is generally attributed to pre-slaughter stress causing low muscle glycogen stores (Lokman et al. 2017; Gawat et al. 2023). Goats are known to be very susceptible to stress, which may limit the pH drop after slaughter. In our study, although management was standard, the goats experienced stress during transport and lairage prior to slaughter. An elevated final pH may negatively affect meat quality (resulting in darker and drier meat). Alende et al. (2014) observed that when goats experience even moderate stress prior to slaughter, muscle glycogen depletion leads to a slower decline in pH. The consistently high pH here suggests that all groups, regardless of diet, likely had some degree of pre-slaughter stress.

Meat color was slightly influenced by CLA treatments. The control and CLA-supplemented groups showed no difference in redness (a-value) or yellowness (b-value) of meat. However, there were indications that meat from CLA-supplemented goats was darker, since luminosity (L value) was lower in the CLA-90 group compared to the control. This is consistent with observations that higher final pH, as observed in our goats, often results in darker meat color. It has been reported that animals fed certain supplements had meat with lower L* values (darker color), possibly associated with changes in muscle chemistry. Martinez (2020) suggested that dietary factors that improve muscle antioxidant status or myoglobin content may also affect color, but in our case the key factor is probably pH and age of the animals. All goats were old (retired breeders), which inherently contributes to darker muscle pigmentation and lower L*. Therefore, any effect of CLA on color would be secondary to these dominant factors.

Meat tenderness, as indicated by shear strength, was not significantly different among treatments. Mean shear strength values were about 5.0–6.0 kg/cm² for all groups,

which exceeds the typical threshold for "tender" meat. In fact, these values classify the meat as relatively tough. This result is not surprising given the age of the animals (5–6 years). Older goats develop more cross-linked collagen in the muscle, which increases toughness. Our shear strength results were higher than the maximum for "soft" meat according to Webb et al. (2005). The advanced age and continued use of these females for breeding probably contributed to tougher meat, regardless of diet. In practical terms, this meat in Mexico is often used for slow-cooked dishes (e.g., *birria*) where prolonged cooking at high temperatures mitigates toughness. Yakan et al. (2016) reported high shear strength values in meat from cull Damascus goats, emphasizing that cooking methods can compensate for inherent toughness. Furthermore, diet did not appear to influence tenderness in our study. Contrary to popular belief, diet type (within typical diets) usually has minimal direct effect on goat meat tenderness, unless it involves extreme diets or beta-adrenergic agonists (Karami and Bagheri 2019). The level of physical activity may also affect toughness; our goats had been on pasture prior to the trial, and exercise may increase muscle firmness (Revilla et al. 2021). In summary, any potential softening effect of CLA (e.g., through altered fat deposition) was not evident, probably overshadowed by the age of the animals and pre-experimental handling.

Other physicochemical attributes of meat showed no adverse effects of CLA. Water activity (aw) of meat was uniform (~0.99) in all treatments and water holding capacity did not differ significantly. Water holding capacity values (around 12–16 mL/100 g) are within normal ranges for 24-h *post-mortem* goat meat. This trait is closely related to pH; higher pH may correspond to higher water retention. In our study, despite elevated pH in all groups, measured water holding capacity did not vary significantly among diets. Lokman et al. (2017) reported slightly lower water retention values in goat meat than those observed by us, but those goats had a more normal pH decline. The lack of differences here suggests that CLA supplementation, at these levels, did not negatively impact the ability of muscle to retain moisture during initial chilling and storage.

The chemical composition of goat meat was not significantly altered by CLA treatments. Meat from all groups had similar percentages of protein (~21.1–21.8%), intramuscular fat (~7–9%), collagen (~2.0–2.4%), ash (~2%) and moisture (~70–71%) ($P > 0.10$). These values are within the expected ranges for adult goat meat 24 hours *post-mortem* and showed no trend attributable to the diets. This indicates that feeding protected CLA, even up to 90 g/day, did not dilute or concentrate the major nutritional components of the meat. Previous studies in lambs and goats also found no change in proximal meat composition with CLA supplementation (Wynn et al. 2006; Pormalekshahi et al. 2019). Our findings concur: although CLA could redistribute fat between depots, it did not change the overall fat or protein content in muscle.

Meat fatty acid profile

Dietary supplementation with CLA had a clear effect on the fatty acid profile of meat in one important aspect: the level of cis-9, trans-11 CLA in goat meat increased significantly with CLA treatments ($P = 0.0001$). In *longissimus* muscle, the concentration of cis-9, trans-11 CLA was highest in the CLA-90 group, intermediate in CLA-50 and lowest in the control (Table 5). This result is expected because the supplemented CLA was an approximately equal mixture of the two major isomers, and part of the dietary CLA bypassed ruminal biohydrogenation to be incorporated into the tissues. In addition, cis-9, trans-11 CLA can be formed endogenously in ruminant tissues via Δ^9-desaturase from vaccenic acid (trans-11 C18:1), a rumen fermentation intermediate (Pariza et al. 2001; Gómez-Pastén et al. 2010). By supplying more CLA (especially in the CLA-90 treatment), we provide more substrate (both CLA itself and the precursor of vaccenic acid) for its deposition in muscle. The significant increase in cis-9, trans-11 CLA content in meat at the 90 g dose demonstrates a nutrigenomic effect of CLA supplementation, as also noted by Abdelatty et al. (2019) in a study on CLA and gene expression in muscle. This result is nutritionally positive, as cis-9, trans-11 CLA is the isomer associated with anti-cancer properties and is considered a value-added component in meat.

In contrast, the isomer -trans-10, cis-12 CLA- was not significantly different in meat between treatments (Table 5). The variability was large and the differences were not statistically clear ($P > 0.05$). Pormalekshahi et al. (2019) found that both CLA isomers in goat meat increased with supplementation of 15 g/kg CLA, although cis-9, trans-11 normally predominates. In our study, the trans-10, cis-12 isomer may have been metabolized more extensively or deposited less efficiently. It is also possible that goat tissues preferentially incorporate or synthesize the cis-9, trans-11 isomer (Adeyemi et al. 2016). Notably, trans-10, cis-12 CLA is usually more active in inhibiting fat synthesis in mammary gland and adipose tissue. Its lack of accumulation in muscle is consistent with findings that its effects are most pronounced in reducing milk fat (not muscle fat) and that it can be partially converted or catabolized.

Overall, our fatty acid results are consistent with the idea that supplementation with protected CLA can enrich ruminant products with CLA without negative effects on other fatty acids. Adeyemi et al. (2016) similarly reported increases in total PUFA and specifically cis-9, trans-11 CLA in goat meat with dietary CLA, while observing a simultaneous increase in total SFA. We also observed a trend toward higher SFA content in the CLA groups (CLA-fed goats had ~1–2 percentage points more SFA than the control in our data, although it was not statistically significant). This increase in SFA could be related to incomplete ruminal biohydrogenation of the additional unsaturated fatty acids, resulting in more saturated end products. However, in this case the changes were of small magnitude. Importantly, the increased CLA content in meat from CLA-supplemented goats could be considered

a functional improvement in the nutritional profile of the meat, as CLA is often touted for its health benefits in human diets.

Conclusion

Inclusion of rumen-protected conjugated linoleic acid supplementation at 50 or 90 g/day in the diet of lactating adult Creole goats did not significantly improve growth performance or alter most carcass and meat quality parameters. Dry matter intake, weight gain, feed efficiency and carcass yields (hot carcass yield and backfat thickness) were similar between CLA-supplemented goats and non-supplemented controls. At the highest CLA dose, a reduction in cold carcass yield was observed. Meat physicochemical properties – including pH, color, tenderness, water holding capacity and proximal composition – showed no detrimental effects of CLA supplementation. All goats, being older lactating animals, produced meat with a high final pH and firm texture, regardless of diet.

The most notable impact of CLA supplementation was on the fatty acid profile of goat meat. Feeding protected CLA, especially at 90 g/day, markedly increased the content of the beneficial cis-9, trans-11 CLA isomer in muscle tissue. This increase in CLA content in meat was achieved without adversely affecting other major fatty acid classes. The trans-10, cis-12 CLA isomer did not accumulate significantly in meat.

In summary, dietary supplementation with CLA in cull dairy goats under these conditions enriched the meat with conjugated linoleic acid, but did not result in improvements in growth rate or conventional meat quality traits. These results suggest that although protected CLA can be used to modify the fatty acid profile of goat meat (which could add value for health-conscious consumers), it does not necessarily translate into improved animal performance or tenderer or cleaner meat in older goats. Future research could explore CLA supplementation in younger meat goats or for longer periods, as well as combinations with management strategies to mitigate pre-slaughter stress, to fully evaluate any potential benefits of CLA in goat meat production.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by MAST, LDGR, JAMJ and OHM. The first draft of the manuscript was written by MAST and OHM and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding

This research was supported by the Research Department of the Colegio de Postgraduados-Mexico, and INIFAP – La Laguna Experimental Campus, at Matamoros, Coahuila, México.

Ethical statement

The care and use of the animals was carried out in accordance with the guidelines of the Federal Animal Health Law (Federal Official Gazette, 25-07-2007) and the study protocol was approved by the Institutional Animal Care Committee (COBIAN/013/23). At the end of the trial, the goats were slaughtered following the humane slaughter guidelines outlined in the Mexican Official Standard NOM-033-ZOO-1995.

Disclosure statement

Authors declare no competing financial interests or personal relationships that could potentially affect outcomes reported in this manuscript.

Data availability statement

The data that support the findings of this study are available from the corresponding author [OHM], upon reasonable request.

Acknowledgements

We greatly thank the National Council of Humanities, Science and Technology (CONAHCyT-Mexico) for the scholarship granted to the first author. Also the Technological Innovation and Food Safety in Livestock Reseach line (LGAC) of the Colegio de Postgraduados, and the sheep producers in the region studied for their invaluable help.

References

Abdelatty AMM, Mohamed SA, Moustafa MMA, Al-Mokaddem AK, Baker MR, Elolimy AA, Elmedany SA, Hussein S, Farid OAAA, Sakr OG, Elhady MA, Bionaz M (2019) Nutrigenomic effect of conjugated linoleic acid on growth and meat quality indices of growing rabbits. PLOS ONE 14(9): e0222404. https://doi.org/10.1371/journal.pone.0222404

Adeyemi KD, Sabow AB, Abubakar A, Samsudin AA, Sazili AQ (2016) Effects of dietary oil blend on fatty acid composition, oxidative stability and physicochemical properties of Longissimus thoracis et lumborum muscle in goats. Animal Science Journal 87(11): 1421–1432. https://doi.org/10.1111/asj.12609

Alende M, Volpi LC, Pordomingo AJ, Pighín D, Grigioni G, Carduza F, Pazos A, Babinec F, Sancho AM (2014) Effects of transport, lairage and ageing time on stress indicators and on instrumental and sensory quality of beef from steers. Archives of Veterinary Medicine 46: 217–227. https://doi.org/10.4067/S0301-732X2014000200007

Anderson S (2007) Determination of fat, moisture, and protein in meat and meat products by using the FOSS FoodScan™ near-infrared spectrophotometer with FOSS artificial neural network calibration model and associated database: collaborative study. Journal of AOAC International 90(4): 1073–1083. https://doi.org/10.1093/jaoac/90.4.1073

Baldin M, Dresch R, Souza J, Fernandes D, Gama MAS, Harvatine KJ, Oliveira DE (2014) CLA induced milk fat depression reduced dry matter intake and improved energy balance in dairy goats. Small Ruminant Research 116(1): 44–50. https://doi.org/10.1016/j.smallrumres.2013.09.009

Baumgard LH, Matitashvili E, Corl BA, Dwyer DA, Bauman DE (2002) Trans-10, cis-12 conjugated linoleic acid decreases lipogenic rates and expression of genes involved in milk lipid synthesis in dairy cows. Journal of Dairy Science 85(9): 2155–2163. https://doi.org/10.3168/jds.S0022-0302(02)74294-X

Bautista-Martínez Y, Maldonado-Jáquez J, Orzuna-Orzuna J, Arenas-Báez P, Granados-Rivera L (2025) Palmitic acid in the diet of dairy goats and its effect on physicochemical characteristics and fatty acid profile of goat kid meat. Animal Science Journal 96: e70030. https://doi.org/10.1111/asj.70030

Candia-López PA, Hernández-Mendo O, Bárcena-Gama JR, Améndola-Massiotti RD (2025) Protected palmitic acid to mitigate milk fat depression in grazing Holstein cows in the Mexican highlands. Archives of Animal Nutrition 79(1): 1–13. https://doi.org/10.1080/1745039X.2025.2453246

Gawat M, Boland M, Singh J, Kaur L (2023) Goat meat: Production and quality attributes. Foods 12(16): 3130. https://doi.org/10.3390/foods12163130

Gökdal Ö (2013) Growth, slaughter and carcass characteristics of Alpine × Hair goat, Saanen × hair goat and Hair goat male kids fed with concentrate in addition to grazing on rangeland. Small Ruminant Research 109: 6–75. https://doi.org/10.1016/j.smallrumres.2012.07.013

Gómez-Pastén M, Mora-Izaguirre O, Melendez-Soto RM, Romano-Muñoz JL, Vera-Ávila H, Shimada-Miyasaka A (2010) Effect of long-term feeding restriction on subsequent body weight, condition score, and tissue composition of mature goats. Revista Mexicana de Ciencias Pecuarias 1(3): 205–219.

Granados-Rivera LD, Hernández-Mendo O, González-Muñoz SS, Burgueño-Ferreira JA, Mendoza-Martínez GD, Arriaga-Jordán CM (2017) Effect of palmitic acid on the mitigation of milk fat depression syndrome caused by trans-10, cis-12 conjugated linoleic acid in grazing dairy cows. Archives of Animal Nutrition 71(6): 428–440. https://doi.org/10.1080/1745039X.2017.1379165

Granados-Rivera LD, Maldonado-Jáquez JA, Domínguez-Martínez PA, Salinas-Chavira J, Bautista-Martínez Y (2022) Effect of the feeding system (grazing vs. zero grazing) on the production, composition, and fatty acid profile in milk of Creole goats in northern Mexico. Emirates Journal of Food and Agriculture 34(6): 502–508. https://doi.org/10.9755/ejfa.2022.v34.i6.2885

Gusha J, Halimani TE, Katsande S, Zvinorova PI (2015) The effect of *Opuntia ficus indica* and forage legumes-based diets on goat productivity in smallholder sector in Zimbabwe. Small Ruminant Research 125: 21–25. https://doi.org/10.1016/j.smallrumres.2015.02.014

Honikel K (1998) Reference methods for the assessment of physical characteristics of meat. Meat Science 49: 447–457. https://doi.org/10.1016/S0309-1740(98)00034-5

Ivanović SD, Stojanović ZM, Nešić KD, Pisinov BP, Baltic MZ, Popov-Raljić JV, Đurić JM (2014) Effect of goat breed on meat quality. Hemijska Industrija 68(6): 801–807. https://doi.org/10.2298/HEMIND131201006I

Ivanović S, Pavlovic I, Pisinov B (2016) The quality of goat meat and its impact on human health. Biotechnology in Animal Husbandry 32(2): 111–122. https://doi.org/10.2298/BAH1602111I

Karami M, Bagheri M (2019) Color characteristics of goat meat under dietary regime. Animal Biology 21(1): 21–26. https://doi.org/10.15407/animbiol21.01.021

Lokman NS, Sabow AB, Abubakar AA, Adeyemi KD, Sazili AQ (2017) Comparison of carcass and meat quality in goats subjected to pre-slaughter head-only electrical stunning or slaughtered without stunning. CYTA Journal of Food 15: 99–104. https://doi.org/10.1080/19476337.2016.1217049

Maki-Petays O, Korkeala H, Alanko T, Sorvettula (1991) Comparison of different pH measurement methods in meat. Acta Veterinaria Scandinavica 32: 123–129. https://doi.org/10.1186/BF03547004

Martinez ED (2020) Carcass and meat characteristics of lambs from an intensive system. Journal of Veterinary Sciences 38(1): 17–27. https://doi.org/10.15359/rcv.38-1.2

NRC [National Research Council] (2007) Nutrient requirements of small ruminants: Sheep, goats, cervids, and new world camelids. National Academy Press.

Oliveira Marques IT, Fernandes CCL, Vasconcelos FR, Alves JPM, Montenegro AR, Silva CP, Oliveira FBB, Figueiredo FC, Moura AA, Rondina D (2022) Meat quality of culled adult goats finished with increased feeding plans. Food Science and Technology 42: e37721. https://doi.org/10.1590/fst.37721

Palmquist DL, Jenkins TC (2003) Challenges with fats and fatty acid methods. Journal of Animal Science 81(12): 3250–3254. https://doi.org/10.2527/2003.81123250x

Pariza MW, Park Y, Cook ME (2001) The biologically active isomers of conjugated linoleic acid. Progress in Lipid Research 40(4): 283–298. https://doi.org/10.1016/S0163-7827(01)00008-X

Plá M (2000) Medida de la capacidad de retención de agua. En: Metodología para el estudio de la calidad de la canal y de la carne en rumiantes. Ministerio de Ciencia y Tecnología – INIA. Madrid, España, 175–179.

Pormalekshahi A, Fatahnia F, Jafari H, Azarfar A, Varmaghany S, Taasoli GG (2019) Interaction effect of ruminal undegradable protein level and rumen-protected conjugated linoleic acid (CLA) inclusion in the diet of growing goat kids on meat CLA content and quality traits. British Journal of Nutrition 122(7): 745–754. https://doi.org/10.1017/S0007114519000904

Quiroz-Cardoso F, Rojas-Hernández S, Olivares-Pérez J, Hernández-Castro E, Jiménez-Guillén R, Córdova-Izquierdo A, Abdel-Fattah S (2015) Nutritional composition, consumption and relative palatability indices of the fruits of three acacias in sheep and goat diets. Archivos de Medicina Veterinaria 47(1): 33–38. https://doi.org/10.4067/S0301-732X2015000100007

Revilla I, Plaza J, Palacios C (2021) The effect of grazing level and ageing time on the physicochemical and sensory characteristics of beef meat in organic and conventional production. Animals 11: 635. https://doi.org/10.3390/ani11030635

Robertson AR (1977) The CIE 1976 color-difference formulae. Color Research & Application 2(1): 7–11. https://doi.org/10.1002/j.1520-6378.1977.tb00104.x

Rodríguez-Zamora J, Elizondo-Salazar J (2012) Consumption, nutritional quality and apparent digestibility of mulberry (*Morus alba*) and star grass (*Cynodon nlemfuensis*) in goats. Agronomía Costarricense 36(1): 13–23.

Schiavon S, Cecchinato A, Pegolo S, Dannenberger D, Tagliapietra F, Bittante G (2019) Dose response of rumen-protected conjugated linoleic acid supplementation to fattening bulls and heifers on growth, and carcass and meat quality. Journal of Animal Physiology and Animal Nutrition 103: 997–1005. https://doi.org/10.1111/jpn.13107

Sinclair LA, Weerasinghe WM, Wilkinson RG, de Veth M, Bauman DE (2010) A supplement containing trans-10, cis-12 conjugated linoleic acid reduces milk fat yield but does not alter organ weight or body fat deposition in lactating ewes. The Journal of Nutrition 140(11): 1949–1955. https://doi.org/10.3945/jn.110.126490

Song MK, Jin GL, Ji BJ, Chang SS, Jeong J, Smith SB, Choi SH (2010) Conjugated linoleic acids content in *M. longissimus dorsi* of Hanwoo Steers fed a concentrate supplemented with soybean oil, sodium bicarbonate-based monensin, fish oil. Meat Science 85: 210–214. https://doi.org/10.1016/j.meatsci.2010.01.001

Statistical Analysis System (SAS) (2008) SAS/STAT user's guide, version 9.3. SAS Institute Inc.

Tajonar K, Lopez Diaz CA, Sanchez Ibarra LE, Chay-Canul AJ, Gonzalez-Ronquillo M, Vargas-Bello-Perez E (2022) A brief update on the challenges and prospects for goat production in Mexico. Animals 12: 837. https://doi.org/10.3390/ani12070837

Walker JW, Heitschmidt RK, Dowhower SL (1985) Evaluation of pedometers for measuring distance traveled by cattle on two grazing systems. Journal Range Management 38: 90–93. https://doi.org/10.2307/3899343

Webb EC, Casey NH, Simela L (2005) Goat meat quality. Small Ruminant Research 60: 153–166. https://doi.org/10.1016/j.smallrumres.2005.06.009

Wynn RJ, Daniel ZCTR, Flux CL, Craigon J, Salter AM, Buttery PJ (2006) Effect of feeding rumen-protected conjugated linoleic acid on carcass characteristics and fatty acid composition of sheep tissues. Journal Animal Science 84(12): 3440–3450. https://doi.org/10.2527/jas.2006-159

Yakan A, Atesa CT, Alasahana S, Odabasioglua F, Unalb N, Ozturkc OH, Gungorb OF, Ozbeyazba C (2016) Damascus kids' slaughter, carcass and meat quality traits in differentproduction systems using antioxidant supplementation. Small Ruminant Research 136: 43–53. https://doi.org/10.1016/j.smallrumres.2016.01.002

Yang B, Chen H, Stanton C, Ross RP, Zhang H, Chen YQ, Chen W (2015) Review of the roles of conjugated linoleic acid in health and disease. Journal of Functional Foods 15: 314–325. https://doi.org/10.1016/j.jff.2015.03.050

Youssouf ML, Tellah M, Khalil DA, Souleyman MS (2019) Carcass yield of Sahelian goats in Guera province at Central-Eastern, Chad. International Journal of Livestock Research 9(9): 30–36. https://doi.org/10.5455/ijlr.20190619074240

Zhang H, Dong X, Wang Z, Zhou A, Peng Q, Zou H, Xue B, Wang L (2016) Dietary conjugated linoleic acids increase intramuscular fat deposition and decrease subcutaneous fat deposition in Yellow Breed × Simmental cattle. Animal Science Journal 87(4): 517–524. https://doi.org/10.1111/asj.12454