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Steam-Flaked Corn in Feedlot Lambs: Growth Performance, Dietary Energetics, Visceral Fat Deposition, and Carcass Characteristics

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Simple Summary

Corn kernels, which provide a high amount of energy, are widely used in fattening diets for beef cattle and lambs. To improve their use, the kernels are processed by cracking or steam-flaking. Steam-flaking is the most common method in cattle because it increases the energy value of corn by about 10%. However, there is limited information about its benefits in lambs. The objective of this study was to evaluate this effect. Compared with ground corn, steam-flaked corn increased final body weight by 4.71%, average daily gain by 30.8%, improved feed efficiency by 24.6%, and increased the observed dietary energy value by 10.4%. Steam-flaked corn also increased dry matter intake by 10.1% compared with whole corn. Lambs fed steam-flaked corn showed 17.7% greater longissimus muscle area than lambs fed ground corn. Corn processing modified visceral fat deposition; however, carcass characteristics, commercial cuts, and meat quality showed no major differences among treatments during the 45 d experimental period. The estimated energy value was higher for steam-flaked corn than for cracked or ground corn and was similar to current feeding standards for lambs, whereas dry-processed corn showed lower energy values. These results indicate that steam-flaked corn may improve energy use in lambs, although its advantages over simpler processing methods under the conditions of the present study may be smaller than expected.

Abstract

Limited empirical evidence is available validating the energy value assigned to steam-flaked corn (SFC) for small ruminants in current NRC feeding standards. Therefore, the objective of this study was to evaluate the effects of corn processing, including steam-flaking, on growth performance, dietary energetics, visceral fat deposition, and carcass characteristics of finishing lambs. Forty-eight Dorper × Katahdin ram lambs (42.0 ± 0.27 kg initial body weight) were assigned to one of four treatments (n = 12 per treatment) and fed high-concentrate diets for 45 d containing 50% yellow corn grain. Treatments differed only in the form of corn presentation: whole corn (WC), cracked corn (CC), ground corn (GC), or SFC. Cracked corn was produced using a roller mill without a sieve (mean particle

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size 4 to 6 mm), whereas ground corn was processed through a 3 mm sieve (mean particle size 1 to 2 mm). For SFC, WC was steamed for 20 min at approximately 102 °C before rolling, and flake density was adjusted to 0.36 kg/L by roller tension. Dry matter intake was 10.1% greater in SFC than in WC ($p = 0.020$), whereas CC and GC showed intermediate responses. Final body weight (+4.7%), average daily gain (+30.8%), and observed dietary net energy for maintenance (NE_m; +10.4%) were greater in SFC than in GC ($p < 0.05$), whereas WC and CC showed intermediate responses. Gain-to-feed ratio was greater in SFC than in GC and CC ($p = 0.028$), representing increases of 24.6% and 18.2%, respectively. Empty body weight and visceral fat deposition were also affected by treatment ($p < 0.05$), with greater visceral fat deposition in SFC and CC than in GC, whereas WC showed intermediate responses. Steam-flaked corn increased *longissimus lumborum* muscle area by 17.7% relative to GC ($p = 0.048$) and increased perirenal fat deposition relative to WC, CC, and GC ($p = 0.048$). However, most carcass characteristics and meat quality variables were not affected during the 45 d experimental period ($p > 0.05$). Using a replacement technique, estimated NE_m values (Mcal/kg) for CC, GC, and SFC were 2.00, 1.88, and 2.24, respectively. The NE_m value for SFC was in close agreement (2.24 vs. 2.30 Mcal/kg) with current feeding standards, whereas dry-processed corn showed lower estimated NE_m values ($p = 0.025$), representing reductions of 9% and 17% for CC and GC, respectively. In conclusion, SFC improved growth performance and dietary energy utilization relative to GC, while producing limited effects on carcass-related responses under the conditions of this 45 d study.

Keywords: average daily gain; corn processing; dietary net energy; feed efficiency; finishing lambs; visceral adiposity

1. Introduction

In intensive finishing systems for ruminants, corn grain is one of the primary energy sources used in México, the United States, and Canada due to its high starch concentration and energy density [1–3]. In high-concentrate feedlot diets, starch may exceed 50% of dietary dry matter (DM), making corn inclusion levels near 50% common under practical finishing conditions and major determinants of energy supply and productive efficiency [4]. Consequently, the nutritive value of corn depends not only on inclusion level but also on grain processing prior to feeding, which alters pericarp integrity, particle size, endosperm structure, and the accessibility of endosperm nutrients to microbial and enzymatic digestion [5–8]. Even when the endosperm becomes exposed after processing, starch granules may remain partially encapsulated by hydrophobic prolamin proteins, limiting energy utilization efficiency [9]. Therefore, both mechanical (cracking, grinding) and thermal processing (steam-flaking) are commonly used to improve grain utilization in feedlot systems [10,11].

Corn grain processing in beef cattle has been shown to increase the net energy (NE) value of corn grain, particularly when intensive processing methods are applied. Mechanical methods such as hammer milling or dry-rolling may slightly increase NE value (~3%) compared with whole corn (WC) [12–14], mainly due to greater starch digestibility [15,16]. In fact, total tract starch digestibility can increase from approximately 89% in WC to more than 92% in cracked corn (CC) and up to 97% in steam-flaked corn (SFC), reflecting the impact of processing intensity on energy availability [16]. However, evidence in sheep is limited and inconsistent. Hejazi et al. [17] reported 4% greater average daily gain (ADG) in lambs fed WC compared with ground corn (GC), and Wang et al. [18] observed greater

final body weight (FBW) with WC at similar dry matter intake (DMI), whereas Petit [19] found no advantages of WC over dry-rolled corn. These inconsistencies may be related to interspecific differences in feeding behavior, ruminal dynamics, and mastication efficiency, as sheep reduce particle size more effectively than cattle and may partially offset the benefits of mechanical processing [11,20,21]. In agreement, current feeding standards assign the same NE for maintenance (NE_m; 2.20 Mcal/kg) to WC and conventional dry-processed corn sources in lambs, whereas SFC is assigned only a modestly greater value (2.30 Mcal/kg) [22], suggesting that the productive advantage of dry processing in feedlot lambs may remain limited under some conditions [10,20].

Steam-flaking is a hydrothermal processing method in which corn kernels are exposed to steam and heat before rolling to produce flakes of controlled density. This process disrupts the endosperm protein matrix, promotes starch gelatinization, and increases enzymatic accessibility [8,23]. As a result, SFC enhances both ruminal and total tract starch digestibility, although it may reduce the proportion of bypass starch available for intestinal digestion and thus modify the site of energy utilization [4]. In beef cattle, SFC provides approximately 9 to 12% more NE_m than WC or CC [14], and its energetic advantages are well established under feedlot conditions. In contrast, information in lambs is limited and inconsistent. Early work reported improved gain-to-feed ratio (G:F) with heat-treated corn [24], whereas current standards indicate only a modest advantage of SFC over CC (2.30 vs. 2.20 Mcal NE_m/kg) [22], values derived from limited information but consistent with earlier cattle estimates [25]. Recent evidence suggests that thermal processing strategies may differentially affect the balance between ruminal fermentation and post-ruminal starch digestion in lambs, influencing overall energy efficiency [4]. From an applied standpoint, although steam-flaking increases energy availability, changes in starch digestion and energy utilization may also alter nutrient partitioning and carcass fat deposition patterns [26,27], potentially influencing carcass value and production efficiency. Therefore, empirical validation of the energetic and productive responses to SFC in feedlot lambs remains necessary.

Based on this evidence, we hypothesized that SFC would improve growth performance and dietary energy utilization relative to dry-processed corn in finishing lambs. The objective of this study was to evaluate the effects of corn processing method on growth performance, dietary energetics, visceral fat deposition, and carcass characteristics of finishing lambs.

2. Materials and Methods

The experiment was conducted at the Multinutrimentos, Aditivos y Asesoría Zootécnica (MAAZ) Experimental Center located in Calera de Víctor Rosales, Zacatecas, Mexico (22°56′51.23″ N, 102°41′32.33″ W; 2162 m above sea level), a region characterized by a temperate semi-arid climate. The 45 d feeding trial was conducted from 11 August to 24 September 2025, during which mean ambient temperature averaged 20.7 °C. Lambs were slaughtered at 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, where carcass fabrication and tissue sample collection were performed. Carcass and meat quality evaluations were subsequently conducted at the Meat Science and Technology Laboratory of UAMVZ-UAZ. Basal diet samples used for chemical composition analysis were processed at the Animal Nutrition Laboratory of the Instituto de Investigaciones en Ciencias Veterinarias, Universidad Autónoma de Baja California.

All animal handling, management, and sampling procedures were reviewed and approved by the Institutional Committee on Bioethics and Animal Welfare of UAMVZ-

UAZ (Protocol #01, August 2025). Experimental procedures were conducted in accordance with applicable Mexican regulations for the care and use of animals in research [28–31].

2.1. Animal Processing, Housing, and Feeding

A total of 78 intact male Dorper × Katahdin lambs were obtained from a single local producer and transported 28 km to the MAAZ Experimental Center. Upon arrival, lambs were approximately six months old and were individually identified with a numbered ear tag, vaccinated against *Clostridium* spp., *Pasteurella multocida*, and *Mannheimia haemolytica* (Exgon 10®, Chinoin Veterinaria, Aguascalientes, Mexico), treated for internal parasites with closantel (Closantel® 5%, Chinoin Veterinaria, Aguascalientes, Mexico), and weighed using an electronic crane scale (Rhino® BAC-300; 300 kg capacity; Rhino Maquinaria SA de CV, Estado de México, Mexico). Lambs then underwent a 21 d adaptation period to feedlot facilities and experimental diets, during which oat hay and alfalfa hay (50:50) were progressively replaced by the basal finishing diet.

At the end of the adaptation period, animals were evaluated and 30 lambs were excluded before treatment allocation to obtain a homogeneous experimental population. Exclusion criteria were established a priori and included inadequate adaptation to feedlot conditions (persistent low feed intake, signs of illness, or digestive disorders during the adaptation period) or extreme deviation from the target initial body weight (IBW) range. Consequently, 48 lambs were selected for the experiment, weighed before the morning feeding, blocked by IBW (6 blocks), and randomly assigned in blocks to treatments. Lambs were housed in individual indoor pens (1.5 × 1.5 m) equipped with individual feeders and automatic waterers and were monitored twice daily throughout the trial to detect signs of illness, lameness, or digestive disorders.

The 45 d feeding period was selected to represent a commercial intensive finishing phase for heavy lambs and to allow for evaluation of growth performance, dietary energetics, and carcass responses under practical feedlot conditions.

2.2. Treatments

Corn grain was purchased from a local marketing company (Bunge México, S.A. de C.V., Jalisco, Mexico), which imports hybrid yellow corn from the United States. According to the warranty analysis provided by the company, the corn contained 8.8% crude protein (CP), 72.1% starch, and 9.5% neutral detergent fiber (NDF).

Whole corn used for the WC and SFC treatments was obtained directly from the supplier. For the SFC treatment, WC was exposed to steam for 20 min to achieve a grain temperature of approximately 102 °C before rolling. Steam was generated using a boiler operating at 483 kPa, and flake density was adjusted to 0.36 kg/L by roller tension [23,32]. Before diet preparation, SFC was air-dried for 5 d to facilitate handling and incorporation into the experimental diets, after which representative samples were collected for nutritional analyses. For dry-processing treatments, WC was processed at our facilities. Cracked corn was produced using a roller mill without a sieve to obtain a coarse particle size of approximately 4 to 6 mm, whereas GC was processed through a hammer mill equipped with a 3 mm sieve, resulting in particles of approximately 1 to 2 mm. Particle size ranges for CC and GC were estimated from the milling configuration and operational characteristics of the respective processing systems and were not confirmed by formal sieve analysis.

Dietary treatments consisted of a growing–finishing diet containing 50% corn grain (DM basis), offered as: (1) WC, (2) CC, (3) GC, and (4) SFC. Diets were prepared daily in a horizontal paddle mixer and offered ad libitum twice daily at 08:00 and 16:00 h in a 40:60 proportion of the daily allotment, respectively. Feed refusals were collected and weighed each morning before feeding, and daily feed allotments were adjusted to maintain approxi-

mately 30 g/kg refusals on an as-fed basis. Dry matter intake was subsequently calculated on a DM basis using the difference between feed offered and feed refused. Representative feed samples from each dietary batch were collected throughout the trial, composited by treatment, sealed in plastic bags, and stored at 4 °C until chemical analysis. Experimental diets were formulated using nutrient requirements for finishing lambs described by NRC [22]. Ingredient composition, analyzed chemical composition, and calculated dietary net energy values of the experimental diets are presented in Table 1.

Table 1. Ingredient composition, chemical composition, and calculated dietary energy values of experimental diets containing different corn grain processing methods (% of DM basis).

Ingredients	Corn Processing Method			
	Whole	**Cracked**	**Ground**	**Steam-Flaked**
Whole corn	50.00	-	-	-
Cracked corn	-	50.00	-	-
Ground corn	-	-	50.00	-
Steam-flaked corn	-	-	-	50.00
Corn stover	22.00	22.00	22.00	22.00
Dried distillers grains with solubles	8.00	8.00	8.00	8.00
Soybean meal, 44% CP	8.00	8.00	8.00	8.00
Cane molasses	7.90	7.90	7.90	7.90
Urea	0.50	0.50	0.50	0.50
Sodium sesquicarbonate	1.50	1.50	1.50	1.50
Calcium carbonate	1.00	1.00	1.00	1.00
Sodium bentonite	1.00	1.00	1.00	1.00
Premix [a]	0.10	0.10	0.10	0.10
Analyzed chemical composition, % [b]				
Dry matter	86.40	87.00	88.00	86.50
Organic matter	91.60	91.80	91.90	91.80
Crude protein	14.30	14.50	14.60	14.40
Starch	36.85	36.85	36.85	36.85
Neutral detergent fiber	22.70	21.60	20.80	19.90
Ether extract	3.45	3.48	3.50	3.49
Ash	8.40	8.20	8.10	8.20
Tabular dietary net energy values [c]				
Net energy for maintenance, Mcal/kg	1.86	1.86	1.86	1.91
Net energy for gain, Mcal/kg	1.20	1.20	1.20	1.25

[a] Contained per kilogram of premix: 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; plus 2,595,000 IU of vitamin A, 468,750 IU of vitamin D, and 28,000 IU of vitamin E. [b] Dry matter, crude protein, and ash were determined according to AOAC [33]; ether extract according to AOCS Official Method Am 5-04 [34]; and neutral detergent fiber using Ankom procedures (Ankom Technology, Macedon, NY, USA). Organic matter was calculated by difference. [c] Tabular net energy values were calculated from ingredient energy values reported by NRC [22]. The net energy for maintenance (NE_m) and net energy for gain (NE_g) assigned to corn were 2.20 and 1.52 Mcal/kg, respectively, for whole and dry-processed corn, and 2.30 and 1.61 Mcal/kg, respectively, for steam-flaked corn.

2.3. Chemical Analyses

Representative samples of the basal diets were collected and analyzed in triplicate to determine chemical composition. Dry matter content was determined by drying samples at 105 °C to constant weight using a forced-air oven (Thermo Scientific, Waltham, MA, USA), following AOAC method 930.15 [33]. Ash concentration was determined by combustion in a muffle furnace according to AOAC method 942.05 [33]. Crude protein was determined from nitrogen concentration using a nitrogen analyzer (FP-528, LECO Corp., St. Joseph, MI, USA), following AOAC method 984.13 [33].

Neutral detergent fiber was analyzed using an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY, USA) according to Van Soest et al. [35]. Ether extract was determined using an Ankom ^{XT15} Extractor (Ankom Technology, Macedon, NY, USA) following AOCS Official Method Am 5-04 [34]. Organic matter was calculated as dry matter minus ash content.

2.4. Calculations

To determine growth performance, lambs were weighed individually at the beginning of the experiment (day 0; before the morning feeding) to obtain IBW and again at the end of the trial (day 45) following an 18 h feed withdrawal with free access to water to obtain FBW. For growth performance and dietary energy calculations, IBW was converted to initial shrunken body weight (ISBW) by multiplying IBW by 0.96 to account for ruminal fill [36]. Average daily gain was calculated as the difference between FBW and ISBW divided by 45. Dry matter intake was determined daily for each lamb as the difference between feed offered and feed refused on a DM basis, whereas G:F was calculated as ADG divided by DMI.

Shrunk body weight was assumed to be 96% of live BW, and average SBW was calculated as the mean of initial and final SBW. Expected DMI was estimated from observed ADG and average SBW according to NRC [37] as Expected DMI (kg/d) = (EM/NE_m) + (EG/NE_g), where EM is the energy required for maintenance (Mcal/d), calculated as $0.056 \times SBW^{0.75}$, and EG is retained energy (Mcal/d), calculated as $0.276 \times ADG \times SBW^{0.75}$. The coefficient 0.276 was derived assuming a mature BW of 113 kg for Dorper × Katahdin intact male lambs, as described by Estrada-Angulo et al. [38]. Tabular dietary NE values used for expected intake calculations corresponded to the dietary NE concentrations presented in Table 1 and were derived from NRC [22] tabular ingredient values. These values were used exclusively for expected intake calculations. Observed dietary NE concentrations were estimated from animal performance using the quadratic solution described by Zinn et al. [39] as $x = (-b - \sqrt{(b^2 - 4ac)})/2c$, where x = dietary NE_m, a = −0.41 EM, b = 0.877 EM + 0.41 DMI + EG, and c = −0.877 DMI. Dietary NE_g was calculated as 0.877 NE_m − 0.41. Ratios of observed-to-expected dietary NE were calculated by dividing observed dietary NE by the expected dietary NE values presented in Table 1.

2.5. Body Fat Reserves and Longissimus Muscle Area

Ultrasound evaluations were performed to estimate body fat reserves and muscle development. Measurements included *longissimus lumborum* muscle area (LMA; cm^2), 12th-rib subcutaneous fat thickness (FAT; mm), and rump fat thickness at the P8 site (RFT; mm). Longissimus muscle area and FAT were measured between the 12th and 13th ribs. Before image collection, the scanning area was clipped, cleaned with compressed air, and coated with ultrasound gel to ensure adequate transducer contact. Measurements were obtained on days 0 and 45 using a real-time ultrasound scanner (Aloka Prosound 2, Hitachi Aloka Medical, Tokyo, Japan) equipped with a 3.5 MHz linear-array transducer. All measurements were performed by the same trained technician to minimize operator variation.

2.6. Slaughter Procedure and Visceral Organ Mass Determination

At the end of the 45 d feeding period, lambs were fasted for 18 h with free access to water before slaughter. Pre-slaughter BW was recorded after the fasting period, and lambs were transported 7.28 km to the UAMVZ-UAZ abattoir for slaughter on the same day. During processing, non-carcass components were collected and individually weighed, including skin, limbs, head, heart, lungs, liver, spleen, kidneys, testicles, gastrointestinal tract, and internal fat depots. Omental, mesenteric, and perirenal fat depots were weighed

separately; visceral fat was calculated as the sum of omental and mesenteric fat, whereas perirenal fat was analyzed independently.

The gastrointestinal tract was weighed full and again after manual removal of digesta to determine gastrointestinal contents. Empty body weight (EBW) was calculated by subtracting gastrointestinal contents from pre-slaughter BW. Organ and fat depot weights were expressed relative to EBW (g/kg).

2.7. Carcass Characteristics

Hot carcass weight (HCW) was recorded immediately after slaughter before carcass chilling. Carcasses were then chilled for 24 h at 4 °C, after which cold carcass weight (CCW) was obtained. Dressing percentage was calculated as (HCW/FBW) × 100, whereas cooling loss (CL) was calculated as [(HCW − CCW)/HCW] × 100. After chilling, carcass morphometric measurements were obtained using a flexible tape measure and included carcass length, leg perimeter, and chest depth. In addition, tissue composition of the left shoulder (IMPS 207) was determined by physical dissection to quantify muscle and fat proportions and estimate the muscle-to-fat ratio according to Luaces et al. [40].

2.8. Wholesale Cuts

Left carcass sides were fabricated according to Institutional Meat Purchase Specifications (IMPSs) and North American Meat Processors Association guidelines [41]. Forequarters were subdivided into neck, shoulder IMPS 206, shoulder IMPS 207, rack IMPS 204, breast IMPS 209, and ribs IMPS 209A, whereas hindquarters were separated into loin IMPS 231, flank IMPS 232, and leg IMPS 233.

2.9. Meat Quality

A section of the longissimus muscle (LM), collected from the area used for LMA measurements between the 9th and 10th ribs (~500 g) from the left carcass side, was collected for meat quality analyses and stored at −20 °C until processing. Muscle pH was measured 24 h postmortem at the level of the second lumbar vertebra using a portable digital pH meter (Hanna Instruments, Woonsocket, RI, USA; Model HI-9025). Water-holding capacity (WHC) was determined according to the Grau and Hamm method as described by Tsai and Ockerman [42]. Briefly, 300 mg of LM sample were placed between Whatman No. 1 filter papers positioned between glass plates (15 × 15 cm) and subjected to a constant pressure of 10 kg for 20 min.

Steaks (2 cm thick) obtained from the LM between the 12th rib and second lumbar vertebra were vacuum-packaged and frozen at −20 °C for 14 d before purge loss (PRL_{24h}) and cooking loss (CKL) determinations. Samples were thawed for 24 h at 4 °C, blotted dry, and weighed. For PRL_{24h} determination, one steak was cut into blocks (15 × 15 × 30 mm) and suspended at 4 °C for 24 h. For CKL determination, a separate steak was vacuum-packaged and heated in a water bath at 80 °C until an internal temperature of 70 °C was reached. Samples were then blotted dry while still warm and weighed to determine post-cooking weight. Water losses for WHC, PRL_{24h}, and CKL were expressed as percentages of initial sample weight.

For Warner–Bratzler shear force (WBSF), LM steaks (2.54 cm thick) were thawed for 24 h at 4 °C and cooked on an electric grill (Spectrum Brands, Middleton, WI, USA; Model GR2120B) to an internal temperature of 70 °C, monitored using a digital thermometer (Model TP700), following AMSA [43] guidelines. Cooked steaks were cooled at 22 °C for 4 h, after which six cores (1.27 cm diameter) were removed parallel to the muscle fiber orientation. Cores were sheared using a Texture Analyzer (G-R Manufacturing, New York, NY, USA) fitted with a Warner–Bratzler blade at a crosshead speed of 200 cm/min. Peak shear force values were averaged and expressed as kg/cm^2.

2.10. Statistical Analyses

Data were analyzed under a randomized complete block design using the GLM procedure of SAS® OnDemand for Academics: SAS Studio Version 3.82 [44]. Initial body weight was used as the blocking criterion, treatment was included as a fixed effect, and block was considered the blocking factor. Individual lambs served as the experimental unit for all analyses. Residual normality was verified before analysis using the PROC UNIVARIATE procedure of SAS. Variables associated with growth performance, dietary energetics, visceral fat deposition, carcass characteristics, wholesale cut distribution, and meat quality were analyzed by analysis of variance (ANOVA). Final ultrasound measurements were analyzed using the corresponding Day 0 values as covariates to adjust for initial variability among lambs. Least squares means were generated for all variables, and treatment means were separated using Tukey's multiple comparison test when significant effects were detected. Statistical significance was declared at $p \leq 0.05$. Data presented in tables are expressed as treatment means ± standard error of the mean (SEM).

3. Results

No morbidity, mortality, or treatment removals occurred during the experimental period.

3.1. Growth Performance and Dietary Energetics

The corn grain processing method affected the growth performance and dietary energetics of finishing lambs (Table 2). Final body weight differed among treatments ($p = 0.039$), with lambs fed SFC and CC showing greater values than those fed GC, representing increases of 4.7 and 1.5%, respectively, whereas WC yielded intermediate values that did not differ from the remaining treatments. Consistent with these results, ADG was greater in lambs fed SFC ($p = 0.037$), exceeding that of GC by 30.8%, whereas WC and CC showed intermediate values without differing from the other treatments. It is important to note that, although lambs fed SFC, compared with those fed WC, showed increases of 15.4% in ADG and 7.3% in G:F, these improvements were not statistically significant. Dry matter intake was affected by treatment ($p = 0.020$), increasing by 10.1% in SFC relative to WC, whereas CC and GC were intermediate and did not differ from the remaining treatments. Gain-to-feed ratio differed among treatments ($p = 0.028$), with greater values observed in SFC compared with GC and CC, whereas WC exhibited intermediate values that did not differ from the remaining treatments, and CC did not differ from GC. Observed-to-expected dietary NE_m ratios were greater in WC than in GC ($p = 0.025$), whereas CC and SFC showed intermediate responses.

3.2. Empty Body Weight and Visceral Organ Mass

The corn grain processing method affected the EBW and visceral fat deposition of finishing lambs (Table 3). Empty body weight was greater in lambs fed SFC and CC compared with those fed WC ($p = 0.041$), representing increases of 7.0 and 5.8%, respectively, whereas GC showed intermediate values. Relative testicular weight was greater in WC than in CC ($p = 0.039$), with SFC and GC showing intermediate values. Omental fat deposition was affected by treatment ($p = 0.048$), being greater in SFC and CC than in GC, with increases of 14.9 and 11.1%, respectively. Similarly, mesenteric fat was greater in SFC and CC compared with GC ($p = 0.031$), representing increases of 67.6 and 38.8%, respectively. Total visceral fat was also greater in SFC and CC than in GC ($p = 0.042$), exceeding GC by 38.8 and 23.7%, respectively, whereas WC and GC did not differ from each other and exhibited lower values than CC and SFC. Likewise, perirenal fat was greater in SFC compared with WC, CC, and GC ($p = 0.048$), with increases of 14.4, 15.3, and 13.4%, respectively. Relative weights of the stomach complex, large intestine, small intestine,

skin, limbs, head, heart, lungs, liver, spleen, and kidneys were not affected by corn grain processing method ($p > 0.05$).

Table 2. Growth performance and dietary energetics of finishing lambs fed diets containing whole or processed corn grain.

Item	Corn Processing Method				SEM [1]	*p*-Values
	Whole	Cracked	Ground	Steam-Flaked		
Body weight, kg [2]						
Initial	41.75	42.47	42.01	41.85	0.295	0.352
Final	50.54 ^{ab}	50.60 ^{a}	49.85 ^{b}	52.20 ^{a}	0.605	0.039
Average daily gain, kg/d	0.195 ^{ab}	0.191 ^{ab}	0.172 ^{b}	0.225 ^{a}	0.013	0.037
Dry matter intake, kg/d	1.29 ^{b}	1.32 ^{ab}	1.34 ^{ab}	1.42 ^{a}	0.038	0.020
Gain to feed, kg/kg	0.151 ^{ab}	0.137 ^{b}	0.130 ^{b}	0.162 ^{a}	0.008	0.028
Observed dietary net energy, Mcal/kg [3]						
Maintenance	1.89 ^{ab}	1.79 ^{ab}	1.73 ^{b}	1.91 ^{a}	0.047	0.025
Gain	1.25 ^{ab}	1.16 ^{ab}	1.10 ^{b}	1.25 ^{a}	0.041	0.025
Observed to expected dietary net energy ratio [4]						
Maintenance	1.02 ^{a}	0.96 ^{a}	0.93 ^{b}	1.00 ^{ab}	0.041	0.025
Gain	1.02 ^{a}	0.95 ^{a}	0.91 ^{b}	1.00 ^{ab}	0.031	0.025
Estimated net energy of processing corns, Mcal/kg						
Maintenance	-	2.00	1.88	2.24	-	-
Gain	-	1.34	1.24	1.55	-	-
Relative NE value compared to the NE value assigned by NRC [22]						
Maintenance	-	0.91	0.85	0.98	-	-

[1] SEM = standard error of the mean. [2] Initial body weight (IBW) was reduced by 4% to account for gastrointestinal fill. Final BW was obtained following an 18 h fast without access to feed, with free access to drinking water. [3] Observed dietary net energy values were estimated from animal performance according to Estrada-Angulo et al. [45]. [4] The observed-to-expected dietary net energy (NE) ratio was calculated by dividing observed NE values by the expected NE content of the experimental diets, which was derived from the ingredient composition of the basal diet (Table 1). To estimate the comparative NE values of the different corn treatments, the net energy for maintenance (NE_m; 2.20 Mcal/kg) and net energy for gain (NE_g; 1.52 Mcal/kg) of whole corn [22] were used as reference values. Using the replacement technique [46], NE values for the other corn treatments (CC, GC, or SFC) were calculated as follows: NE_m (Mcal/kg) of test corn = [(NE_m of test diet − NE_m of WC diet)/0.50] + 2.20; NE_g (Mcal/kg) of test corn = [(NE_g of test diet − NE_g of WC diet)/0.50] + 1.52, where 0.50 represents the proportion of corn in the diet. [a, b] Means within a row with different superscripts differ ($p \leq 0.05$) according to Tukey's multiple comparison test.

3.3. Ultrasound Measurements and Carcass Characteristics

The corn grain processing method affected only the ultrasound-measured LMA (Table 4). Lambs fed SFC exhibited greater LMA than those fed GC ($p = 0.048$), representing an increase of 17.7%, whereas WC and CC showed intermediate values without differing from the remaining treatments. Rib fat thickness and RFT were not affected by corn grain processing method ($p > 0.05$). Carcass characteristics, including HCW, CCW, dressing percentage, CL, carcass length, leg perimeter, and chest depth, did not differ among treatments ($p > 0.05$). Shoulder tissue composition, expressed as muscle proportion, fat proportion, and muscle:fat ratio, was also not affected by corn grain processing method ($p > 0.05$).

3.4. Wholesale Cuts and Meat Quality Characteristics

The corn grain processing method did not affect the wholesale cut distribution or meat quality characteristics of finishing lambs (Table 5). The proportions of forequarters, hindquarters, and individual wholesale cuts evaluated according to IMPSs did not differ among treatments ($p > 0.05$). Meat quality variables, including pH_{24h}, PRL_{24h}, CKL, WHC, and WBSF, were also not affected by corn grain processing method ($p > 0.05$).

Table 3. Empty body weight and visceral organ mass of finishing lambs fed diets containing whole or processed corn grain.

Item	Corn Processing Method				SEM [1]	*p*-Values
	Whole	Cracked	Ground	Steam-Flaked		
Empty body weight, kg	43.63 [b]	46.14 [a]	45.64 [ab]	46.67 [a]	0.918	0.041
Non-carcass components, g/kg empty body weight						
Stomach complex	28.74	26.69	28.32	28.78	1.067	0.498
Large intestine	13.02	12.71	13.38	13.41	0.969	0.950
Small intestine	19.47	18.57	19.59	16.88	0.945	0.167
Skin	163.74	158.51	169.24	160.44	8.575	0.824
Limbs	26.12	25.46	25.61	25.74	0.778	0.949
Head	42.02	42.38	42.38	41.10	1.051	0.791
Heart	4.96	4.44	4.52	4.54	0.227	0.442
Lungs	21.73	21.28	21.82	19.36	1.052	0.311
Liver	19.42	18.72	18.41	19.55	0.590	0.472
Spleen	1.66	1.69	1.74	1.75	0.104	0.934
Kidney	2.61	2.42	2.19	2.36	0.135	0.241
Testicles	19.58 [a]	17.05 [b]	18.07 [ab]	18.00 [ab]	0.549	0.039
Omental fat	17.70 [ab]	18.81 [a]	16.93 [b]	19.44 [a]	1.040	0.048
Mesenteric fat	16.15 [ab]	19.51 [a]	14.06 [b]	23.57 [a]	1.340	0.031
Visceral fat [2]	33.84 [b]	38.32 [a]	30.99 [b]	43.02 [a]	1.240	0.042
Perirenal fat	13.06 [b]	12.96 [b]	13.17 [b]	14.94 [a]	0.505	0.048

[1] SEM = standard error of the mean. [2] Visceral fat was calculated as the sum of omental and mesenteric fat depots. [a, b] Means within a row with different superscripts differ ($p \leq 0.05$) according to Tukey's multiple comparison test.

Table 4. Ultrasound measurements and carcass characteristics of finishing lambs fed diets containing whole or processed corn grain.

Item	Corn Processing Method				SEM [1]	*p*-Values
	Whole	Cracked	Ground	Steam-Flaked		
Ultrasound measurements						
Rib fat thickness, mm	3.20	3.32	2.76	3.23	0.218	0.292
Rump back fat thickness, mm	2.96	3.13	3.22	3.09	0.179	0.795
Longissimus lumborum muscle area, cm^2	14.90 [ab]	14.11 [ab]	13.29 [b]	15.64 [a]	0.684	0.048
Carcass characteristics						
Hot carcass weight, kg	26.17	26.16	26.12	26.04	0.451	0.234
Cold carcass weight, kg	24.94	25.44	25.27	25.80	0.364	0.454
Dressing, %	57.88	55.23	55.44	54.88	1.071	0.289
Cooling loss, %	3.01	3.00	2.81	2.53	0.176	0.242
Carcass length, cm	70.82	71.88	71.26	69.19	1.662	0.703
Leg perimeter, cm	45.81	46.59	46.81	48.11	0.884	0.447
Chest depth, cm	19.80	19.76	19.54	19.23	0.362	0.664
Shoulder composition, %						
Muscle	67.62	67.03	68.24	68.52	0.855	0.617
Fat	15.49	14.43	14.13	14.57	0.876	0.758
Muscle:fat ratio	4.39	4.64	4.73	4.61	0.394	0.623

[1] SEM = standard error of the mean. [a, b] Means within a row with different superscripts differ ($p \leq 0.05$) according to Tukey's multiple comparison test.

Table 5. Wholesale cuts and meat quality characteristics of finishing lambs fed diets containing whole or processed corn grain.

Item	Corn Processing Method				SEM [a]	*p*-Values
	Whole	Cracked	Ground	Steam-Flaked		
Whole cuts, % of cold carcass weight						
Forequarter	52.43	52.89	52.03	53.22	0.761	0.687
Hindquarter	44.59	45.22	44.51	44.40	0.655	0.823
Neck	3.41	3.57	3.37	3.70	0.171	0.508
Shoulder IMPS206	9.32	9.58	9.18	9.38	0.387	0.902
Shoulder IMPS207	17.26	16.86	16.86	16.93	0.362	0.882
Rack IMPS204	6.38	6.92	6.53	6.64	0.248	0.547
Breast IMPS209	3.60	3.55	3.63	3.73	0.131	0.803
Ribs IMPS209A	5.45	5.29	5.46	5.41	0.190	0.921
Loin IMPS231	7.06	7.01	6.60	6.93	0.306	0.690
Flank IMPS232	7.49	7.26	7.68	7.53	0.282	0.766
Leg IMPS233	30.04	30.96	30.23	29.95	0.358	0.226
Meat characteristics						
pH_{24h}	5.52	5.48	5.56	5.53	0.039	0.541
Purge $loss_{24h}$, %	3.12	3.05	3.21	3.28	0.343	0.742
Cooking loss, %	28.14	27.63	29.31	28.92	0.857	0.681
Water-holding capacity, %	28.95	29.94	29.21	30.72	1.231	0.554
Warner–Bratzler shear force, kg/cm^2	2.93	3.21	3.08	3.25	0.251	0.838

[a] SEM = standard error of the mean.

4. Discussion

4.1. Growth Performance and Dietary Energetics

The results of the present study indicate that corn grain processing modified dietary energy utilization and, consequently, the productive performance of finishing lambs. In particular, SFC increased ADG by 30.8%, G:F by 24.6%, and observed NE_m by 10.4% relative to GC, indicating greater efficiency of starch utilization under steam processing conditions. This response is consistent with the well-documented effects of steam-flaking, which increases starch availability through heat, moisture, and mechanical compression, promoting disruption of the starch–protein matrix and greater accessibility to microbial and enzymatic digestion [5,6,10]. These physicochemical changes, including starch gelatinization and structural disruption of the endosperm, have been associated with greater enzymatic hydrolysis and microbial attachment, which may contribute to increases in ruminal and total tract digestibility [8]. Consequently, steam processing may modify both the extent and pattern of starch digestion, potentially contributing to greater energetic utilization, particularly in high-concentrate diets where relatively small improvements in digestibility can translate into proportional increases in G:F and observed dietary energy value [47,48].

Information regarding the effects of steam-flaked corn in finishing lambs remains limited and, in some cases, inconsistent. Early work by Cunningham and Perry [24] reported a 9.6% improvement in feed efficiency in lambs fed heat-treated corn compared with WC, which is consistent with the direction of the response observed in the present study. In contrast, He and Sun [4] reported greater ADG and G:F in lambs fed WC compared with steam-treated corn under diets containing 50% corn, suggesting that the response to steam processing in sheep is highly dependent on processing conditions. Part of this variation may be associated with differences in steaming time, flake density, and the balance between ruminal starch fermentation and post-ruminal starch digestion. In this regard, steaming time and processing intensity are critical factors influencing flake quality and

nutritional value, since excessive steaming has been reported to reduce flake durability and compromise energy utilization efficiency [4,23,32].

Using the replacement technique [46], the estimated NE_m values were 2.00, 1.88, and 2.24 Mcal/kg for CC, GC, and SFC, respectively. The NE_m value estimated for SFC was slightly lower than current feeding standards (−2.6%; 2.24 vs. 2.30 Mcal/kg; [22]), supporting the validity of the observed response. In contrast, dry-processed corn showed reductions of 9% and 17% for CC and GC, respectively, relative to tabular values, indicating that dry processing did not improve dietary energy utilization under the conditions of the present study. These results suggest that the expected benefits of reducing particle size were not realized and that excessive reduction may have negatively influenced energetic efficiency.

The lower NE values observed for GC relative to CC and WC may reflect differences in starch fermentation characteristics associated with particle size reduction. Fine grinding has been associated with faster starch fermentation rates, which under feedlot conditions could predispose animals to subclinical acidosis and alter starch utilization efficiency [47–49]. Additionally, more intensive processing increases the proportion of rapidly fermentable starch, which has been related to greater heat production and lower energetic efficiency despite improvements in total tract digestibility [16]. Furthermore, the higher DMI observed in lambs fed SFC diets may be associated with increased passage rate, a factor particularly relevant in small ruminants due to their higher intake relative to rumen capacity and faster digesta turnover [20]. Under these conditions, the balance between starch availability and fermentation rate appears to be an important factor influencing energy utilization.

Previous studies in lambs support the lack of advantage of intensive dry processing. He and Sun [4], Hejazi et al. [17] and Wang et al. [18] reported either similar or reduced performance in lambs fed GC compared with WC, whereas Petit [19] observed no differences between WC and dry-rolled corn, suggesting similar energetic value. Taken together, these findings indicate that dry processing does not consistently improve productive performance and may even reduce energetic efficiency when particle size is excessively reduced. Overall, the present results suggest that SFC improved dietary energy utilization relative to GC, whereas WC and CC provide intermediate responses, highlighting that in finishing lambs the benefits of grain processing are likely influenced by the interaction between starch availability and fermentation characteristics.

4.2. Empty Body Weight and Visceral Organ Mass

The differences observed in EBW among treatments indicate that corn grain processing modified body energy partitioning beyond the changes detected in FBW. Lambs fed SFC and CC exhibited 7.0 and 5.8% greater EBW, respectively, than those fed WC, suggesting greater net deposition of empty body tissues consistent with the higher dietary energy availability observed in these treatments. Because EBW excludes gastrointestinal contents, it represents a more accurate indicator of net nutrient retention than total live BW [22,26]. Under conditions of increased dietary energy supply, differences in retained energy are more clearly expressed in EBW than in FBW, particularly when variation in gut fill may mask treatment effects on live weight [23,50].

The increase in visceral fat deposition indicates that the greater energetic supply derived from SFC and CC may have been preferentially directed toward internal adipose tissue deposition. Compared with GC, lambs fed SFC showed increases of 14.9% in omental fat, 67.6% in mesenteric fat, and 38.8% in total visceral fat, whereas CC also increased these depots relative to GC. In contrast, WC showed intermediate values for omental and mesenteric fat deposition. Perirenal fat deposition was greater in SFC than in WC, CC, and GC. In finishing ruminants, visceral fat is considered one of the first

compartments to respond to increases in metabolizable energy intake due to its relatively high lipogenic activity and metabolic turnover [51,52], such that increases in internal fat may precede detectable changes in subcutaneous fat or carcass composition, particularly during relatively short finishing periods. Previous studies have suggested that greater ruminal starch fermentation may increase the availability of glucogenic precursors, particularly propionate, which could contribute to greater substrate availability for lipogenesis in internal depots under high-energy feeding conditions [48,50,53]. Consequently, differences in energy utilization are often reflected initially in internal energy partitioning rather than in external carcass traits, particularly under moderate increases in dietary energy supply [26].

This pattern is consistent with the general response observed in finishing lambs, where moderate increases in dietary energy availability promote preferential deposition of internal adipose tissue before affecting external fat reserves or carcass composition. Similarly, Haddad [54] reported increased fat deposition as dietary energy density increased, supporting the concept that, once lean tissue growth requirements are met, excess energy in finishing lambs may be preferentially directed toward internal adipose depots. The greater visceral fat deposition observed with SFC is consistent with its higher energetic value and suggests that increased starch utilization may have contributed to a greater energy surplus available for lipogenesis, a response also reported in finishing cattle under increased dietary energy supply [23,50]. In addition, differences in starch digestion site and rate could influence nutrient partitioning, as increased ruminal starch fermentation may alter the profile of absorbed metabolites and reduce the contribution of post-ruminal starch digestion, potentially favoring adipose tissue deposition [4]. However, ruminal fermentation characteristics and related metabolic indicators were not directly measured in the present study; therefore, these mechanisms should be interpreted as possible physiological explanations supported by previous literature.

In contrast, the absence of treatment effects on most visceral organs and non-carcass components suggests that corn grain processing primarily affected energy reserve deposition without substantially modifying the relative development of metabolically active tissues. Likewise, the absence of major differences in carcass traits should be interpreted within the context of the 45 d experimental period, which may have limited the detection of carcass-level responses associated with differences in dietary energetics. This pattern agrees with classical observations indicating that moderate increases in dietary energy intake alter adipose deposition without proportionally affecting liver mass, gastrointestinal tract size, or other visceral organs [26,55]. Similarly, Oliveira et al. [56] reported changes in FBW without relevant modifications in several carcass components, indicating that productive responses derived from grain processing are not necessarily accompanied by proportional changes in structural tissues. The observed difference in relative testicular weight likely lacks biological relevance and may be attributed to normal individual variation among animals.

4.3. Ultrasound Measurements and Carcass Characteristics

The increase in LMA observed in lambs fed SFC indicates greater relative muscularity compared with GC, consistent with its higher ADG and dietary energy value (+17.7%). Ultrasound-measured LMA is considered a reliable indicator of overall muscle development and carcass muscularity potential in sheep [57], and moderate increases in dietary energy density have been associated with greater muscle accretion and longissimus development in growing finishing lambs [26,54]. However, despite the effect observed on LMA, carcass characteristics were not modified by corn grain processing, as indicated by the absence of differences in HCW, CCW, dressing percentage, and morphometric measurements, suggesting that the variations in muscularity detected by ultrasound were not of sufficient

magnitude to translate into detectable changes at the commercial carcass level during the experimental period.

This apparent dissociation between ultrasound and carcass responses may be explained by the relatively short duration of the trial (45 d), since muscle deposition occurs more gradually and is generally less responsive than visceral fat deposition to moderate increases in dietary energy availability [26]. Moreover, improvements in dietary energy supply are often first expressed as changes in nutrient partitioning and tissue accretion at the organ or depot level before being reflected in whole-carcass traits [50,55]. The absence of differences in HCW despite greater EBW in SFC-fed lambs may reflect preferential energy partitioning toward visceral adipose depots rather than carcass tissue accretion during the relatively short experimental period. Under these conditions, responses to improved energy supply are frequently detected earlier by sensitive indicators such as ultrasound than by carcass weight or dressing percentage.

The lack of effect on FAT, shoulder tissue composition, and muscle:fat ratio further indicates that, although corn grain processing modified dietary energy availability, this effect was not sufficient to alter external tissue distribution within the carcass. This response is consistent with the physiological sequence of growth in finishing ruminants, in which moderate increases in energy intake are initially reflected in greater visceral fat deposition before detectable changes occur in subcutaneous fat or regional carcass composition [50,52]. In addition, differences in starch digestion rate and site could influence the partitioning of absorbed nutrients, as increased ruminal fermentation may favor lipogenic precursors without necessarily increasing muscle deposition proportionally [4,48]. Although ruminal fermentation characteristics and related metabolic indicators were not directly measured in the present study, previous studies suggest that these mechanisms may contribute to differences in nutrient partitioning and tissue deposition under high-concentrate feeding conditions. In agreement, Oliveira et al. [56] did not observe differences in LMA, dressing percentage, or FAT among lambs fed WC, GC, or high-moisture corn, despite differences in FBW, indicating that moderate modifications in corn processing do not necessarily translate into detectable changes in overall carcass composition.

Taken together, these results indicate that differences in dietary energy availability induced by corn grain processing were sufficient to modify early indicators of muscularity, such as LMA, but insufficient to significantly alter overall carcass characteristics under the conditions of the present study.

4.4. Wholesale Cuts and Meat Quality Characteristics

The lack of effect of corn grain processing on wholesale cut distribution suggests that differences in dietary energy availability among treatments were not of sufficient magnitude to modify regional tissue distribution within the carcass. This is consistent with the absence of changes in overall carcass characteristics and supports the interpretation that, although some treatments improved productive performance and visceral fat deposition, these responses were insufficient to produce detectable differences in the relative yield of commercial cuts under the conditions of the present study. Similar responses have been reported in lambs, where moderate changes in dietary energy supply did not result in proportional modifications in carcass cut distribution, particularly when the feeding period is relatively short [58,59].

Meat quality variables were also not affected by corn grain processing, suggesting that changes in dietary energy availability and tissue deposition patterns derived from grain processing did not substantially modify the physicochemical or mechanical properties of the evaluated muscle. The stability of postmortem pH may indicate that there were no major differences in muscle glycogen reserves or in the extent of postmortem glycolysis,

which is considered a major determinant of pH decline in fresh meat [60,61]. Consistent with this, the lack of differences in PRL_{24h}, CKL, WHC, and WBSF suggests that physical corn processing did not substantially modify muscle functional properties or instrumental tenderness. These results further indicate that the magnitude of change in dietary energy availability observed in the present study may have been insufficient to induce detectable modifications in muscle biochemical characteristics at slaughter.

This pattern agrees with previous observations in small ruminants, where moderate increases in dietary energy density do not consistently modify pH, WHC, or WBSF, indicating a lower sensitivity of these variables to nutritional changes compared with productive performance or energy partitioning responses [58,59]. In agreement, Oliveira et al. [56] did not observe effects of corn processing on final pH, CKL, color, or WBSF in lambs fed high-concentrate diets, even when different physical forms of the grain were used. Collectively, these findings suggest that meat quality traits are relatively stable and may require more pronounced differences in growth rate, body composition, or pre-slaughter metabolic status to be significantly affected [50,61].

Taken together, the present results indicate that variations in dietary energy utilization derived from corn grain processing mainly influenced internal energy partitioning and productive performance, without producing detectable changes in carcass commercial traits or meat quality under the conditions of the present study.

5. Conclusions

Under the conditions of the present study, corn grain processing altered dietary energy utilization and productive performance in finishing lambs. Steam-flaked corn increased ADG, G:F, and observed dietary NE_m relative to GC, indicating greater energetic utilization efficiency, although it also increased visceral fat deposition without major effects on carcass characteristics, wholesale cut distribution, or meat quality during the 45 d experimental period. The estimated NE value of SFC (2.24 Mcal/kg) was in close agreement with current nutritional standards for lambs (2.30 Mcal/kg), whereas the estimated NE values for CC and GC were 9% and 17% lower, respectively, suggesting that intensive grinding under the conditions of the present study may have reduced energetic efficiency and productive performance. In contrast, CC exhibited a 9% lower estimated energy value than WC, whereas WC may still represent a practical alternative under intensive finishing conditions, as its estimated NE value was only 2.7% lower than SFC. Additionally, future studies should evaluate whether sheep fed steam-flaked corn may benefit from higher-density flakes than those commonly used in finishing cattle. Extended feeding periods may also be required to detect carcass-level responses associated with differences in dietary energetics. Because this study was conducted exclusively with intact male Dorper × Katahdin lambs under intensive finishing conditions, extrapolation of these findings to females, castrated lambs, or other genotypes should be made with caution.

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Institutional Review Board Statement: The experiment was conducted at the MAAZ Experimental Center, located in Calera de Víctor Rosales, Zacatecas, Mexico. All animal handling and experimental procedures complied with applicable Mexican regulations for animal care and welfare. The protocol was evaluated and approved by the Institutional Committee on Bioethics and Animal Welfare of UAMVZ-UAZ (Protocol #01; approved on 4 August 2025). Animals were observed daily throughout the trial, managed by trained personnel, and maintained under feeding and housing conditions intended to safeguard their health and well-being.

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