

Article

Corn Processing Method Modulates the Effects of Calcium Propionate Supplementation on Dietary Energetics and Fat Deposition in Finishing Lambs

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Simple Summary

Corn processing is one of the main strategies used to modify energy availability in high-concentrate finishing diets for lambs; however, ground corn (GC), although widely used because of its lower cost and ease of handling, has a lower energetic value than steam-flaked corn (SFC). This study evaluated whether calcium propionate (CaPr) supplementation could improve productive responses in GC diets or modify responses depending on corn processing method. We hypothesized that SFC would enhance dietary energy utilization and growth performance relative to GC, whereas CaPr supplementation would alter energy partitioning responses according to corn processing method. Results showed that SFC increased average daily gain, gain-to-feed ratio, and observed dietary energetics, confirming greater energy utilization efficiency than GC diets. In contrast, CaPr increased dry matter intake without improving productive performance or dietary energetics. However, interactions between corn processing and CaPr supplementation modified subcutaneous, muscular, and visceral fat deposition. In GC diets, CaPr reduced fat deposition, whereas in SFC diets CaPr supplementation increased fat depots, while most carcass characteristics, wholesale cuts, and meat-quality variables remained unchanged during the 45 d feeding period. Overall, CaPr did not overcome the lower energetic value associated with GC diets but influenced nutrient partitioning and fat accretion according to the corn processing method used.



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Abstract

The objective of this study was to evaluate the effects of corn processing method (ground corn, GC, vs. steam-flaked corn, SFC) and daily calcium propionate (CaPr; 0 vs. 9.45 g/lamb/d) supplementation on productive performance, dietary energetics, fat deposition, and carcass characteristics in finishing lambs. Thirty-six Dorper × Katahdin lambs (44.95 ± 3.30 kg initial body weight, IBW), blocked by IBW and randomly assigned within block to a 2×2 factorial arrangement, were used. Diets contained 50% corn grain and treatments consisted of: (1) GC, (2) SFC, (3) GC plus CaPr, and (4) SFC plus CaPr. There

were no corn processing $\times$ CaPr interactions for growth performance, dietary energetics, or observed-to-expected dietary net energy (NE) ratios. Steam-flaked corn decreased DMI (1.30 vs. 1.35 kg/d; $p = 0.0036$) and increased average daily gain (ADG; 0.168 vs. 0.144 kg/d), gain-to-feed ratio (G:F), and observed-to-expected dietary NE ratios compared with GC diets ($p < 0.05$). In contrast, CaPr supplementation increased DMI (1.35 vs. 1.30 kg/d; $p = 0.0215$) without affecting ADG, G:F, or observed-to-expected dietary NE ratios ($p > 0.05$). Steam-flaked corn increased hot carcass weight ($p = 0.0339$), cold carcass weight ($p = 0.0241$), *Longissimus lumborum* muscle area ($p = 0.0206$), and chest depth ($p = 0.0368$), whereas CaPr increased carcass length ($p = 0.0451$). Interactions between corn processing and CaPr supplementation were observed for rib fat thickness ($p = 0.0491$), rump fat thickness ($p = 0.0272$), visceral fat ($p = 0.0485$), perirenal fat ($p = 0.0209$), and shoulder tissue composition, including muscle ($p = 0.0309$), fat ($p = 0.0438$), and muscle:fat ratio ($p = 0.0348$). In GC diets, CaPr supplementation decreased fat deposition and increased muscle proportion, whereas in SFC diets CaPr supplementation increased fat deposition and reduced muscle proportion. Neither corn processing nor CaPr supplementation affected visceral mass (g viscera/g empty body weight). Calcium propionate supplementation decreased hindquarter yield ($p = 0.0494$), increased shoulder IMPS207 yield ($p = 0.0494$), and increased purge loss at 24 h ($p = 0.0496$). Water-holding capacity showed a corn processing $\times$ CaPr interaction ($p = 0.0170$), whereas the remaining meat-quality variables were not affected. Overall, SFC improved productive performance and dietary energy utilization, whereas CaPr increased DMI and altered fat deposition and tissue composition responses depending on corn processing method.

Keywords: carcass traits; energy partitioning; ground corn; meat quality; steam-flaked corn; tissue composition

1. Introduction

In intensive lamb finishing systems, productive efficiency is determined by the availability and utilization of dietary energy, which, in turn, regulate average daily gain (ADG), dry matter intake (DMI), and gain-to-feed efficiency ratio (G:F) [1,2]. Dietary energy, particularly that derived from grain starch sources such as corn, is one of the main determinants of productive performance in high-concentrate diets. Therefore, changes in starch availability and utilization can modify productive performance, dietary energetics, energy utilization efficiency, and nutrient partitioning [3,4].

Corn is the primary energy source in finishing diets; however, its nutritional value depends on the processing method, which modifies starch digestibility and dietary net energy [1,5]. In finishing lambs, steam-flaked corn (SFC) has been shown to increase net energy for maintenance (NE_m) and net energy for gain (NE_g) by approximately 13–22%, as well as G:F by 25%, compared with ground corn (GC), indicating greater dietary energetics and energy utilization efficiency with steam flaking [6]. These responses are consistent with previous studies reporting improvements in starch digestibility, dietary NE, and G:F when SFC is compared with dry-processed corn sources in feedlot ruminants [1,7,8]. In production systems such as those commonly used in Mexico, GC remains one of the most widely used processing methods because of its lower cost, ease of handling, and broad availability, making it a practical, although energetically less efficient, alternative. However, differences in dietary energetics do not always translate proportionally into improvements in ADG or G:F, suggesting that productive responses depend not only on dietary energy availability but also on how energy is utilized and partitioned within the animal.

In this context, calcium propionate (CaPr) supplementation could represent a strategy to improve energy utilization in diets with lower energetic value. Calcium propionate supplies propionate, the main gluconeogenic precursor in ruminants, which is converted to glucose in the liver and may improve metabolizable energy utilization [9]. Previous studies have shown that CaPr supplementation can improve growth performance in ruminants, increasing ADG, DMI, G:F, and final body weight (FBW), although responses vary according to dietary energy density, supplementation period, and production system [10,11]. In finishing lambs, improvements of up to 38% in ADG, 14% in DMI, 26% in G:F, and 7% in FBW have been reported; nevertheless, prolonged supplementation or greater dietary energy availability may also increase fat deposition, indicating that additional energy can be partitioned toward body reserves rather than exclusively supporting lean tissue accretion [12,13].

Nevertheless, it remains unclear whether CaPr can compensate for the lower dietary energetics associated with GC or whether its effects are expressed primarily through modifications in energy utilization and nutrient partitioning rather than through changes in dietary energy availability itself. Likewise, uncertainty remains regarding how the interaction between corn processing method and CaPr supplementation influences productive performance, fat deposition, and carcass responses in finishing lambs fed diets differing in energetic value.

Therefore, the objective of the present study was to evaluate the effects of corn processing method (GC vs. SFC) and CaPr supplementation on productive performance, dietary energetics, fat deposition, and carcass characteristics in finishing lambs. It was hypothesized that SFC would increase dietary energy utilization and productive performance relative to GC, whereas CaPr supplementation would modify energy utilization and nutrient partitioning, particularly under lower-energy dietary conditions, without necessarily eliminating the energetic differences associated with corn processing method.

2. Materials and Methods

The study was carried out at the Multinutrimientos, Aditivos y Asesoría Zootécnica (MAAZ) Experimental Center in Calera de Víctor Rosales, Zacatecas, Mexico (22°56′51.23″ N, 102°41′32.33″ W; 2162 m above sea level). The area is representative of the semi-arid temperate conditions of northern Mexico and exhibits pronounced daily temperature variation. Animals were evaluated during a feeding trial conducted from 13 October to 26 November 2025, with a mean ambient temperature of 20.2 °C throughout the experimental period. A 45 d finishing phase was adopted because it resembles the duration commonly used in commercial feedlot operations for heavy lambs while providing sufficient time to assess growth performance, dietary energetics, fat deposition, and carcass responses.

Following completion of the feeding period, lambs were transported to the municipal abattoir of the Unidad Académica de Medicina Veterinaria y Zootecnia, Universidad Autónoma de Zacatecas (UAMVZ-UAZ), located in General Enrique Estrada, Zacatecas, Mexico. Slaughter, carcass fabrication, and biological sample collection were performed at this facility. The distance between the experimental facilities and the abattoir was approximately 7.3 km, and animals were slaughtered on the same day following feed withdrawal. Carcass measurements and meat-quality evaluations were subsequently conducted at the Meat Science and Technology Laboratory of UAMVZ-UAZ, whereas chemical analyses of feed ingredients and experimental diets were performed at the Animal Nutrition Laboratory of the Instituto de Investigaciones en Ciencias Veterinarias, Universidad Autónoma de Baja California.

All animal-related procedures received approval from the Institutional Committee on Bioethics and Animal Welfare of UAMVZ-UAZ (Protocol No. 02; August 2025). Animal handling, sampling, transport, stunning, and slaughter procedures followed current Mexican regulations for the care and use of animals in research [14–17]. All experimental activities were conducted in accordance with national standards governing animal welfare and research practices.

2.1. Animal Processing, Housing, and Feeding

Thirty-six intact male Dorper $\times$ Katahdin lambs were used in this study. Animals originated from a commercial flock located near Calera de Víctor Rosales, Zacatecas, Mexico, and were transported approximately 28 km to the MAAZ Experimental Center. Upon arrival, lambs averaged 6.0 ± 0.4 months of age and received routine processing procedures, including ear-tag identification, vaccination against *Clostridium* spp., *Pasteurella multocida*, and *Mannheimia haemolytica* (Exgon 10[®], Chinoin Veterinaria, Aguascalientes, Mexico), antiparasitic treatment with closantel (Closantel[®] 5%, Chinoin Veterinaria, Aguascalientes, Mexico), and determination of initial body weight (IBW) using an electronic crane scale (Rhino[®] BAC-300; 300 kg capacity; Rhino Maquinaria SA de CV, Atizapan de Zaragoza, Estado de México, Mexico). Prior to treatment assignment, animals underwent a 21 d adaptation period to the feedlot facilities, management procedures, and experimental diets. During adaptation, a forage-based diet consisting of oat hay and alfalfa hay (50:50) was gradually replaced by the basal finishing diet to reduce the risk of digestive disturbances associated with transition to high-concentrate feeding systems.

Following the adaptation phase, lambs were weighed before the morning feeding. Thirty-six animals (44.95 ± 3.30 kg initial body weight, IBW) were selected, grouped according to IBW, and randomly allotted to treatments within block. Lambs were maintained in individual indoor pens (1.5 m $\times$ 1.5 m) provided with individual feed bunks and automatic waterers, with unrestricted access to fresh water throughout the experiment. Health status was evaluated twice daily through visual observation, including assessment of digestive disorders, lameness, and other clinical abnormalities. No cases of morbidity or mortality were recorded, and no animals were removed from the study.

The experimental feeding period lasted 45 d and was intended to simulate a practical intensive finishing phase for heavy lambs under commercial feedlot conditions. Experimental diets were offered according to the treatment assigned to each animal throughout the study. At the end of the feeding phase, lambs underwent an 18 h feed withdrawal period while maintaining unrestricted access to water prior to FBW determination and slaughter.

2.2. Treatments

A 2×2 factorial arrangement was used to evaluate the effects of corn grain processing method (GC vs. SFC) and CaPr supplementation. Thirty-six lambs were assigned to four treatments ($n = 9$ lambs/treatment): (1) GC without CaPr (0 g/lamb/d), (2) GC with CaPr (9.45 g/lamb/d), (3) SFC without CaPr (0 g/lamb/d), and (4) SFC with CaPr (9.45 g/lamb/d).

Corn grain was obtained from a commercial supplier (Bunge México, S.A. de C.V., Guadalajara, Jalisco, Mexico) that imports hybrid yellow corn from the United States. Based on the supplier's warranty analysis, corn contained 8.8% crude protein (CP), 72.1% starch, and 9.5% neutral detergent fiber (NDF). For GC treatments, whole corn was ground at the MAAZ Experimental Center using a hammer mill fitted with a 3 mm screen, producing particles averaging approximately 1–2 mm in size. Steam-flaked corn used in the SFC treatments was purchased directly from the manufacturer. According to manufacturer specifications, corn kernels were steamed for approximately 20 min until reaching about

102 °C prior to flaking. Steam was produced at approximately 483 kPa, and flakes were processed to a density of approximately 0.36 kg/L. To facilitate storage and mixing, SFC was air-dried for 5 d before incorporation into the experimental diets. Representative samples of both corn sources were subsequently collected for chemical analyses. The two processing methods were selected because they are widely used in commercial ruminant production systems and differ markedly in their effects on starch availability and dietary energy utilization.

Calcium propionate was supplied as a commercial product (Propical®, Dresen Química, SAPI de C.V., Ciudad de México, México) containing approximately 73% propionic acid and was supplemented at 9.45 g CaPr/lamb/d, equivalent to approximately 0.21 g/kg IBW and 7.2 g/kg average DMI. Daily doses were individually weighed using a certified analytical balance (Pioneer-PX523, Ohaus Corp., Parsippany, NJ, USA). To maintain similar handling among treatments, sodium bentonite was used as an inert carrier and placebo in lambs not receiving CaPr and was provided at an amount equivalent to the CaPr dose. During the final 28 d of the feeding period, all lambs received zilpaterol hydrochloride (ZH; Zilmax®, MSD Salud Animal México, Ecatepec de Morelos, Estado de México, Mexico) at 7.2 mg/lamb/d. Daily ZH doses were weighed individually using the same analytical balance and incorporated into the corresponding treatment before administration. Consequently, ZH was mixed with CaPr in GCCaPr and SFCCaPr, whereas sodium bentonite was used as the carrier in GC and SFC. To ensure complete consumption, the daily treatment dose (CaPr or sodium bentonite placebo, with or without ZH according to feeding phase) was mixed with approximately 100 g of the basal diet and offered individually at 08:00 and 16:00 h before the remainder of the feed was delivered. Lambs completely consumed this portion before receiving the rest of the ration, thereby minimizing variation in additive intake caused by feed refusals. Zilpaterol hydrochloride supplementation was discontinued 3 d before slaughter following manufacturer recommendations, although animals continued receiving their assigned diets during this period. Zilpaterol hydrochloride was included under the same supplementation protocol across all treatments.

Basal finishing diets were formulated according to NRC [2] recommendations and contained 50% corn grain and 22% corn stover on a DM basis. Experimental diets were mixed daily using a horizontal paddle mixer and offered *ad libitum* twice daily at 08:00 and 16:00 h, corresponding to approximately 40 and 60% of the daily allotment, respectively. Orts were collected and weighed each morning before feeding, and feed delivery was adjusted daily to maintain approximately 30 g/kg refusals on an as-fed basis. Dry matter intake was estimated as the difference between feed offered and feed refused. Feed samples from each dietary batch were collected throughout the study, composited by treatment, placed in labeled plastic bags, and stored at 4 °C pending laboratory analyses. Ingredient composition, analyzed chemical composition, and calculated dietary energy values of the complete experimental diets are presented in Table 1.

Table 1. Ingredient and nutrient composition and calculated dietary energy values of complete finishing diets containing ground or steam-flaked corn (% DM basis).

Ingredients	Corn Processing Method	
	Ground	Steam-Flaked
Ground corn	50.00	-
Steam-flaked corn	-	50.00
Corn stover	22.00	22.00
Dried distillers grains with solubles	8.00	8.00
Soybean meal, 44% CP	8.00	8.00

Table 1. *Cont.*

Ingredients	Corn Processing Method	
	Ground	Steam-Flaked
Cane molasses	7.90	7.90
Urea	0.50	0.50
Sodium sesquicarbonate	1.50	1.50
Calcium carbonate	1.00	1.00
Sodium bentonite	1.00	1.00
Premix ¹	0.10	0.10
Chemical composition, % ²		
Dry matter	88.00	86.50
Organic matter	91.90	91.80
Crude protein	14.60	14.40
Starch ³	36.85	36.85
Neutral detergent fiber	20.80	19.90
Ether extract	3.50	3.49
Ash	8.10	8.20
Tabular dietary net energy values ⁴		
Net energy for maintenance, Mcal/kg	1.86	1.91
Net energy for gain, Mcal/kg	1.20	1.25

¹ The premix provided per kilogram contained 221.6 mg Co, 125,420 mg Fe, 402.5 mg I, 10,064 mg Mn, 17,078.5 mg Zn, 267 mg Se, and 7813 mg Cu, together with 2,595,000 IU vitamin A, 468,750 IU vitamin D, and 28,000 IU vitamin E. ² Dry matter, crude protein, and ash concentrations were analyzed following AOAC [18] procedures. Ether extract was determined using AOCS Official Method Am 5-04 [19], whereas neutral detergent fiber was analyzed using Ankom methodology (Ankom Technology, Macedon, NY, USA). Organic matter content was obtained by subtracting ash from dry matter. ³ Starch concentration was estimated from dietary ingredient composition according to NRC [2]. ⁴ Reference net energy values were derived from NRC [2] tabular ingredient data. Values assigned to ground corn were 2.20 and 1.52 Mcal/kg for maintenance and gain, respectively, whereas corresponding values for steam-flaked corn were 2.30 and 1.61 Mcal/kg.

2.3. Chemical Analyses

Samples representative of each experimental diet were collected at regular intervals during the feeding period, composited within treatment, and analyzed in triplicate. Dry matter concentration was determined by drying samples at 105 °C to constant weight in a forced-air oven (Thermo Scientific, Waltham, MA, USA) following AOAC method 930.15 [18]. Ash concentration was determined after combustion in a muffle furnace according to AOAC method 942.05 [18]. Nitrogen content was analyzed using a nitrogen analyzer (FP-528, LECO Corp., St. Joseph, MI, USA), and CP concentration was calculated according to AOAC method 984.13 [18].

Neutral detergent fiber concentration was analyzed using an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY, USA) following the procedure described by Van Soest et al. [20]. Ether extract was quantified using an Ankom ^{XT15} Extractor (Ankom Technology, Macedon, NY, USA) according to AOCS Official Method Am 5-04 [19].

2.4. Calculations

Growth performance variables were calculated from individual BW records obtained at the start (day 0 before morning feeding) and end (day 45 after an 18 h feed withdrawal with free access to water) of the experiment. These measurements were used to determine IBW and FBW, respectively. To account for gastrointestinal contents, IBW was converted to shrunk body weight (SBW) using a factor of 0.96 [21]. Average daily gain was calculated from the difference between final and initial SBW divided by the duration of the feeding period (45 d). Individual DMI was calculated as the difference between feed offered and

feed refused on a DM basis, and G:F was obtained as the ratio between ADG and DMI. Average SBW was calculated as the arithmetic mean of initial and final SBW.

Expected DMI was calculated from observed ADG and average SBW according to the following equation: expected DMI (kg/d) = (EM/NE_m) + (EG/NE_g). Maintenance energy requirement (EM; Mcal/d) was estimated as $0.056 \times \text{SBW}^{0.75}$ [22], whereas retained energy (EG; Mcal/d) was calculated as $0.276 \times \text{ADG} \times \text{SBW}^{0.75}$. The coefficient 0.276 assumes a mature BW of 113 kg for intact Dorper $\times$ Katahdin male lambs. Dietary NE_m and NE_g values used in the expected DMI calculations were obtained from the energy concentrations shown in Table 1, which were derived from NRC [2] tabular ingredient values. These same reference values were used to calculate observed-to-expected dietary NE ratios.

Observed dietary NE_m was estimated from animal performance using the quadratic equation described by Zinn et al. [3]: $x = (-b - \sqrt{(b^2 - 4ac)})/(2c)$, where x = dietary NE_m, $a = -0.41 \times \text{EM}$, $b = (0.877 \times \text{EM}) + (0.41 \times \text{DMI})$, e.g., and $c = -0.877 \times \text{DMI}$. Dietary NE_g was then derived as $(0.877 \times \text{NE}_m) - 0.41$. Observed-to-expected dietary NE ratios were calculated by dividing the dietary NE values estimated from animal performance by the corresponding expected dietary NE concentrations presented in Table 1. Calculations for retained energy and performance-derived dietary NE were performed following the procedures described by Estrada-Angulo et al. [23] and Zinn et al. [3].

2.5. Body Fat Reserves and Longissimus Muscle Area

Real-time ultrasonography was used to evaluate body fat reserves and muscular development in finishing lambs. Measurements included *Longissimus lumborum* muscle area (LMA; cm²), subcutaneous fat thickness measured between the 12th and 13th ribs (FAT; mm), and rump fat thickness at the P8 anatomical site (RFT; mm). Longissimus muscle area and FAT measurements were collected at the 12th–13th rib interface according to established ultrasound procedures for small-ruminant carcass evaluation.

Prior to image collection, wool was removed from the scanning site, the area was cleaned with compressed air, and ultrasound gel was applied to optimize acoustic contact between the transducer and skin surface. Ultrasound measurements were obtained on days 0 and 45 using a real-time scanner (Aloka Prosound 2, Hitachi Aloka Medical, Tokyo, Japan) fitted with a 3.5 MHz linear-array transducer. To reduce measurement variability, all scans were performed and interpreted by the same trained technician throughout the experimental period.

2.6. Slaughter Procedure and Visceral Organ Mass Determination

Following completion of the 45 d feeding period, lambs were fasted for 18 h before slaughter while maintaining unrestricted access to water. Pre-slaughter BW was recorded after the withdrawal period, and animals were then transported approximately 7.28 km to the abattoir of the UAMVZ-UAZ, located in General Enrique Estrada, Zacatecas, Mexico. Slaughter and carcass fabrication were completed on the day of transport. During processing, non-carcass components were collected and weighed individually, including skin, limbs, head, heart, lungs, liver, spleen, kidneys, testicles, gastrointestinal tract, and internal adipose depots.

To characterize internal fat deposition, omental, mesenteric, and perirenal fat depots were recorded separately. Visceral fat was defined as the combined weight of omental and mesenteric fat, whereas perirenal fat was evaluated as an independent variable. The gastrointestinal tract was weighed before and after removal of digesta to estimate gastrointestinal contents. Empty body weight (EBW) was obtained as the difference between pre-slaughter BW and gastrointestinal contents. Organ and adipose tissue weights were

subsequently expressed relative to EBW (g/kg), thereby reducing variation attributable to differences in gastrointestinal fill among animals.

2.7. Carcass Characteristics

Immediately after slaughter, hot carcass weight (HCW) was recorded prior to carcass chilling. Carcasses were then stored at 4 °C for 24 h, after which CCW was determined. Dressing percentage was calculated as HCW divided by FBW and multiplied by 100, whereas CL was calculated as $[(HCW - CCW)/HCW] \times 100$.

Following refrigeration, carcass morphometric traits were measured using a flexible tape and included carcass length, leg perimeter, and chest depth. The left shoulder (IMPS 207) was physically dissected to determine muscle and fat proportions and to calculate the muscle:fat ratio according to Luaces et al. [24]. This measurement was used as an indicator of tissue deposition and nutrient partitioning responses associated with the experimental treatments.

The left side of each carcass was fabricated according to Institutional Meat Purchase Specifications (IMPS) and North American Meat Processors Association guidelines [25]. Forequarter components included neck, shoulder IMPS 206, shoulder IMPS 207, rack IMPS 204, breast IMPS 209, and ribs IMPS 209A. The hindquarter was separated into loin IMPS 231, flank IMPS 232, and leg IMPS 233.

2.8. Meat Quality

A sample of the *Longissimus lumborum* muscle was collected from the region corresponding to LMA measurements between the 9th and 10th ribs (approximately 500 g) on the left carcass side and stored at −20 °C until analysis. Muscle pH was recorded 24 h postmortem at the second lumbar vertebra using a portable digital pH meter (Hanna Instruments, Woonsocket, RI, USA; Model HI-9025). Water-holding capacity (WHC) was evaluated using the Grau and Hamm procedure described by Tsai and Ockerman [26]. For this determination, 300 mg of LM tissue was placed between Whatman No. 1 filter papers positioned between two glass plates (15 cm × 15 cm) and subjected to a constant load of 10 kg for 20 min.

Steaks (2 cm thick) obtained from the LM between the 12th rib and the second lumbar vertebra were vacuum packaged and maintained at −20 °C for 14 d before evaluation of purge loss (PRL_{24h}) and cooking loss (CKL). Prior to analysis, samples were thawed for 24 h at 4 °C, dried superficially, and weighed. For PRL_{24h} determination, one steak was cut into blocks (15 mm × 15 mm × 30 mm) and suspended at 4 °C for 24 h. Cooking loss was determined using a separate vacuum-packaged steak heated in a water bath at 80 °C until an internal temperature of 70 °C was reached. Following heating, samples were gently dried and weighed to obtain post-cooking weight. Values for WHC, PRL_{24h}, and CKL were expressed as percentages of initial sample weight.

Warner–Bratzler shear force (WBSF) was determined using LM steaks (2.54 cm thick) thawed for 24 h at 4 °C and cooked on an electric grill (Spectrum Brands, Middleton, WI, USA; Model GR2120B) until reaching an internal temperature of 70 °C, monitored with a digital thermometer (Model TP700), following AMSA [27] recommendations. After cooking, steaks were allowed to cool at room temperature (22 °C) for 4 h. Six cylindrical cores (1.27 cm diameter) were then removed parallel to the muscle fiber direction. Shear force was measured with a texture analyzer (G-R Manufacturing, New York, NY, USA) fitted with a Warner–Bratzler blade operating at a crosshead speed of 200 cm/min. Final WBSF values were calculated as the average peak force and expressed as kg/cm².

2.9. Statistical Analyses

A randomized complete block design with a 2×2 factorial arrangement was used to evaluate treatment effects. Data were analyzed using the GLM procedure of SAS[®] OnDemand for Academics: SAS Studio Version 3.82 [28]. Initial body weight served as the blocking criterion. The statistical model included the fixed effects of corn processing method (GC vs. SFC), CaPr supplementation (0 vs. 9.45 g/lamb/d), their interaction, and block as a source of variation. The individual lamb was considered the experimental unit.

Before conducting the analyses, residual distributions were examined using PROC UNIVARIATE to verify normality assumptions. Growth performance, dietary energetics, ultrasound measurements, visceral organ mass, carcass characteristics, wholesale cut distribution, and meat-quality variables were evaluated using analysis of variance (ANOVA). Final ultrasound traits were analyzed using analysis of covariance (ANCOVA), incorporating the corresponding day 0 values as covariates to account for baseline variation among animals. Whenever significant treatment effects were identified, least-squares means were compared using Tukey's adjustment for multiple comparisons. Statistical differences were declared at $p \leq 0.05$. Data are reported as least-squares means accompanied by their standard error of the mean (SEM).

3. Results

3.1. Growth Performance, Dietary Energetics, and Ultrasound Measurements

Final BW was affected by corn processing method ($p = 0.0464$), with no effect of CaPr supplementation ($p = 0.5959$) or the processing $\times$ CaPr interaction ($p = 0.9041$) (Table 2). Lambs fed SFC diets exhibited greater FBW values than those fed GC diets, with increases of approximately 3–4%. Similarly, ADG was affected by corn processing method ($p = 0.0418$), whereas no effects of CaPr supplementation ($p = 0.6029$) or the interaction ($p = 0.9635$) were detected. Lambs fed SFC diets showed greater ADG values than those fed GC diets ($p < 0.05$), with increases of approximately 17–20%. Dry matter intake was affected by both corn processing method ($p = 0.0036$) and CaPr supplementation ($p = 0.0215$), without a processing $\times$ CaPr interaction ($p = 0.4018$). The SFC treatment presented the lowest DMI, whereas GC, GCCaPr, and SFCCaPr showed greater values and did not differ among them ($p < 0.05$). Gain-to-feed ratio was also affected by corn processing method ($p = 0.0210$), with no effect of CaPr supplementation ($p = 0.9215$) or the interaction ($p = 0.8419$). Lambs fed SFC diets exhibited greater G:F values than those fed GC diets, with increases of approximately 24–26%. Overall, SFC increased FBW, ADG, and G:F, whereas CaPr supplementation increased DMI without affecting ADG, G:F, or FBW.

Table 2. Effects of corn processing method and calcium propionate supplementation on growth performance of finishing lambs.

Item ¹	Calcium Propionate, g/lamb/d				SEM ²	Significance		
	0		9.45			Processing Method	CaPr	Processing × CaPr
	Processing Method							
	Ground	Steam-Flaked	Ground	Steam-Flaked				
IBW, kg	44.59	45.19	44.84	45.16	0.55	0.4096	0.8423	0.8052
FBW, kg	50.89 ^b	52.55 ^a	51.46 ^b	52.91 ^a	0.87	0.0464	0.5959	0.9041
ADG, kg/d	0.140 ^b	0.164 ^a	0.147 ^b	0.172 ^a	0.02	0.0418	0.6029	0.9635
DMI, kg/d	1.34 ^a	1.25 ^b	1.37 ^a	1.32 ^a	0.02	0.0036	0.0215	0.4018
G:F	0.104 ^b	0.131 ^a	0.107 ^b	0.130 ^a	0.01	0.0210	0.9215	0.8419

¹ IBW = initial body weight, FBW = final body weight, ADG = average daily gain, DMI = dry matter intake, G:F = gain-to-feed ratio. ² SEM = standard error of the mean. ^{a,b} Different superscripts within a row indicate significant differences ($p \leq 0.05$) according to Tukey's test.

Observed NE_m and NE_g were affected by corn processing method ($p = 0.0034$), with no effect of CaPr supplementation ($p = 0.8175$) or the interaction ($p = 0.7208$) (Table 3). Expected DMI was not affected by corn processing method ($p = 0.0946$), CaPr supplementation ($p = 0.6077$), or the interaction ($p = 0.9755$). Consistently, the observed-to-expected ratios for NE_m and NE_g were affected by corn processing method ($p = 0.0034$), whereas the observed-to-expected DMI ratio was also affected by processing method ($p = 0.0023$), with no effect of CaPr supplementation ($p = 0.8410$) or the interaction ($p = 0.7275$). Lambs fed SFC diets exhibited greater observed-to-expected dietary energy ratios and lower observed-to-expected DMI ratios than those fed GC diets, reflecting greater dietary energy utilization associated with SFC processing.

Table 3. Effects of corn processing method and calcium propionate supplementation on dietary energy utilization and ultrasound measurements of finishing lambs.

Item ¹	Calcium Propionate, g/lamb/d				SEM ²	Significance		
	0		9.45			Processing Method	CaPr	Processing × CaPr
	Processing Method							
	Ground	Steam-Flaked	Ground	Steam-Flaked				
Dietary net energy (Mcal/kg)								
NE _m	1.61	1.85	1.61	1.81	0.07	0.0034	0.8175	0.7208
NE _g	0.99	1.21	1.00	1.18	0.06	0.0034	0.8175	0.7208
Expected DMI, kg/d	1.10	1.17	1.13	1.21	0.06	0.0946	0.6077	0.9755
Observed:expected ratio								
NE _m	0.86	0.97	0.87	0.95	0.04	0.0034	0.8175	0.7208
NE _g	0.83	0.97	0.83	0.95	0.05	0.0034	0.8175	0.7208
Observed:expected DMI ratio	1.22	1.06	1.21	1.09	0.06	0.0023	0.8410	0.7275
Ultrasound measurements								
FAT, mm	3.48	3.45	2.89	3.79	0.25	0.0957	0.6255	0.0491
RFT, mm	4.14 ^a	4.03 ^a	3.69 ^b	4.49 ^a	0.19	0.0897	0.9747	0.0272
LMA, cm ²	13.53 ^a	14.71 ^a	12.88 ^b	14.09 ^a	0.48	0.0206	0.1988	0.9765

¹ NE_m = net energy for maintenance, NE_g = net energy for gain, DMI = dry matter intake, FAT = subcutaneous fat thickness between the 12th and 13th ribs, RFT rump fat thickness at the P8 anatomical site, LMA = *Longissimus lumborum* muscle area. ² SEM = standard error of the mean. ^{a,b} Different superscripts within a row indicate significant differences ($p \leq 0.05$) according to Tukey's test.

For ultrasound measurements, FAT showed a processing $\times$ CaPr interaction ($p = 0.0491$), with no main effects of corn processing method ($p = 0.0957$) or CaPr supplementation ($p = 0.6255$). Similarly, RFT exhibited a processing $\times$ CaPr interaction ($p = 0.0272$), where GCCaPr presented the lowest value, whereas GC, SFC, and SFCCaPr were greater and did not differ among them ($p < 0.05$), representing increases of approximately 9–22% relative to GCCaPr. In contrast, LMA was affected only by corn processing method ($p = 0.0206$), with no effect of CaPr supplementation ($p = 0.1988$) or the interaction ($p = 0.9765$). Lambs fed SFC diets exhibited greater LMA values than those fed GC diets. Overall, ultrasound responses differed according to corn processing method and its interaction with CaPr supplementation, affecting FAT, RFT, and LMA.

3.2. Empty Body Weight and Visceral Organ Mass

Empty body weight was not affected by corn processing method ($p = 0.1602$), CaPr supplementation ($p = 0.2530$), or the processing $\times$ CaPr interaction ($p = 0.9789$) (Table 4). Similarly, organ weights expressed relative to EBW were not affected by corn processing method, CaPr supplementation, or their interaction ($p \geq 0.0905$), indicating a similar relative development of visceral organs and non-carcass components among treatments.

Table 4. Effects of corn processing method and calcium propionate supplementation on organ mass and internal fat deposition of finishing lambs.

Item ¹	Calcium Propionate, g/lamb/d				SEM ²	Significance		
	0		9.45			Processing Method	CaPr	Processing × CaPr
	Processing Method							
	Ground	Steam-Flaked	Ground	Steam-Flaked				
EBW, kg	44.61	46.05	45.78	47.16	0.98	0.1602	0.2530	0.9789
Organ, g/kg EBW								
Stomach complex	25.89	24.88	27.35	26.42	1.55	0.5359	0.3426	0.9807
Large intestine	12.40	12.12	13.36	12.38	0.68	0.3626	0.3814	0.6096
Small intestine	17.02	19.64	19.65	18.96	1.33	0.4746	0.4705	0.2228
Skin	190.26	201.21	187.91	186.20	11.90	0.7011	0.4726	0.5995
Limbs	27.44	28.17	25.62	25.44	1.02	0.7908	0.4705	0.6573
Head	33.76	32.53	34.53	32.53	1.57	0.3135	0.8089	0.8076
Heart	17.56	14.62	13.87	13.44	2.10	0.4300	0.2578	0.5554
Lungs	19.80	26.95	22.17	22.56	2.61	0.1600	0.7001	0.2060
Liver	18.02	19.65	18.21	18.30	0.76	0.2655	0.4508	0.3176
Spleen	2.81	2.03	1.56	3.96	1.04	0.4421	0.7470	0.1387
Kidney	2.76	2.76	2.94	2.60	0.21	0.4276	0.9500	0.4135
Testicles	18.70	18.72	16.76	16.68	1.13	0.9798	0.0905	0.9636
Omental fat	20.08	18.85	17.44	22.41	2.16	0.3939	0.8347	0.1624
Mesenteric fat	18.32	14.84	15.28	18.01	1.82	0.8391	0.9703	0.1000
Visceral fat ³	38.40	33.69	32.72	40.42	3.73	0.6918	0.8896	0.0485
Perirenal fat	16.15	11.38	11.29	15.00	1.73	0.7609	0.7249	0.0209

¹ EBW = empty body weight. ² SEM = standard error of the mean. ³ Visceral fat was calculated as the sum of omental and mesenteric fat depots.

Regarding internal fat deposition, omental and mesenteric fat were not affected by corn processing method, CaPr supplementation, or the processing × CaPr interaction ($p \geq 0.1000$). However, total visceral fat exhibited a processing × CaPr interaction ($p = 0.0485$), where SFCCaPr presented the greatest value and GCCaPr the lowest, whereas GC and SFC showed intermediate values. Likewise, perirenal fat also showed a processing × CaPr interaction ($p = 0.0209$), where GCCaPr presented lower values than GC and SFCCaPr, whereas SFC showed intermediate values. Overall, these results indicate that the response of internal fat deposition to CaPr supplementation depended on corn processing method.

3.3. Carcass Characteristics

Hot carcass weight and CCW were affected by corn processing method ($p = 0.0339$ and $p = 0.0241$, respectively), with no effect from CaPr supplementation ($p \geq 0.7683$) or the processing × CaPr interaction ($p \geq 0.8673$) (Table 5). Lambs fed SFC diets exhibited greater carcass weights than those fed GC diets, regardless of CaPr supplementation. Dressing percentage and CL were not affected by treatments ($p \geq 0.1268$). Regarding carcass morphometric measurements, carcass length was affected by CaPr supplementation ($p = 0.0451$), with greater values observed in supplemented treatments, whereas chest depth was affected by corn processing method ($p = 0.0368$), with greater values in GC diets. Leg perimeter was not affected by corn processing method, CaPr supplementation, or the interaction ($p \geq 0.1953$).

For shoulder tissue composition, processing × CaPr interactions were detected for muscle ($p = 0.0309$), fat ($p = 0.0438$), and the muscle:fat ratio ($p = 0.0348$). The SFC treatment without CaPr supplementation presented the greatest muscle proportion, whereas GCCaPr showed the greatest muscle:fat ratio. In contrast, SFCCaPr exhibited greater fat proportions relative to GCCaPr. Overall, these results indicate that the response of shoulder tissue composition to CaPr supplementation depended on corn processing method.

Table 5. Effects of corn processing method and calcium propionate supplementation on carcass characteristics and tissue composition of finishing lambs.

Item ¹	Calcium Propionate, g/lamb/d				SEM ²	Significance		
	0		9.45			Processing Method	CaPr	Processing × CaPr
	Processing Method							
	Ground	Steam-Flaked	Ground	Steam-Flaked				
Carcass characteristics								
HCW, kg	25.79	26.85	25.57	26.71	0.47	0.0339	0.7683	0.8673
CCW, kg	24.84	25.97	24.79	25.94	0.46	0.0241	0.9618	0.9072
Dressing, %	51.48	50.27	50.18	51.39	1.39	0.9578	0.9331	0.3692
CL, %	3.78	3.42	3.19	2.99	0.29	0.3577	0.1268	0.7776
Carcass length, cm	68.57	65.80	69.62	69.43	1.07	0.2199	0.0451	0.1923
Leg perimeter, cm	42.71	45.40	43.88	43.00	1.26	0.646	0.6663	0.1953
Chest depth, cm	21.50	19.80	21.88	21.14	0.55	0.0368	0.1419	0.2503
Shoulder tissue composition, %								
Muscle	62.12	64.96	64.82	62.70	1.09	0.9104	0.8160	0.0309
Fat	18.77	16.90	16.20	17.31	0.81	0.7188	0.1638	0.0438
Muscle:fat ratio	3.42	3.87	4.03	3.67	0.19	0.9174	0.2501	0.0348

¹ HCW = hot carcass weight, CCW = cold carcass weight, CL = cooling loss. ² SEM = standard error of the mean.

3.4. Wholesale Cuts and Meat Quality

For wholesale cut distribution, most variables were not affected by corn processing method, CaPr supplementation, or the processing × CaPr interaction ($p \geq 0.0647$) (Table 6). However, hindquarter yield was affected by CaPr supplementation ($p = 0.0494$), with greater values observed in non-supplemented treatments. Similarly, shoulder IMPS207 was also affected by CaPr supplementation ($p = 0.0494$), with greater values observed in supplemented treatments. No effects of corn processing method or interactions were detected for these variables ($p \geq 0.4216$).

Table 6. Effects of corn processing method and calcium propionate supplementation on wholesale cut distribution and meat quality of finishing lambs.

Item ¹	Calcium Propionate, g/lamb/d				SEM ²	Significance		
	0		9.45			Processing Method	CaPr	Processing × CaPr
	Processing Method							
	Ground	Steam-Flaked	Ground	Steam-Flaked				
Whole cuts, % of cold carcass weight								
Forequarter	55.13	53.96	56.85	56.30	1.19	0.6496	0.1021	0.9992
Hindquarter	44.06	44.69	42.25	42.53	0.58	0.4439	0.0494	0.7359
Neck	4.41	3.84	4.62	5.18	0.49	0.6637	0.2009	0.4489
Shoulder IMPS206	9.17	9.09	9.54	8.69	0.35	0.1453	0.8096	0.2981
Shoulder IMPS207	17.04	16.80	17.91	17.12	0.32	0.0933	0.0494	0.4216
Rack IMPS204	6.27	6.72	6.63	6.29	0.19	0.9441	0.8884	0.0647
Breast IMPS209	3.84	3.82	3.75	3.85	0.16	0.7659	0.9521	0.7234
Ribs IMPS209A	6.15	6.02	6.01	6.15	0.19	0.9058	0.9947	0.4904
Loin IMPS231	6.26	6.71	6.91	6.70	0.22	0.7660	0.1481	0.1751
Flank IMPS232	6.76	7.39	5.51	6.04	0.35	0.0721	0.1436	0.6893
Leg IMPS233	31.04	30.59	29.83	29.78	0.54	0.6151	0.0862	0.6505
Meat characteristics								
pH _{24h}	5.53	5.50	5.49	5.56	0.04	0.6278	0.8684	0.1866
PRL _{24h} , %	6.04	7.03	8.36	8.27	0.95	0.6713	0.0496	0.5634
CKL, %	27.20	25.24	24.54	28.23	1.97	0.6974	0.9325	0.1531
WHC, %	35.44	40.69	37.37	35.54	1.41	0.2889	0.2564	0.0170
WBSF, kg/cm ²	4.22	3.99	4.46	3.86	0.24	0.1402	0.8346	0.4387

¹ PRL_{24h} = Purge loss at 24 h, CKL = cooking loss, WHC = water-holding capacity, WBSF = Warner-Bratzler shear force. ² SEM = standard error of the mean.

Regarding meat quality characteristics, pH_{24h}, CKL, and WBSF were not affected by treatments ($p \geq 0.1402$). Purge loss at 24 h was affected by CaPr supplementation ($p = 0.0496$), with greater values observed in supplemented treatments, without effects of corn processing method or the interaction ($p \geq 0.5634$). In contrast, WHC exhibited a processing $\times$ CaPr interaction ($p = 0.0170$), indicating that the response of this variable depended on the combination of both factors. Overall, most instrumental meat quality variables were not affected by corn processing method, CaPr supplementation, or their interaction.

4. Discussion

4.1. Growth Performance, Dietary Energetics, and Ultrasound Measurements

Greater FBW (3–4%), ADG (17–20%), and G:F (24–26%) observed in lambs fed SFC, together with the increases in observed dietary NE_m, NE_g, and observed-to-expected dietary NE ratios, indicate that SFC improved dietary energetics and energy utilization relative to GC. These responses are consistent with previous reports showing that steam flaking increases starch availability and dietary energetic value by disrupting the endosperm matrix and increasing starch gelatinization [1,5,7,8,29,30]. Steam flaking also disrupts the protein matrix surrounding starch granules, increasing starch exposure and accessibility to microbial and enzymatic attack, thereby enhancing ruminal fermentation and total tract starch digestion [7,30]. Rivera-Villegas et al. [6] reported increases of 13–22% in dietary NE_m and NE_g and a 25% improvement in G:F in lambs fed SFC compared with GC. Comparable responses have also been reported in finishing cattle and lambs, where SFC increased starch digestibility, dietary energetic value, and G:F relative to dry-processed corn sources [1,7,8,31], partly due to greater ruminal starch digestion and propionate production compared with less extensively processed corn [32].

In contrast, CaPr supplementation increased DMI as a main effect, whereas the lowest DMI was observed in SFC. However, CaPr did not improve ADG, G:F, or observed dietary energetics. These responses partially differ from previous studies in high-risk calves and finishing lambs in which CaPr improved ADG, DMI, or G:F under conditions associated with lower dietary energetic density or greater metabolic challenge [10,11]. Murillo-Ortiz et al. [33] reported greater ADG and G:F in feedlot steers supplemented with a glucogenic precursor containing CaPr, together with increased ruminal propionate concentration and nitrogen flow to the duodenum, suggesting improved nutrient utilization under those feeding conditions. However, previous reports have indicated that responses to CaPr depend on dietary energetic conditions and supplementation level, with some studies reporting changes in energy-related variables without proportional improvements in productive performance [10,34]. Consistent with the present results, Velázquez-Cruz et al. [35] observed that supplementation with 10 g CaPr/kg DM did not affect ADG, G:F, or observed dietary energetics in finishing lambs fed high-concentrate diets, whereas Zhang et al. [36] reported no changes in ADG, DMI, or G:F in finishing steers supplemented with CaPr. Those authors suggested that when ruminal propionate production is already elevated because of the dietary concentrate level, supplemental CaPr may provide limited additional benefits for growth performance. Although CaPr has been shown to increase glucose turnover and endogenous glucose production in sheep, confirming its role as a glucogenic precursor capable of modifying energy metabolism [37], under the conditions of the present study, CaPr supplementation increased DMI without affecting ADG, G:F, or observed dietary energetics. Collectively, these findings suggest that the productive response to CaPr may be limited when dietary energy supply is already sufficient and additional glucogenic substrate does not represent a limiting factor for growth performance.

Ultrasound measurements were consistent with the productive and energetic responses observed during the feeding period. The interactions detected for FAT and RFT indicate that fat deposition depended on the combination of corn processing method and CaPr supplementation. In particular, RFT responses varied according to the combination of both factors, whereas LMA was affected only by corn processing method, with greater values observed in lambs fed SFC diets. These findings are consistent with previous reports indicating that increased dietary energy availability may influence tissue deposition patterns once growth requirements are met, favoring fat accretion when energy supply exceeds requirements [29,38]. Moreover, greater starch digestibility and dietary energy availability associated with SFC have been consistently related to improvements in growth performance and G:F in feedlot cattle and lambs [7,31]. Similarly, studies evaluating CaPr supplementation have reported increased body fat deposition under conditions associated with prolonged supplementation or greater dietary energy supply, even when improvements in productive performance or G:F were limited [11,13,39]. This response may be related, at least in part, to the reported role of propionate as a signaling molecule involved in adipocyte differentiation, as CaPr supplementation has been associated with increased expression of adipogenic markers such as PPARG and CEBPA in finishing steers [36]. However, the lack of improvements in ADG, G:F, and dietary energetics observed in the present study is consistent with reports indicating that CaPr supplementation may exert only minor effects on ruminal fermentation characteristics and microbial community structure when animals are fed high-energy diets [40,41]. Collectively, these results suggest that corn processing primarily influenced muscular development, whereas fat deposition responses depended on the interaction between corn processing method and CaPr supplementation.

Overall, the present results indicate that SFC improved dietary energetics and energy utilization relative to GC, whereas CaPr increased DMI without affecting ADG, G:F, or observed dietary energetics. Fat deposition responses, however, varied according to the combination of corn processing method and CaPr supplementation.

4.2. Empty Body Weight and Visceral Organ Mass

Empty body weight and the relative weight of most visceral organs were not affected by corn processing method, CaPr supplementation, or their interaction. These results indicate that the greater FBW, ADG, and dietary energetic responses previously observed were not accompanied by major changes in visceral organ development or non-carcass components. Therefore, the productive advantages associated with SFC appear to be more closely related to improvements in dietary energetics and energy utilization than to changes in visceral organ mass.

In contrast, visceral and perirenal fat deposition were influenced by the interaction between corn processing method and CaPr supplementation. Lambs fed SFCCaPr exhibited the greatest visceral fat deposition, whereas GCCaPr showed the lowest values. Likewise, perirenal fat deposition was lower in GCCaPr than in GC and SFCCaPr, with SFC showing intermediate values. These results indicate that internal fat deposition depended on the combination of corn processing method and CaPr supplementation rather than on independent main effects.

This pattern is generally consistent with Rivera-Villegas et al. [6], who reported that increases in observed-to-expected dietary NE associated with corn processing were accompanied by greater internal fat deposition in finishing lambs. Similarly, Papi et al. [42] observed that increased dietary energetic density enhanced body fat deposition without proportional changes in organ weight, suggesting that excess available energy may be preferentially directed toward lipid reserves rather than visceral tissue growth. Owens et al. [43] likewise described that increases in dietary energy availability may favor adipose tissue

deposition before proportional changes occur in other body components. In agreement, Hejazi et al. [44] reported that different corn processing methods modified digestibility and productive performance in lambs without producing consistent changes in visceral organ mass, which agrees with the limited visceral organ responses observed in the present study.

Responses to CaPr supplementation also appear to depend on dietary energetic conditions, supplementation level, and feeding duration. Carrillo-Muro et al. [12] reported increases in EBW and some carcass-related variables in lambs supplemented with CaPr, although responses among fat depots were not consistent. Subsequently, Carrillo-Muro et al. [11] observed that prolonged CaPr supplementation increased fat deposition, whereas Carrillo-Muro et al. [13] reported improvements in productive performance and LMA under specific finishing conditions with ZH supplementation. In addition, Zhang et al. [36] suggested that propionate may participate in adipogenic signaling pathways, which could partially explain why responses to CaPr supplementation are often more evident in fat deposition variables than in growth performance or visceral organ development. In high-risk calves, CaPr supplementation has also been associated with greater body reserve accretion during receiving periods; however, those studies did not evaluate visceral organ mass, and direct comparisons with the present results should therefore be made cautiously [11–13].

Taken together, the present results indicate that SFC improved dietary energetics and energy utilization without major changes in visceral organ development, whereas internal fat deposition responses depended on the interaction between corn processing method and CaPr supplementation. These findings are consistent with the interaction effects observed for FAT and RFT, indicating that several indicators of fat deposition responded differently according to the combination of corn processing method and CaPr supplementation.

4.3. Carcass Characteristics

The response observed for LMA indicated that corn processing method influenced muscular development, as lambs fed SFC diets exhibited greater LMA values on average than those fed GC diets. *Longissimus lumborum* muscle area is considered a reliable indicator of muscular development in lambs [45], and increases in LMA are commonly associated with greater dietary energy availability derived from improved starch utilization and energy supply [43,46]. Greater starch digestibility associated with steam flaking may increase the supply of metabolizable energy available for tissue accretion, thereby supporting muscle development and carcass growth [7,32]. In agreement, Rivera-Villegas et al. [6] reported a 17.7% increase in LMA together with improvements in ADG (30.8%) and G:F (24.6%) in lambs fed SFC, indicating that responses to grain processing may be reflected in indicators of muscular development before broad carcass modifications become evident.

Despite the differences observed in LMA, most carcass characteristics were not modified by corn processing method, since dressing percentage, cooling loss, and most morphometric variables were not consistently affected by corn processing method, even though HCW and CCW were greater in SFC-fed lambs. This apparent dissociation between dietary energetics and carcass responses was also reported by Rivera-Villegas et al. [6], where improvements in dietary energetics were not accompanied by consistent changes in most carcass-related variables. Similarly, Oliveira et al. [47] did not observe differences in HCW, dressing percentage, or LMA among corn processing methods in finishing lambs despite differences in FBW, which agrees with the limited carcass response observed in the present study. Although chest depth was greater in GC-fed lambs, this response was not accompanied by corresponding improvements in HCW, CCW, ADG, or LMA. Therefore, the biological significance of this isolated morphometric difference appears limited and

may reflect normal variation in body conformation rather than a meaningful change in carcass development.

This pattern suggests that moderate increases in dietary energetic availability may initially promote tissue accretion and internal fat deposition before producing detectable modifications in integrated carcass traits [43,48]. In this context, Rivera-Villegas et al. [6] reported increases in visceral fat deposition and LMA without major changes in most carcass variables, suggesting that additional dietary energy may first be partitioned toward tissue deposition rather than broad carcass composition changes.

Regarding CaPr supplementation, the absence of consistent effects on LMA, HCW, and CCW indicates that the increase in DMI was not sufficient to generate detectable changes in muscular growth or carcass weight under the conditions of the present study. Similar responses have been reported in studies where CaPr supplementation increased FBW, ADG, or DMI without consistently modifying carcass characteristics or meat quality variables [11]. Likewise, Martínez-Aispuro et al. [34] and Carrillo-Muro et al. [12] reported increases in EBW and tendencies toward greater HCW and CCW with CaPr supplementation, although responses varied depending on dietary energetic density and supplementation duration. Furthermore, prolonged CaPr supplementation may promote greater fat accretion rather than proportional increases in muscle deposition [13], which agrees with the physiological pattern described in ruminants where increases in dietary energy availability are preferentially directed toward adipose tissue reserves before major changes occur in muscular composition [43,49]. This interpretation is also consistent with reports suggesting that propionate may influence adipogenic pathways, potentially favoring nutrient partitioning toward fat deposition rather than additional muscle accretion under certain feeding conditions [36].

Collectively, the present results indicate that SFC improved dietary energetics and energy utilization, which was associated with greater HCW, CCW, and LMA relative to GC, whereas CaPr supplementation did not consistently affect carcass traits. Under the conditions of the present study, differences in dietary energetics were sufficient to modify indicators of muscular development and carcass weight, but not enough to generate broad changes in carcass composition or most carcass characteristics.

4.4. Wholesale Cuts and Meat Quality

The absence of major effects of SFC on most wholesale cuts indicates that, although corn processing increased carcass weight, it did not substantially modify carcass regional distribution. This suggests that the greater HCW and CCW previously observed were translated into a proportional increase in carcass mass rather than into marked modifications in anatomical composition. These results agree with Rivera-Villegas et al. [6], who reported that improvements in dietary energy utilization associated with SFC were not accompanied by consistent changes in wholesale cut distribution, but rather by a general increase in carcass weight. Similarly, Díaz et al. [50] and Santos et al. [51] reported that moderate increases in dietary energetic density do not necessarily produce proportional modifications in the yield of commercial cuts in finishing lambs.

In contrast, the effects of CaPr supplementation on hindquarter and shoulder IMPS 207 indicate specific responses in carcass regional distribution. Lambs not supplemented with CaPr exhibited greater hindquarter values, whereas lambs supplemented with CaPr showed greater shoulder IMPS 207 values. Similar responses have been reported in lambs, where CaPr supplementation did not consistently modify carcass weight but affected variables associated with carcass tissue distribution or composition under certain feeding conditions [11,13].

Regarding meat quality, the stability in $\text{pH}_{24\text{h}}$, CKL, and WBSF indicates that the observed changes in dietary energy availability and utilization were insufficient to alter postmortem processes associated with muscle acidification, cooking losses, or instrumental tenderness. The stability in $\text{pH}_{24\text{h}}$ is consistent with the absence of major treatment effects on postmortem processes associated with pH decline in fresh meat [52,53]. Likewise, the absence of differences associated with corn processing in CKL, WBSF, $\text{PRL}_{24\text{h}}$, and WHC indicates that grain processing did not substantially modify the functional properties of muscle tissue or instrumental tenderness. Similar responses have been reported in small ruminants, where moderate increases in dietary energy density did not consistently affect pH, WHC, or WBSF [50,51]. Likewise, Oliveira et al. [47] did not observe effects of corn processing on pH, CKL, or WBSF in lambs fed high-concentrate diets.

On the other hand, the increase in $\text{PRL}_{24\text{h}}$ associated with CaPr supplementation indicates a specific effect on postmortem water loss, whereas the interaction observed for WHC indicates that water retention capacity depended on the combination of corn processing method and CaPr supplementation. The limited effects of CaPr on most meat-quality traits are consistent with previous reports indicating that glucogenic supplementation may modify energy metabolism and body tissue deposition without necessarily producing proportional changes in postmortem muscle characteristics [11,13]. However, most instrumental meat quality traits remained unaffected by either factor.

Overall, these results indicate that, although SFC improved growth performance and increased carcass weight, it did not substantially modify wholesale cut distribution or most meat quality characteristics. In contrast, CaPr supplementation affected the distribution of some wholesale cuts, whereas responses in some water retention variables depended on the combination of corn processing method and CaPr supplementation.

From a practical perspective, the improvements observed with SFC should be interpreted considering the additional infrastructure and processing costs associated with steam-flaking. Although an economic evaluation was beyond the scope of the present study, the consistent improvements in ADG, G:F, dietary energetics, HCW, CCW, and LMA indicate that SFC may represent a valuable nutritional strategy for intensive finishing systems where maximizing G:F and carcass weight is a priority. In contrast, CaPr supplementation increased DMI but did not improve ADG, G:F, or dietary energetics and therefore did not compensate for the lower energetic value associated with GC diets. Nevertheless, the consistent increase in DMI observed with CaPr supplementation suggests that this additive may have practical value under production scenarios where maintaining or stimulating voluntary DMI is a priority. Examples include periods of heat stress, receiving programs, nutritional transitions, or other situations commonly associated with reduced DMI. Under such conditions, increasing nutrient intake may be beneficial even when improvements in ADG or G:F are not immediately observed. However, these potential applications were not evaluated in the present study and therefore should be interpreted cautiously. In addition, the interaction effects observed for subcutaneous, visceral, and perirenal fat deposition, as well as shoulder tissue composition, suggest that CaPr may influence nutrient partitioning according to the energetic conditions created by corn processing. Consequently, decisions regarding the adoption of SFC and CaPr supplementation should consider not only biological responses, but also processing costs, production objectives, and the desired balance between growth performance, DMI, and tissue deposition.

Finally, it is important to consider that the present study was conducted under controlled feedlot conditions using a single CaPr inclusion level and a single genetic type, which may limit the extrapolation of the results to other production systems, dietary conditions, or genotypes. Moreover, the experimental period focused exclusively on the finishing phase; therefore, responses could differ under longer feeding programs or during earlier

productive stages. In addition, serum metabolites, ruminal fermentation characteristics, and molecular markers associated with energy metabolism or adipogenesis were not evaluated; therefore, the physiological and molecular mechanisms underlying the responses to CaPr supplementation and corn processing could not be directly confirmed.

5. Conclusions

Under the conditions evaluated, corn grain processing influenced energy utilization and several productive responses in finishing lambs. Feeding SFC improved growth performance and increased observed dietary NE_m and NE_g compared with GC, demonstrating a greater capacity to utilize dietary energy. Calcium propionate supplementation increased DMI but did not improve ADG, G:F, observed dietary energetics, or observed-to-expected dietary energy ratios, indicating that its inclusion was insufficient to overcome the lower energetic value of GC diets. The interaction between corn processing method and CaPr supplementation affected visceral, perirenal, and subcutaneous fat deposition, as well as selected indicators of shoulder tissue composition, suggesting that nutrient partitioning responses depended on the combination of both nutritional strategies. Although these effects were evident in some measures of tissue deposition, most carcass traits, wholesale cut yields, and meat-quality characteristics were not altered. Overall, these findings indicate that the benefits of steam-flaking were primarily associated with improved dietary energy utilization and growth performance, whereas CaPr supplementation mainly increased DMI and modified fat deposition patterns, without producing substantial changes in carcass composition or meat quality.

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