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Carcass Traits and Meat Quality of Pasture-Finished Sheep Supplemented with Palm Kernel Oil

Mailin Vasconcelos dos Santos Lima [1,2], Emmanuel Emydio Gomes Pinheiro [2], Núbia Amorim Oliveira [2], Rafael Henrique de Tonissi e Buschinelli de Goes [3], Claudia Andrea Lima Cardoso [4] and Adriana Regina Bagaldo [2,*]

1 Department of Animal Science, Federal University of Bahia, Salvador 40170110, BA, Brazil
2 Center for Agricultural, Environmental and Biological Sciences, Federal University of Recôncavo da Bahia, Cruz das Almas 44380000, BA, Brazil
3 Faculty of Agricultural Sciences, Federal University of Grande Dourados, Dourados 79804970, MS, Brazil
4 Center for Studies in Natural Resources, State University of Mato Grosso do Sul, Dourados 79804970, MS, Brazil
* Correspondence: arbagaldo@gmail.com

Simple Summary

When vegetable oils are included in the diets of ruminants, they can increase energy density, modulate ruminal fermentation, and alter fatty acid composition and meat quality. In this study, we observed that the inclusion of palm kernel oil in the diets of pasture-raised sheep at up to 60 g/kg DM of the supplement had an effect on carcass weight, but it did not affect yield. It also affected the color and composition of the *Longissimus lumborum* muscle, although it did not alter its fatty acid profile.

Abstract

This study evaluated the effects of including palm kernel oil in the diets of pasture-raised sheep on carcass characteristics, meat quality, and fatty acid profiles. A completely randomized design with four treatments was used, consisting of 0, 20, 40, and 60 g/kg of palm kernel oil in the dry matter of the supplement, with eight replicates. Thirty-two uncastrated Santa Inês sheep, with an average initial body weight of 23.2 ± 2.6 kg, were used in this study. The animals were kept on Aruana grass (*Panicum maximum* (syn. *Megathyrsus maximum*) cv. Aruana) pastures under continuous stocking for 59 days (preceded by 15 days of adaptation), with each one fed supplements (1.4% of body weight) at 8 am. At the end of the experimental period, the animals were slaughtered in a commercial slaughterhouse for carcass and meat quality evaluation. The inclusion of palm kernel oil had a decreasing linear effect on hot and cold carcass weight ($p = 0.0403$) ($p = 0.0398$), but it did not affect hot or cold carcass yields or carcass morphometric measurements, commercial cut weights, pH, or loin area ($p > 0.05$). However, it affected the color of the *L. lumborum* muscle, showing an increasing linear effect on yellow intensity (b*) ($p = 0.002$) and on the centesimal composition, with an increasing linear effect on ether extract content ($p = 0.006$). Shear force, cooking loss, and water-holding capacity were not affected ($p > 0.05$). Fatty acid profiles, the atherogenicity and thrombogenicity indices, and the ratio of hypocholesterolemic to hypercholesterolemic fatty acids (h:H) were also unaffected by the inclusion of palm kernel oil ($p > 0.05$). The inclusion of up to 60 g/kg of palm kernel oil in the diets of pasture-raised sheep had an effect on carcass weight but not yield. It also had an effect on the color and chemical composition of *L. lumborum* muscle, but these changes did not compromise the overall quality of the meat.

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1. Introduction

Sheep production in grazing systems, especially in tropical regions, is strongly influenced by climatic factors, such as the distribution of rainfall throughout the year, which directly affects the availability and nutritional quality of pastures [1]. Under these conditions, forage alone often does not meet the nutritional needs of growing sheep, making concentrated supplementation an essential strategy for improving productive performance, reducing slaughter age, and promoting adequate carcass finishing [2–4].

Among supplementation strategies, the inclusion of vegetable oils in rations can increase the energy density of diets and improve animal growth [5]. In addition, studies have indicated that the inclusion of vegetable oils in diets can modify the ruminal microbial community and fermentation patterns as well as influence the flow of fatty acids in the digestive tract and lipid deposition in tissues [6–9]. For example, supplementation with macadamia oil combined with vitamin E can improve the fatty acid profile and meat quality of lambs [8], whereas the inclusion of canola oil can increase the proportion of unsaturated fatty acids in meat [6]. However, these effects depend on factors such as the level of inclusion, the fatty acid profile of the oil, and interaction with the basal diet [10–12].

Palm kernel oil (PKO), obtained from the kernels of the palm fruit (*Elaeis guineensis*), is characterized by a high concentration of medium-chain saturated fatty acids, especially lauric acid (>46%) and myristic acid (>16%) [13]. These fatty acids have distinct metabolic pathways compared to long-chain fatty acids and can partially escape ruminal biohydrogenation, allowing their absorption in the small intestine and subsequent deposition in tissues [14]. Furthermore, lauric acid has recognized antimicrobial activity, being able to reduce the protozoan population in the rumen and alter the ruminal microbiota, thereby affecting fermentation patterns [15,16] and lipid metabolism [17]. However, increased deposition of saturated fatty acids in meat can negatively impact its nutritional value for human consumption, which reinforces the need for careful evaluation of this ingredient in ruminant diets [18].

Although palm kernel oil is a potentially viable lipid source owing to its availability and economic relevance in tropical regions, its effects on the carcass characteristics, meat quality, and fatty acid profiles of grazing sheep are still poorly understood. Previous studies on palm kernel oil were predominantly conducted in confined systems with sheep and cattle and demonstrated variable responses, including reductions in performance and limited improvements in meat quality [19,20]. Furthermore, the interaction between medium-chain fatty acids and pasture-based diets may result in responses distinct from those observed in confinement systems, highlighting the need for specific evaluations. Therefore, it was hypothesized that the inclusion of palm kernel oil in the diet of grazing sheep alters lipid metabolism as a function of the medium-chain fatty acid profile, which may affect carcass characteristics and the fatty acid composition of the meat. Thus, the effects of including PKO in the diets of grazing sheep on carcass characteristics, fatty acid profiles, and meat quality were evaluated in this study.

2. Materials and Methods

2.1. Animals, Management, and Experimental Diets

This study was conducted in the sheep sector of the Experimental Farm of the Center for Agricultural, Environmental, and Biological Sciences of the Federal University of Recôncavo da Bahia in Cruz das Almas, Bahia, Brazil (UFRB).

The experimental period lasted 59 days, and it was preceded by 15 days of adapting the animals to the environment, management, and diets. Thirty-two uncastrated Santa Inês sheep, which were approximately 5 months old and had an average initial body weight of 23.2 ± 2.6 kg, were vaccinated and dewormed. The animals were kept in four paddocks (approximately 0.25 ha each) with Aruana grass pasture (*Panicum maximus* (syn. *Megathyrsus maximus*) cv. Aruana) in a continuous grazing system. In each paddock, a group of eight animals from the same treatment was housed, and the groups were rotated between paddocks weekly. The paddocks were delimited by barbed wire fences and wire mesh and equipped with individual waterers, feeders, and shelters.

The supplement consisted of ground corn, soybean meal, mineral core for sheep, and 0, 20, 40, and 60 g/kg of palm kernel oil on a dry-matter basis (Table 1). The oil was purchased from Paldenba Company in Taperoá, BA, Brazil.

Table 1. Proportions of ingredients, chemical composition, and fatty acid profiles of experimental supplements and aruana grass.

Ingredients (g/kg DM)	**Palm Kernel Oil Levels in the Supplement (g/kg DM)**					
	0	**20**	**40**	**60**		
Ground corn grain	610	580	550	525		
Soybean meal	350	360	370	375		
Palm kernel oil	-	20	40	60		
Mineral supplement [1]	40	40	40	40		
	Chemical composition (g/kg DM)				Aruana grass	
Dry matter (g/kg as fed)	901.4	903.7	906.1	908.3	211.9	
Mineral matter	77.3	77.3	77.2	77.0	87.7	
Crude protein	199.4	200.6	201.8	201.5	145.6	
Ether extract	34.9	53.8	72.8	91.8	41.0	
NDFap [2]	86.6	85	83.4	81.7	602.2	
Acid detergent lignin	7.7	7.5	7.3	7.1	46.0	
Cellulose	19.9	20.0	20.1	20.0	197.2	
Hemicellulose	54.4	53.6	52.8	51.9	359.0	
Non-fibrous carbohydrates	503.2	487.0	470.9	456.4	113.6	
	Fatty acid profile (g/100 g total fat)				Aruana grass	Palm kernel oil
Capric (C:10)	0.09	0.16	0.23	0.30	0.10	3.41
Lauric (C:12)	0.10	1.05	2.00	2.96	0.10	47.71
Myristic (C:14)	1.39	1.68	1.96	2.25	0.15	17.33
Palmitic (C:16)	10.87	10.81	10.76	10.70	17.73	7.71
Palmitoleic (C:16:1)	0.09	0.09	0.09	0.09	0.10	0.1
Stearic (C:18:0)	4.91	4.80	4.68	4.58	2.15	2.22
Oleic (C:18:1)	35.44	34.73	34.03	33.40	1.15	13.57
Linoleic (C:18:2)	31.12	30.95	30.79	30.52	13.17	5.13
α-Linolenic (C:18:3)	0.28	0.29	0.29	0.30	65.15	0.1

[1] Assurance levels (per kilogram of product): 1800 mg of zinc; 83 g of sodium; 790 mg of manganese; 6;5 mg of cobalt; 135 mg of copper; 3700 mg of sulfur; 13 mg of selenium; 41 mg of iodine; 690 mg of iron; 150 g of calcium; 270 g of maximum calcium; 44 g of phosphorus. The supplement contains an antioxidant additive and a palatable additive. [2] Neutral detergent fiber corrected for ash and protein.

Daily, at 8 a.m., the animals were fed the supplements in individual troughs. The supplements were formulated to meet the nutritional requirements for a weight gain of 200 g/day, as per NRC requirements [16]. The supplements were isonitrogenous and offered at 1.4% of body weight.

The animals were weighed at the beginning and end of the experimental period after a 12 h fasting period to obtain the initial body weight (IBW) and final body weight (FBW). Animals were also weighed every 15-day intervals to adjust the supplement supply according to body weight. Weights were measured on days 1, 15, 30, 45, and 59 of the experimental period.

2.2. Slaughter, Carcass, and Meat Evaluation

At the end of the experimental period, the animals were slaughtered in a commercial slaughterhouse. After stunning, bleeding, skinning, evisceration, and removal of the head, hooves, and genitals, the hot carcass weight (HCW) was measured. The carcasses were then chilled for 24 h at 4 °C and weighed to obtain the cold carcass weight (CCW). Based on the obtained data, the chilling losses (CL) was calculated as follows:

$$CL\ (\%) = (HCW - CCW) \times 100/HCW \quad (1)$$

and the commercial carcass yield or cold carcass yield (CCY), where

$$CCY\ (\%) = CCW/FBW \times 100 \quad (2)$$

Immediately after obtaining the cold carcass weight, morphometric measurements of the carcass were performed, including the external and internal lengths of the carcass, internal and external lengths of the legs, width and thickness of the rump, and depth of the ribs, according to Osório and Osório [21]. At this stage, the pH of the carcass was measured in the *L. lumborum* muscle region using a portable digital potentiometer.

Next, the carcasses were sectioned longitudinally into two halves. The left half was subdivided into the main commercial cuts: neck (1st to 7th cervical vertebra), shoulder (bony base of the scapula, humerus and carpus), rack (region that has as its bony base the 13 dorsal vertebrae, together with the upper part of the body of the corresponding ribs), rib (floating vertebrae, resulting from the division of the rack), loin (cut that has as its anatomical base the six lumbar vertebrae) and leg (posterior section of the carcass, composed of the femur and tibia bones), according to a methodology adapted from Colomer-Rocher [22], with each cut being weighed individually. Additionally, samples from the left loin and the 13th thoracic vertebra (taken from the rack) were collected in individual plastic bags, without vacuum packaging, and sent to the food analysis laboratory at UFRB, where they remained refrigerated for approximately 24 h (totaling approximately 48 h after slaughter) until the time of analysis of the loin eye area (LEA), subcutaneous fat thickness (SFT), and color. The loin eye area and subcutaneous fat thickness were measured at the 13th thoracic vertebra, in the *L. thoracis* muscle. (LEA) was determined using the geometric method described by Costa et al. [18], while SFT was obtained according to the methodology proposed by Osório and Osório [21].

For color determination, the loin samples were removed from the refrigerator, sectioned, and exposed to oxygen for five minutes to promote contact between myoglobin and oxygen. The samples were then subjected to color evaluation using a Minolta CR-200 colorimeter through the CIELAB system, in which color is expressed by the coordinates L* (luminosity), a* (red intensity), and b* (yellow intensity). The equipment was calibrated with a white standard, and readings were taken at three distinct points on the muscle to ensure sample representativeness, considering the average of the three values as the meat color. After these analyses, the samples were individually repackaged and stored in a freezer at −20 °C for approximately 3 months until the time of the other evaluations.

The *L. lumborum* muscle was analyzed for water retention capacity, cooking losses, shear force, chemical composition, and fatty acid profile evaluation were performed on the *L. lumborum* muscle.

Water-holding capacity (WHC) was determined by adapting Hamm's methodology [23], using 3 g meat samples, placed on filter paper and subjected to a 10 kg load for 5 min. Subsequently, the samples were weighed, and the WHC was calculated based on the weight difference before and after the application of the load, with the values expressed as a percentage.

Cooking losses were analyzed according to the recommendations of the American Meat Science Association (AMSA) [24]. Two meat samples (2.5 cm thick), free of subcutaneous fat, were weighed, wrapped in aluminum foil and grilled using a stainless-steel thermometer. The samples were cooked until the internal temperature in the center of the muscle reached 71 °C. Then, they were removed, cooled to room temperature and weighed again. The cooking losses of each sample were determined by the weight difference before and after cooking, with the values expressed in g/100 g of exudate. After analyzing cooking losses, three cylindrical samples, 1 cm in diameter and 2.0 cm in length, were taken parallel to the muscle fibers [24]. Each cylindrical sample was cut perpendicular to the fiber direction to determine the shear force (kgf/cm^2). Shear force was measured using a texture analyzer (TAXT 2 Plus, Stable Micro Systems, Scarsdale, NY, USA), equipped with a Warner-Bratzler type blade, according to the methodology described by Shackelford, Wheeler and Koohmaraie [25]. The shear force values obtained were expressed in Newtons (N).

To evaluate the centesimal composition of *L. lumborum* muscle, fresh meat samples were individually ground in a food processor. Subsequently, they were lyophilized for 72 h and subjected to centesimal composition analyses. Moisture, mineral matter, and crude protein contents were determined according to the AOAC [26]. Ether extract (EE) content was determined using an extractor (ANKOM TX10) according to the AOCS methodology [27].

2.3. Fatty Acid Profile

Samples of freeze-dried meat, palm kernel oil, and diets were analyzed for their fatty acid profiles according to the recommendations of Folch et al. [28]. Lipids were extracted from lamb meat samples using a chloroform-methanol mixture (2:1, v/v). Triglyceride transesterification was performed using n-heptane and KOH/methanol solution. Fatty acids were analyzed using gas chromatography with a flame ionization detector. A 100 m × 0.25 mm × 0.20 µm fused-silica capillary column was used for elution. The conditions adopted in the chromatographic separation process and the quantification of fatty acids were performed using peak area correction factors, according to Carneiro et al. [29].

Based on the analysis of fatty acids in meat, the atherogenicity (AI) and thrombogenicity (TI) indices were calculated according to Ulbricht and Southgate [25], in addition to the ratio between hypocholesterolemic and hypercholesterolemic fatty acids, by adapting the methodology of Santos-Silva et al. [30].

Where:

$$(AI) = [(C12{:}0 + (4 \times C14{:}0) + C16{:}0)]/(\sum MUFA + \sum \omega 6 + \sum \omega 3) \quad (3)$$

$$(TI) = (C14{:}0 + C16{:}0 + C18{:}0)/[(0.5 \times \sum MUFA) + (0.5 \times \sum \omega 6 + (3 \times \sum \omega 3) + (\sum \omega 3/\sum \omega 6)] \quad (4)$$

$$(h{:}H) = (C18{:}1cis9 + C18{:}2\omega 6 + 20{:}4\omega 6 + C18{:}3\omega 3 + C20{:}5\omega 3 + C22{:}5\omega 3 + C22{:}6\omega 3)/(C14{:}0 + C16{:}0) \quad (5)$$

2.4. Analysis Statistics

The initial and final body weights of the animals, carcass characteristics, and meat quality were evaluated using a completely randomized design. The statistical model used was as follows:

$$Yij = \mu + Ti + eij \quad (6)$$

where Yij is the observation of animal j receiving treatment i, μ is the overall mean, Ti is the fixed effect of treatment i, and eij is the random error associated with each observation. The initial body weights of the animals were included in the model as covariates when significant.

The data were analyzed using the SAS OnDemand for Academics (SAS Institute Inc., Cary, NC, USA) [31]. The homogeneity of variances was verified using Levene's test, and the normality of errors was verified using the Shapiro–Wilk test. The PROC MIXED procedure was used for the analysis of variance and polynomial regression. Orthogonal contrasts were used to test the linear and quadratic effects of adding palm kernel oil to the diet of sheep on carcass characteristics and meat quality. The additional control contrast (0) was compared with other PKO levels (20, 40, and 60 g/kg). The significance level was set at $p < 0.05$.

3. Results

The inclusion of palm kernel oil in sheep feed had a decreasing linear effect on hot carcass weight ($p = 0.0403$) and cold carcass weight ($p = 0.0398$), but it did not affect chilling losses, hot carcass yield, cold carcass yield, loin eye area, or subcutaneous fat thickness ($p > 0.05$) (Table 2).

Table 2. Carcass characteristics, morphometric carcass measurements, and weight of the main commercial cuts of sheep finished on pasture and supplemented with palm kernel oil.

Variables	Palm Kernel Oil Levels in the Supplement (g/kg)				*p*-Value [2]			
	0	20	40	60	SEM [1]	L	Q	0 × PKO [3]
Initial body weight (kg)	22.88	23.25	23.00	23.75	0.9599	0.5845	0.8465	0.6824
Final body weight (kg)	33.31	32.91	32.07	32.40	0.3420	0.0273	0.2986	0.0403
Hot carcass weight (kg)	13.76	13.66	13.39	12.98	0.2709	0.0403	0.5803	0.1908
Cold carcass weight (kg)	13.57	13.49	13.16	12.84	0.2649	0.0398	0.9357	0.1780
Chilling losses (kg)	0.175	0.175	0.225	0.150	0.0502	0.9122	0.4615	0.9538
Hot carcass yield (%)	41.32	41.48	41.74	40.05	0.6335	0.2216	0.1524	0.7079
Cold carcass yield (%)	40.78	40.95	41.04	39.60	0.6327	0.2305	0.2074	0.6930
Subcutaneous fat thickness (mm)	1.40	1.93	1.73	1.89	0.3079	0.3652	0.5501	0.2136
Loin eye area (cm^2)	15.92	15.65	15.55	16.2	1.0713	0.8732	0.6773	0.9252
Measurements (cm)								
External carcass length	55.56	54.94	54.50	55.13	0.3268	0.5356	0.3607	0.3695
Internal carcass length	51.06	49.94	49.50	50.44	0.3571	0.4777	0.1623	0.1940
External leg length	36.94	37.25	36.94	37.13	0.2287	0.9079	0.8070	0.7652
Internal leg length	33.13	32.56	32.94	32.94	0.1535	0.8946	0.3775	0.3955
Thigh thickness	10.43	10.29	10.31	10.34	0.1040	0.8094	0.7122	0.6585
Rib depth	18.75	18.38	18.75	18.69	0.1234	0.8696	0.5419	0.6216
Rump width	14.94	15.00	14.98	14.51	0.1444	0.3318	0.3800	0.7523
Weight (kg)								
Leg	2.20	2.21	2.16	2.13	0.0682	0.4190	0.7847	0.6795
Shoulder	1.35	1.28	1.25	1.29	0.0438	0.2764	0.2097	0.1232
Rib	0.87	0.92	0.83	0.87	0.0385	0.6406	0.8849	0.8965
Rack	1.16	1.22	1.15	1.18	0.0599	0.9650	0.7845	0.7186
Loin	0.58	0.57	0.55	0.63	0.0412	0.5426	0.2981	1.0000
Neck	0.88	0.95	0.96	0.97	0.0562	0.3082	0.5907	0.7059

[1] Standard error of the mean. [2] Significance level $p < 0.05$; L, linear; Q, quadratic. [3] Contrast between 0 g (control) and diets with PKO = palm kernel oil (20, 40 and 60 g/kg MS).

The morphometric measurements of the carcass (external length, internal length, external leg length, internal leg length, thigh thickness, rib depth), and weight of the main commercial cuts (leg, shoulder, rib, loin, and neck) were not influenced by the inclusion of palm kernel oil in the supplement ($p > 0.05$) (Table 2).

The inclusion of palm kernel oil in the sheep supplement did not affect pH ($p = 0.2857$) or the color parameters L* and a* ($p = 0.2540$), but it linearly increased the parameter b* ($p = 0.0018$). Shear force, water-holding capacity, and cooking losses were not affected by the levels of palm kernel oil inclusion ($p > 0.05$) (Table 3).

The ether extract content in the *L. lumborum* muscle of the sheep increased linearly with palm kernel oil inclusion ($p = 0.0064$). The moisture content, ash, and protein were not affected ($p > 0.05$) (Table 3).

Regarding the fatty acid profile of *L. lumborum*, no significant effects were observed on the concentrations of lauric acid and other saturated fatty acids in this study. The inclusion of palm kernel oil in the supplement also did not alter the concentration of monounsaturated and polyunsaturated fatty acids in the meat ($p > 0.05$) (Table 4).

Table 3. Qualitative characteristics and proximate composition of *L. lumborum* muscle from sheep finished on pasture and supplemented with palm kernel oil.

Variables	Palm Kernel Oil Levels in the Supplement (g/kg)				*p*-Value [2]			
	0	20	40	60	SEM [1]	L	Q	0 × PKO [3]
pH	5.69	5.70	5.56	5.65	0.049	0.2857	0.4388	0.3999
L* (Lightness)	39.95	39.47	41.68	41.06	0.8173	0.1413	0.9352	0.4141
a* (Redness)	9.67	9.91	10.06	10.17	0.3183	0.2540	0.8358	0.3107
b* (Yellowness)	10.23	10.01	11.21	11.57	0.3361	0.0018	0.3894	0.0853
Shear force	1.89	1.85	2.06	1.94	0.1612	0.6127	0.7991	0.7374
Water-holding capacity (%)	71.68	70.98	66.54	68.10	1.8972	0.0846	0.5574	0.1634
Cooking losses (%)	26.96	27.71	25.29	27.42	1.8928	0.9028	0.7189	0.9441
Composition (%)								
Moisture	75.33	75.89	75.77	75.44	0.2368	0.8420	0.0669	0.1864
Mineral matter	0.97	1.00	0.98	1.11	0.0654	0.1956	0.4110	0.4861
Crude protein	21.95	21.10	22.22	22.16	0.5105	0.4506	0.4499	0.8387
Ether extract	1.36	1.40	1.46	1.99	0.1473	0.0064	0.1036	0.1478

[1] Standard error of the mean. [2] Significance level $p < 0.05$; L, linear; Q, quadratic. [3] Contrast between 0 g (control) and diets with PKO = palm kernel oil (20, 40 and 60 g/kg MS).

Table 4. Fatty acid profile of *L. lumborum* muscle from sheep finished on pasture and supplemented with palm kernel oil.

Variables (%)	Palm Kernel Oil Levels in the Supplement (g/kg)				*p*-Value [2]			
	0	20	40	60	SEM [1]	L	Q	0 × PKO [3]
Lauric (C:12)	0.20	0.21	0.21	0.22	0.0032	0.0757	0.8457	0.1237
Myristic (C:14)	2.47	2.43	2.40	2.42	0.0209	0.4448	0.5119	0.3499
Palmitic (C:16)	21.72	21.82	21.70	21.68	0.0471	0.5340	0.4992	0.9176
Heptadecanoic (C:17)	1.35	1.35	1.36	1.34	0.0107	0.7868	0.7215	0.9491

Table 4. *Cont.*

Variables (%)	Palm Kernel Oil Levels in the Supplement (g/kg)				*p*-Value [2]			
	0	20	40	60	SEM [1]	L	Q	0 × PKO [3]
Stearic (C:18)	15.40	15.39	15.39	15.41	0.0190	0.8239	0.6588	0.9786
Arachic (C:20)	0.15	0.14	0.14	0.14	0.0023	0.3771	0.1522	0.1533
Myristoleic (C:14:1)	0.37	0.38	0.37	0.37	0.0040	0.8704	0.7155	0.8332
Palmitoleic (C:16:1)	1.66	1.68	1.67	1.65	0.0095	0.7035	0.3024	0.7295
Oleic (C:18:1)	50.63	50.55	50.68	50.69	0.0734	0.6568	0.7958	0.9441
Eicosanoic (C:20:1)	0.11	0.11	0.11	0.11	0.0009	0.6810	0.3608	0.8594
Linoleic (C:18:2n − 6)	3.57	3.57	3.58	3.61	0.0215	0.4753	0.7612	0.7138
CLA [4] (Cis-9 trans 11)	0.29	0.30	0.29	0.29	0.0038	0.8037	0.5791	0.7483
Linolenic (C:18:3n − 3)	0.15	0.14	0.14	0.15	0.0023	0.2876	0.1889	0.1312
Eicosadienoic (C:20:2)	0.11	0.12	0.11	0.11	0.0007	0.8429	0.6582	0.4451
Eicosatrienoic (C:20:3n − 3)	1.35	1.34	1.35	1.34	0.0105	0.8115	0.9776	0.7583
Diomo-γ- Linolenic (C:20:3n − 6)	0.11	0.11	0.11	0.11	0.0006	1.000	1.000	1.0000
Aracdonic (C:20:4)	0.14	0.14	0.14	0.14	0.0037	0.4929	0.9354	0.9057
Eicosapentanoic (C:20:5n − 3)	0.11	0.10	0.10	0.10	0.0009	0.3592	1.000	0.6076
Satured	41.40	41.45	41.32	41.32	0.0530	0.4576	0.7904	0.7965
Monounsaturated	52.77	52.72	52.84	52.82	0.0742	0.7069	0.9269	0.8992
Polyunsaturated	5.82	5.82	5.84	5.86	0.0330	0.7374	0.8303	0.9015
PUFA:SFA [5]	0.14	0.14	0.14	0.14	0.0007	0.5866	0.7558	0.8490
Omega3	1.61	1.59	1.60	1.59	0.0119	0.6337	0.7849	0.5390
Omega6	3.68	3.68	3.70	3.72	0.0214	0.4729	0.7599	0.7123
Omega6:Omega3	2.29	2.31	2.32	2.34	0.0128	0.1658	0.9685	0.2234
AI [6]	0.54	0.55	0.54	0.54	0.0017	0.2761	0.8868	0.4511
TI [7]	1.09	1.09	1.08	1.08	0.0020	0.5161	0.6487	0.9815
h:H [8]	2.26	2.24	2.27	2.27	0.0065	0.3411	0.6545	0.7779

[1] Standard error of the mean. [2] Significance level $p < 0.05$; L, linear; Q, quadratic. [3] Contrast between 0 g (control) and diets with PKO = palm kernel oil (20, 40 and 60 g/kg MS). [4] Conjugated linoleic acid; [5] Ratio between polyunsaturated and saturated fatty acids; [6] Atherogenicity index; [7] Thrombogenicity index; [8] Ratio between hypocholesterolemic and hypercholesterolemic fatty acids.

4. Discussion

The decreasing linear effect on hot and cold carcass weights was related to the reduction in final bodyweight, suggesting that the inclusion of palm kernel oil contributed to the reduction in the productive performance of the animals. This effect may be associated with changes in dry-matter intake, since the addition of vegetable oils can reduce dry-matter intake and fail to meet the nutritional needs of the animals [32], resulting in less availability of nutrients for tissue deposition, directly impacting the final bodyweight and, consequently, carcass weight. Despite this, carcass yield was not affected, indicating that growth occurred proportionally among the different body parts. These results are consistent with the findings of Wang et al. [33], who reported lower live and carcass weights among lambs raised on pasture than among confined animals, while the carcass yields remained similar. These results suggest that even when overall growth is reduced, the ratio of carcass weight to live weight can be maintained. This was also observed in the morphometric measurements and weights of commercial cuts, showing that the inclusion of palm kernel oil did not affect carcass conformation.

The inclusion of palm kernel oil in the sheep supplement had an effect on the coloration of the *L. lumborum* muscle, showing a linear increase in the intensity of the yellow color (b*). Meat color is influenced by the chemical state and oxidation of myoglobin, the main pigment responsible for meat coloration, and this process is affected by factors such as

pH [34]. In the present study, the pH of the meat was not affected by the treatments, indicating that the observed increase in b* values cannot be attributed to changes in pH. Thus, the increase in the b* parameter is most likely associated with changes in muscle composition, particularly in lipid composition [20,35] and the presence of fat-soluble pigments, such as carotenoids [36]. The inclusion of palm kernel oil linearly increased the ether extract content in *L. lumborum* muscle, contributing to greater light scattering and to the composition of compounds related to carotenoids, which are known to intensify the yellowish color of the meat [36]. Furthermore, the values obtained for yellow (b*) and red (a*) are in agreement with the values reported in studies involving younger sheep. Soares Júnior et al. [37], working with sheep raised on pasture supplemented with carob pod meal, also evaluated the meat of animals slaughtered at a similar age to that in this study (7 months of age) and found similar values: 11.4 for a* and 12.13 for b*.

The effect on EE content in muscle may be related to a possible higher consumption and greater digestibility of ether extract, which may favor an increase in fat deposition in the meat. Van Cleef et al. [38] also reported higher EE concentrations in *L. lumborum* of sheep when they added soybean oil or residual frying oil to the animals' diet, attributing this to a higher energy intake, especially in the form of ether extract, compared to those that did not receive oil in their diet. According to the authors [38], this occurred because higher EE consumption possibly allowed for better metabolic efficiency of anabolic reactions in adipose tissue. Furthermore, the fatty acid profile of palm kernel oil is mainly composed of medium-chain fatty acids, such as lauric (47.71%) and myristic (17.33%) acid, which are saturated fatty acids and do not impair biohydrogenation, favoring their direct absorption by the small intestine and deposition in the muscle [14], affecting the amount of fat in sheep *L. lumborum*.

Although the inclusion of palm kernel oil affected meat composition, no changes were observed in the meat quality of these animals, since the water retention capacity and shear force, which are related to the tenderness and juiciness of the meat, were not affected by dietary treatment. These characteristics are also related to meat pH [39], which did not change with the inclusion of oil in the animal feed.

The inclusion of palm kernel oil did not alter the fatty acid profiles of the sheep *L. lumborum*. Dos Santos et al. [20], who evaluated the inclusion of palm kernel oil in the diet of young steers, observed an increase in lauric acid concentrations in the meat of the animals as the levels of oil inclusion increased. According to the authors [20], increasing the amount of oil in the diet resulted in greater availability of lauric acid to the animals, which was reflected in the higher composition of this fatty acid in meat. However, this was not observed in our study, possibly due to the lower levels used, since palm kernel oil was present only in the dry matter of the supplement, unlike in the previous study, which considered it in the total diet.

Despite its highly saturated profile, the inclusion of palm kernel oil in sheep supplements did not affect the total amount of fatty acids in the *L. lumborum*. Ruminant meat is rich in saturated fatty acids, and an increase in the content of these acids is undesirable, as they can harm human health by increasing blood concentrations of total cholesterol and low-density lipoprotein (LDL), which are considered the main risk factors for coronary heart disease (CHD) [18].

In addition, due to its low content of unsaturated fatty acids, the total amount of monounsaturated and polyunsaturated fatty acids in *L. lumborum* was not affected by the levels of palm kernel oil inclusion in the diet. The same occurred with the amount of CLA, which was not affected. The formation of CLA (Cis-9 trans 11) is associated with increased consumption of polyunsaturated fatty acids and undergoes ruminal biohydrogenation, which is necessary for its formation [40]. However, in the case of palm kernel oil, the

toxic effect of lauric acid on ruminal bacteria has inhibitory effects on the ruminal biohydrogenation process and may increase the quantity of trans fatty acids, such as CLA, deposited in the meat [7]. However, in our study, this effect was not observed, possibly due to the amount of oil used in the diet.

The inclusion of palm kernel oil did not affect the atherogenicity and thrombogenicity indices or the ratio of hypocholesterolemic to hypercholesterolemic fatty acids. Similar to saturated fatty acids, an increase in these indices is undesirable because they are associated with the risk of cardiovascular diseases [41].

5. Conclusions

It was concluded that the inclusion of palm kernel oil in the supplement for sheep finished on pasture, with up to 60 g/kg in the dry matter of the supplement, resulted in a reduction in carcass weight but did not affect commercial yield. Furthermore, it increased the fat content of the meat without altering the fatty acid profile or compromising the overall quality of the meat. Therefore, supplementation with palm kernel oil can be adopted, provided that its effects on carcass weight are considered.

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