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Inclusion of paper packaging in a small fraction of the diet of confined lambs

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Introduction: In ruminant production systems, packaging is commonly used for the transport and storage of feed ingredients such as grains and minerals. The development of edible, cellulose-based packaging that can be safely ingested by ruminants offers a promising approach to reducing environmental waste on farms. This study aimed to evaluate the inclusion of edible paper packaging in the diets of lambs and its effects on nutrient digestibility, nitrogen balance, growth performance, carcass characteristics, and meat quality.

Methods: Twenty crossbred lambs, 3 months old; initial body weight of 23.40 ± 1.00 kg, were randomly assigned to two dietary treatments: a control diet without packaging (CTL) and a diet including edible paper packaging (PACK). The experiment was in a completely randomized design, with two treatments and ten replications. Data were analyzed using Tukey's test at a 5% significance level.

Results: No significant differences ($P > 0.05$) were observed between treatments for dry matter intake or apparent nutrient digestibility. Growth performance was not affected ($P > 0.05$). However, cold carcass yield was reduced ($P = 0.043$), and higher cooking losses ($P = 0.011$) were observed in the PACK group.

Discussion: The inclusion of edible paper packaging can be used in lamb diets, as it did not alter dry matter intake or nutrient intake, and therefore did not affect production performance, most carcass characteristics, or meat quality, except for cold carcass yield and water loss during cooking.

KEYWORDS

sheep, lignin, carcass, digestibility, residue, natural polymers

1 Introduction

In a globalized world, packaging has emerged as a crucial link in the logistics chain, connecting different regions and enabling products to be transported and marketed worldwide, from producers to final consumers (Monteiro et al., 2019). Various materials are used in the manufacture of packaging, with plastic and paper being the most common. Each material presents specific advantages and disadvantages, depending on factors such as cost, durability, and environmental impact (Jayakumar et al., 2019).

In livestock production, plastic packaging is widely used to transport feed ingredients, such as foodstuffs and mineral supplements. Among these, raffia stands out as the most commonly used material. It is typically made from low-density polyethylene and polypropylene, which are petrochemical derivatives (Mohan et al., 2022). Waste generated from petroleum-based plastic packaging, such as raffia, has a considerable environmental impact. These materials are mostly incinerated, releasing large amounts of carbon dioxide, and they are neither biodegradable nor compostable (Thrän et al., 2024).

The search for packaging solutions with lower environmental impact is ongoing across all productive sectors (Gündoğdu et al., 2024; Gupta et al., 2024). One such approach is the development of packaging made from plant-derived natural polymers (Gupta et al., 2022). Cellulose is among the most important natural polymers and plays a central role in the paper packaging industry. Trees are the primary source of cellulose; however, only the cellulose fibers are extracted and used.

In the context of animal nutrition, cellulose from forage is a major nutritional component in ruminant diets (Tedeschi et al., 2023). The rumen hosts microorganisms capable of digesting dietary cellulose. In ruminant diets, cellulose is classified as a structural carbohydrate and is fermented into short-chain fatty acids—such as acetate, propionate, and butyrate—which serve as primary energy sources (Van Soest, 2019). Given this digestive capacity, it is reasonable to assume that paper packaging may be safely ingested by ruminants.

Although there are studies in the literature on the use of kraft wood pulp in animal feeding, specific studies using kraft paper are lacking. Kraft wood pulp has been included in the diets of dairy calves at 12% inclusion without affecting feed intake or growth performance, and it even reduced the duration of diarrhea episodes (Inabu et al., 2023). Similarly, when included at the same level in the diets of lactating cows, no reductions were observed in dry matter intake, nutrient digestibility, or milk production. Moreover, its inclusion improved ruminal pH, modified the acetate-to-propionate ratio, and reduced the risk of subacute ruminal acidosis (Nishimura et al., 2019). In growing steers, the inclusion of 10% kraft pulp did not alter feed intake, body weight, nutrient digestibility, ruminal pH, or short-chain fatty acid production (Maeda et al., 2019). These findings suggest that kraft pulp has beneficial effects on rumen fermentation without compromising animal performance.

Based on this evidence, we propose that the paper packaging used for transporting cereal grains be ground together with the grains during the preparation of concentrate feeds or total mixed rations. This approach aims to reduce packaging waste on farms without compromising animal performance.

Thus, the hypothesis of this study is that incorporating Kraft paper packaging into the total diet of lambs is a safe strategy that does not compromise animal health or performance. Therefore, the objective of this study was to evaluate the effects of adding paper packaging to lamb diets on nutrient intake, nitrogen balance, growth performance, carcass traits, and meat quality.

2 Materials and methods

2.1 Study location and ethical considerations

The experiment was conducted at the University of São Paulo, Faculty of Veterinary Medicine and Animal Science, Pirassununga, São Paulo, Brazil. All procedures were approved by the Ethics Committee for the Use of Animals (CEUA, FMVZ, USP, 4157040423).

2.2 Animals, general procedures, and experimental diets

Twenty uncastrated male crossbred lambs, 23.40 ± 1 kg body weight, 90 days old, were housed in individual pens (0.55 x 1.25 m) with slatted floors and provided with individual feeders and drinking troughs. The experiment lasted 50 days, preceded by a 5-day adaptation period to the experimental diets. The experimental design was completely randomized, with two treatments of ten animals per treatment.

The experimental diets were CTL, which did not include paper wrappers, and PACK, which included paper wrappers in the total diet. The complete diet consisted of Tifton 85 grass hay [Cynodon dactylon (L.)], ground corn, soybean meal, limestone, and mineral supplements (Table 1). Animals were fed twice daily, at 7:00 am and 2:00 pm. Feed consumption and scraps were measured daily and individually.

Considering that the paper packaging is intended to be crushed together with the grains, the PACK diet contained two packages per 100 kg of total diet. Each package had a capacity of 40–45 kg of grain. The total diet contained 81 kg of grain, i.e., two packages for every 100 kg of total mixture. The packages were made of kraft paper with food coloring and cornstarch-based glue. Each package weighed 215 g, for a total of 430 g per 100 kg of diet (0.43% inclusion). The packages were crushed in a crusher with a 5 mm sieve (model DPM-4, brand Nogueira, from São João da Boa Vista, São Paulo, Brazil) and included in the total diet (Figure 1).

2.3 Laboratory analyses

The analysis of the chemical composition of the diet was done every seven days during the confinement period. However, in the

TABLE 1 Ingredients and chemical composition of the experimental diet without (CLT) and with paper packaging (PACK).

Ingredient, % DM	Treatment		Packaging
	CTL	PACK*	
Ground Corn	70.00	70.00	
Soybean meal	11.00	11.00	
Tifton-85 hay	15.00	15.00	
Limestone	2.00	2.00	
Mineral supplement[1]	2.00	2.00	
Chemical composition, % DM	CTL	PACK	
Dry matter	90.28	92.94	91.77
Crude protein	13.73	12.95	0.26
Ether extract	2.67	2.84	0.50
Neutral detergent fiber	23.53	23.73	100.00
Acid detergent fiber	13.09	14.69	94.27
Lignin	2.26	2.53	9.86
Cellulose	10.83	12.16	84.41
Hemicellulose	10.44	9.04	5.73
Mineral matter	6.37	6.48	1.02
Calcium	1.19	0.96	0.09
Phosphor	0.35	0.33	0.01

DM, Dry matter; CTL, control; PACK, packaging.
*The paper packaging was included together with the grains, in the amount of 0.430 kg per kg of dry matter in the diet.
[1]Assurance levels (per kilogram of active elements): calcium - 130 g; phosphorus - 60 g; sodium - 120 g; magnesium - 20 g; sulfur - 20 g; zinc - 2720 mg; fluorine - 600 mg; manganese - 1360 mg; cobalt - 68 mg; organic chrome - 20 mg; iodine - 50 mg e selenium - 20 mg.
*added to the total diet mix.

last five days, it was done daily so that the information could be used to calculate nutrient intake. Daily dry matter intake (DMI) was calculated as the difference between the total DM of the consumed feed and the total DM in the leftovers. All samples were stored in a freezer at -20°C. Before analysis, samples were dried in a forced-air oven at 55°C for 72 h and ground to 1 mm. A sub-sample was taken for analysis of dry matter (DM) (method 930.15; AOAC, 2000), mineral matter (MM) (method 942.05; AOAC, 2000), MO (MS – MM), crude protein (CP=N × 6, 25; Kjeldahl method 984.13; AOAC, 2000), and ether extract (EE) (method 920.39, AOAC, 2000). Neutral detergent fiber (NDF) using α-amylase and sodium sulfite (TE-149 fiber analyzer; Tecnal Equipamentos para Laboratório Inc.) as described by Van Soest and Mason (1991), acid detergent fiber (ADF), and lignin (Method 973.18, AOAC, 2000).

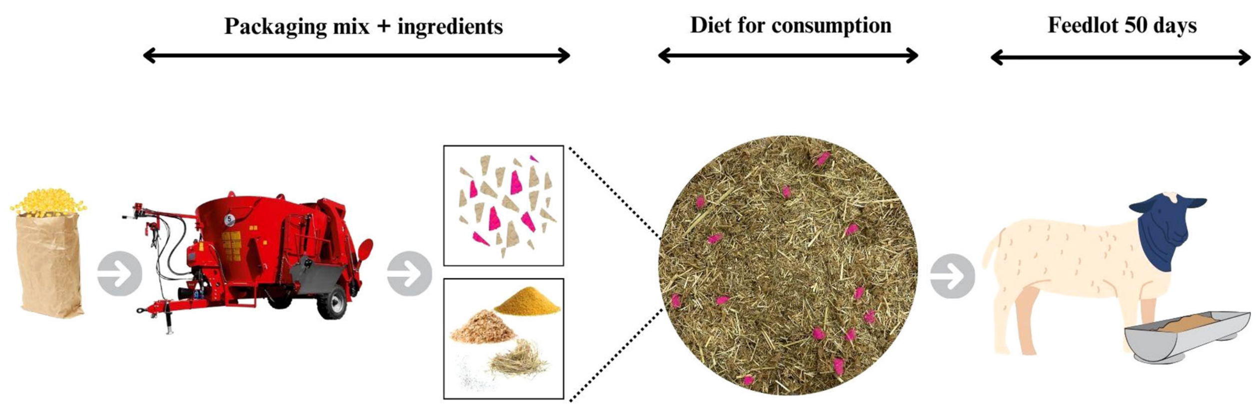

FIGURE 1
Experimental design of inclusion of total diet for confined lambs.

Calcium and phosphorus analyses were performed by optical emission spectrometry (ICP-OES) (Caputi, 2017).

The packages were crushed individually, without drying, and the respective analyses were performed using the same standards as the others: DM, OM, CP, ADF, NDF, lignin, calcium, and phosphorus.

2.4 Nutrient intake, digestibility apparent and nitrogen balance

The intake of each nutrient was calculated as the difference between the amounts of that nutrient in the diet and in the orts, according to the following formula: Nutrient intake (kg) = nutrient in diet - nutrient in orts.

Fecal samples for the digestibility test were collected every 24 hours for the last five days of confinement. Feces were collected through collection bags attached to the animal. The bags were weighed and emptied at the end of each day. A sub-sample of 10% of the total amount of feces was collected for further analysis (Paiva et al., 2022).

Urine samples were collected by whole urine collection on days 47 and 48 (Paiva et al., 2022). Urine was collected in a plastic bucket with a protective screen to prevent the ingress of dirt. Sulfuric acid (H_2So_4) 36 g/dL was added to each container to maintain urine pH below 3. At the end of each 24-hour cycle, urine was weighed, and a 10 mL sub-sample was diluted with 40 mL of 0.018 mol/L H_2So_4. (v/v) and frozen (-20°C) for subsequent analysis of crude protein (N × 6.25; Kjeldahl method 984) (AOAC, 2000).

The nitrogen balance (NB) was calculated from the nitrogen intake and the nitrogen excreted in the feces and urine of the animals, according to the equations NB = N ingested - (N feces + N urine); in g/day.

2.5 Slaughtering procedure and carcass characteristics

At the end of the experiment, the animals were fasted for 16 h and weighed to determine the slaughter weight (PS). The lambs were then slaughtered, their carotid arteries and jugular veins cut to allow bleeding, followed by skinning, evisceration, and removal of the head and limb extremities following procedures characteristic of human slaughter (MAPA, 2020).

After slaughter, the carcasses were hung by the tendon of the gastrocnemius, and weighed to determine the weight (HCW) and its yield hot carcass (HCY). Subsequently, they were placed in a cold camera chamber at 4 °C for 24 h, after this period, they were weighed to determine the weight (CCW) and yield cold carcass (CCY), and the chilling loss percentage (CL = (HCW - CCW/HCW) × 100) were calculated.

The pH and temperature measurements were taken 30 minutes and 24 hours after slaughter in the longissimus muscle at the level of the 12th rib with a digital pH meter and a thermometer, both equipped with a penetration probe (model HI8314, Hanna Instruments), previously calibrated with buffer solutions pH 4.01 and 7.01.

Measurements were taken on the longissimus muscle at the 12th and 13th thoracic ribs to calculate the rib eye area (AIE) using the formula: $(A/2 \times B/2) \times \pi$. Where A = maximum length of the longissimus muscle, in cm, and B = maximum depth of the longissimus muscle, in cm (Sobrinho et al., 2003). The thickness of the subcutaneous fat was measured on the surface of the 13th rib using a digital caliper (Gallo et al., 2014). The carcasses were split lengthways, with the left half divided into five anatomical regions: loin, shank, shoulder, ribs, and neck, which were weighed individually (Furusho-Garcia et al., 2006).

For the right half, the loins between the 12th and 13th ribs were weighed, identified, packed in plastic bags, and stored at -20°C for further analysis of physicochemical characteristics and proximate composition. Before these analyses, the samples were thawed in a refrigerator (4°C) for 12 hours.

2.6 Meat physicochemical composition analysis

Samples were exposed to ambient temperature for 30 minutes before analysis. Meat color was evaluated in the loins using a portable colorimeter (model MiniScan XE, HunterLab®) using the CIELAB system: L* (brightness), a* (redness), and b* (yellowness). A standard observation angle of 10° was used, and the coordinates L*, a*, and b* were measured at three different points on the internal muscle surface. Chroma (C) and Hue angle (H) values were calculated as C = (a2 + b2) 0.5 and H = tan−1(b/a), respectively. Final conversion of hue from radians to degrees was achieved by multiplying tan−1(b/a) by 180/p (Holman et al., 2015; Hernández Salueña et al., 2019; Santos et al., 2025).

Cooking loss (CL) was determined on each loin sample as described by AMSA (2015). While still raw, the samples were weighed, placed on an aluminum-coated tray, and cooked in a preheated oven at 180 °C until the center of the meat reached a temperature of 72 °C. Individual sample temperature control was performed using thermopairs (Exacta) connected to a temperature indicator (Gulton). The samples were later cooled to room temperature and reweighed. Cooking losses were calculated using the following equation: CL = [(initial weight - final weight)/initial weight] x 100. Results were expressed as percentages.

The TAXT plus texturometer equipped with a Warner Bratzler device (24 mm high, 8 mm wide) was used to evaluate the shear force (SF). The instrument was calibrated with a 5 kg standard weight and a traceable standard. The descent speed of the device was 200 mm/min. For each sample, five parallelepiped-shaped specimens measuring 1 × 1 × 2 cm (height, width, and length, respectively) were taken and placed with the fibers oriented in the direction perpendicular to the Warner-Bratzler probe blade, and the results were expressed in Newtons (N) (AMSA, 2015).

2.7 Statistical analyses

Statistical analyses were performed using SAS 9.4 (SAS Institute, 2013). The experimental design was a completely randomized design with two treatments and 10 replicates per treatment.

All data were initially screened for outliers using the interquartile range (IQR) method, and outliers were removed when biologically unjustifiable and statistically extreme. The assumptions of normality and homogeneity of variances were evaluated using the Shapiro–Wilk test and Levene's test, respectively. When necessary, data were transformed using logarithmic (log10). Non-transformed means are presented in the tables for ease of interpretation.

Analysis of variance (ANOVA) was conducted using the GLM (General Linear Model) procedure to determine the effect of treatment on nutrient intake, nitrogen balance, growth performance, carcass characteristics, and meat quality. When significant differences among treatments were detected ($p < 0.05$), means were compared using Tukey's Honest Significant Difference (HSD) test to control for Type I error.

Results are reported as least square means (LSMeans) ± standard error of the mean (SEM). Differences were considered statistically significant at $p < 0.05$, and tendencies were discussed when $0.05 \leq p < 0.10$.

The mathematical model was:

$$Yij = \mu + Ti + eij$$

Where: Yij is the dependent variable (i = treatment and j = replicate), μ is the overall mean, Ti is the fixed effect of treatment (i = 1-2), and eij is the residual error.

3 Results

There was no effect (P>0.05) of the inclusion of packaging (PACK) in the diet of growing lambs on nutrient intake. Apparent digestibility of nutrients was similar (P>0.05) between the diets (P>0.05) (Table 2).

The amount of nitrogen consumed, and excreted in feces and urine, absorbed and retained, and the ratios of N retained/N ingested and N retained/N absorbed by the lambs were not altered (P>0.05) by the inclusion of edible packaging (Table 3).

The production performance variables were not altered (P>0.05) by the experimental diets, but the variable cold carcass yield of lambs was lower (P=0.043) with the inclusion of packaging (PACK) in the diet. Commercial cuts were not affected (P>0.05). The inclusion of packaging in the diet modified the cooking loss (P=0.011) of sheep meat. Thus, higher values were found in the PACK diet. The variables of pH, color parameters, and shear force were not modified (P>0.05) by the inclusion of the packaging in the diet (Table 4).

4 Discussion

Some authors point to the feed selectivity of ruminants, which can identify and stop the consumption of toxic feeds or those that cause gastrointestinal discomfort within 8 hours after ingestion. As well as the ability to select feeds of their preference, especially those with high nutritional value (Villalba et al., 2013; Ginane et al., 2015).

TABLE 2 Intake of nutrients of lambs fed without (CLT) and with paper packaging (PACK).

Variable	Treatment				
Intake, kg/day	CTL	PACK	Mean	SEM	P-value
Dry matter	1.21	1.21	1.21	0.11	0.945
Crude protein	0.17	0.16	0.17	0.01	0.481
Neutral detergent fiber	0.26	0.26	0.26	0.03	0.965
Acid detergent fiber	0.14	0.16	0.15	0.02	0.140
Ether extract	0.03	0.03	0.03	0.003	0.392
Lignin	0.67	0.68	0.67	0.002	0.811
Non-fiber carbohydrate	0.67	0.68	0.67	0.06	0.811
Digestibility, g/kg					
Dry matter	853.39	870.42	861.91	4.02	0.427
Crude protein	835.07	846.29	840.68	4.77	0.610
Neutral detergent fiber	668.81	693.51	681.16	8.57	0.627
Acid detergent fiber	677.55	712.99	695.27	8.26	0.524
Non-fibrous carbohydrates	906.30	922.75	914.53	2.84	0.281

TABLE 3 Nitrogen balance in lambs fed without (CLT) and with paper packaging (PACK).

Variable	Treatment				
	CTL	PACK	Mean	SEM	P-value
g/dia					
N - intake	25.65	28.60	27.12	2.66	0.171
N – fecal excretion	4.24	3.70	3.98	1.15	0.437
N – urinary excretion	11.03	10.13	10.58	3.49	0.475
N - Retained	10.38	14.77	12.56	3.28	0.175
%					
N balance	48.04	54.71	51.53	13.18	0.400
N retained/N ingested	40.11	51.64	46.31	10.22	0.303

Therefore, in this experiment, it was important to ensure that the animals would accept the packaging, consume it, and would not make any type of selection. These parameters can be observed in the feed consumption, which was similar between the two groups (Table 2).

Dry matter intake, as well as intakes of crude protein, acid detergent fiber, neutral detergent fiber, ether extract, lignin, and nonfibrous carbohydrates, were similar between the groups, suggesting that the inclusion of Kraft paper packaging in the diet was well accepted by the animals. The use of wood Kraft pulp in the diet of calves, dairy cows and steel, with inclusion of 10 to 12% in the total diet, did not alter dry matter intake, body weight, weight gain and productivity (Maeda et al., 2019; Nishimura et al., 2019; Inabu et al., 2023). Protein digestibility, NDF, ADF and ether extract were also not altered by the inclusion of wood Kraft pulp (Maeda et al., 2019), as in this experiment.

Detergent fiber (NDF) content is crucial for ruminants, as it plays a key role in chewing and saliva production, which buffers pH in the rumen and influences performance (Tedeschi et al., 2023). Based on chemical analyses, the packaging presented a NDF index of 100%, therefore, the proportion of NDF introduced into the diet was 0.43%, which was not enough to significantly alter the NDF composition between treatments. NDF content is inversely proportional to dry matter intake (Van Soest, 2019); however, in this experiment, the diets presented the same NDF chemical composition, approximately 23%, so there was no change in feed intake and animal performance (Tables 1, 2).

PACK and CTL was similar for balance nitrogen (Table 3). Another parameter to consider in nitrogen metabolism is the amount retained (Chanjula et al., 2016). The difference between the amount of N ingested and excreted has a direct impact on metabolism and retention. In this case, retention was similar between treatments. Nutritional balance is adequate when N intake exceeds N excretion in feces. In this sense, the positive N balance observed in this study indicates that there was no imbalance between intake and excretion (Table 3).

The inclusion of Kraft packaging in the diet did not change the average daily gain of the animals. However, animals in the PACK treatment had a lower cold carcass yield when compared to CTL. Although the average daily gain is correlated with carcass yield, other factors can influence the cold carcass yield (Ke et al., 2023). For example, a diet with more structural carbohydrates can reduce carcass yield (Pereira et al., 2024). The Kraft paper used in this research had a high amount of cellulose in its composition; therefore, this may be the reason for the lower cold carcass yield. However, although the cold carcass yield was lower in animals fed the PACK diet, the yields obtained were within the range considered normal for lamb (Prache et al., 2022).

The meat quality analyses were carried out to ensure that the paper packaging in the diet would maintain the physicochemical characteristics of the meat within the values considered normal. This guarantee is important for farmers, the industry, and consumers. Carcass yield is very important and is related to the animal's nutrition, genetics, fat deposition, slaughter weight, muscularity, among other factors (Prache et al., 2022). In this study, cold carcass yield was 1.56% lower for PACK than for CTL. The values found for CTL and PACK are within the standard established for the species, which is 40 to 52% (Prache et al., 2022). However, there were no significant differences in the animals' nutrition or other carcass characteristics that could have caused this difference.

Carcass and commercial cut weights showed no significant differences between treatments, demonstrating that the inclusion of paper packaging resulted in the same proportion of meat as the animals fed the control diet.

Final pH is a parameter used as an indicator of meat quality, as it directly affects tenderness, color, and water loss during cooking (Ekiz et al., 2024). Among the treatments, the average pH at 24 hours after slaughter was 5.80, which is considered the ideal range (5.5 to 5.8) to ensure good meat quality (Silva Sobrinho et al., 2005).

The color variables L*, a*, and b* showed mean values of 38.16, 12.71, and 9.22, respectively, similar to studies on lamb meat quality (Monaco et al., 2015; Ortuño et al., 2021; Leal et al., 2023). At the time of purchase, consumers evaluate the color of the meat, the color and amount of fat, and the marbling. Conventionally, dark meat is associated with animals of advanced age (Hopkins and Mortimer, 2014). The coloration of meat is determined by the concentration and configuration of myoglobin present within the meat. Myoglobin is composed of a polypeptide chain and a heme group. The iron present in the heme group can bind with oxygen and can adopt various forms, which are reversible. Myoglobin can be found in three different

TABLE 4 Productive performance, carcass characteristics, commercial weight, and physicochemical characteristics of meat from lambs fed without (CLT) and with paper packaging (PACK).

Variable	Treatment		SEM	P-value
	CTL	PACK		
Performance				
Initial body weight, kg	23.41	23.40	0.54	0.979
Final body weight, kg	37.75	36.22	2.62	0.404
Average daily gain, kg/dia	0.292	0.261	0.055	0.368
Feed efficiency	0.275	0.247	0.032	0.084
Carcass characteristics				
Hot carcass weight, kg	17.46	16.28	1.71	0.076
Cold carcass weight, kg	17.11	15.91	1.68	0.075
Hot carcass yield, %	46.92	45.45	2.07	0.074
Cold carcass yield, %	45.99	44.43	2.01	0.043
pH, 30 minute	6.65	6.72	0.13	0.405
Temperature 30 min, °C	31.31	31.85	1.01	0.210
pH, 24 h	5.78	5.81	0.08	0.408
Temperature 24h, °C	4.77	4.80	0.23	0.754
Rib eye area, cm^2	15.83	14.58	2.40	0.139
Subcutaneous fat thickness, mm	1.81	1.65	0.37	0.408
L* (Lightness)	37.68	38.65	3.04	0.484
a* (Redness)	12.48	12.94	0.71	0.622
b* (Yellowness)	8.85	9.60	0.87	0.469
HUE	35,15	36.39	2.21	0.227
Chroma	15.31	16.13	2.19	0.413
Shear force, N	50.30	60.01	20.20	0.196
Cooking loss, %	23.76	28.15	4.87	0.011
Commercial cut, % half carcass				
Loin	9.32	9.26	0.01	0.929
Leg	33.02	31.64	0.02	0.136
Shoulder	21.02	20.15	0.02	0.401
Rib + neck	36.67	38.97	0.03	0.096

forms: the reduced form (Mb), which is purple-red in color; the oxygenated form, or oxymyoglobin (O2Mb), which is bright red in color; and the oxidized form, or metmyoglobin (MetMb), which is brown in color (Ragucci et al., 2024). One method of measuring color is the CIELAB system, which utilizes the L* scale to quantify brightness, the a* scale to measure red content (ranging from red to green), and the b* scale to determine yellow content (ranging from yellow to blue) (Purslow et al., 2020). The values obtained in this study indicate that the meat is bright red.

On the other hand, the evaluation of cooking losses reflects the water retention capacity; the lower the water losses during cooking, the higher the retention capacity of the meat (Estrada-León et al., 2024), and in this case, the animals consuming the CTL diet had meat with a higher water retention capacity. Parameters such as final pH, storage and cooking temperature, and subcutaneous and intramuscular fat influence the water retention capacity of cooked meat; in the case of fat, both act as a barrier, creating a film that prevents water loss (Lawrie, 2006). In the current study, the samples were stored under the same conditions, and all were roasted at the same time; the final pH did not differ between the treatments, nor did the thickness of the subcutaneous fat. Therefore, the parameters that can alter water retention capacity were not altered by PACK, and consequently cannot explain the difference in value between PACK and CTL. One speculation would be that the animals on the PACK diet had less intramuscular fat (Starkey et al., 2016), or alteration in lipid degradation, or denaturation of protein, or protein degradation (Suleman et al., 2020). However, these parameters were not measured in our study, so they are just a hypothesis.

Meat color, shear force, loin eye area, and the commercial cuts of the carcass were also not altered by the consumption of the packaging, therefore again showing that the packaging was nutritionally inert and that the meat was not altered.

This study used the inclusion of 0.43% of packaging in the diet, as it represents the inclusion of two packages for every 100 kg of total diet. Studies with greater inclusion of packaging may be interesting. The use of Kraft paper in ruminant diets was appropriate as it supported the grain load and was consumed by the lambs without reducing their performance or altering the carcass and meat of the animals. Other types of paper may be tested. Based on this study, plastic packaging could be replaced by paper packaging for the transportation of grain and minerals used in ruminant feed.

5 Conclusion

This study looked at a strategy to minimize the improper disposal of plastic packaging by replacing it with paper packaging and including paper packaging in the total diet of sheep. We can conclude that the inclusion of Kraft paper packaging can be used in lamb diets, as it was consumed by the animals without compromising their performance, food digestibility, and most of the carcass and meat quality characteristics. However, parameters such as cold carcass yield and water loss due to cooking of the meat were worse in diets with paper packaging, and more studies are needed on this subject.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was approved by Ethics Committee for the Use of Animals (CEUA, FMVZ, USP, 4157040423). The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

MdS: Conceptualization, Data curation, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. DdA: Conceptualization, Methodology, Project administration, Writing – review & editing. AdC: Methodology, Project administration, Writing – review & editing. BM: Methodology, Project administration, Writing – review & editing. VK: Methodology, Writing – review & editing. LG: Methodology, Writing – review & editing. MC: Conceptualization, Data curation, Methodology, Writing – review & editing. SG: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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