Acta Scientiarum

http://periodicos.uem.br/ojs
ISSN on-line: 1807-8672
Doi: 10.4025/actascianimsci.v45i1.59105

RUMINANT NUTRITION

Carcass characteristics and meat quality of lambs fed diets with different roughage: concentrate ratios supplemented with liquid residue of cassava

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ABSTRACT. The objective of this study was to evaluate the effects of lambs fed two roughage: concentrate (R:C) ratios, with or without the liquid residue of cassava (LRC) on carcass traits and meat quantity. Forty lambs (19.5 ± 1.45 kg body weight), non-castrated, crossbred Santa Inês were distributed in a completely randomized 2 × 2 factorial design. There was no effect ($p > 0.05$) of the inclusion of LRC on the variables. The roughage:concentrate ratio of 40:60 promoted higher values for empty body weight, hot carcass weight, cold carcass weight, subcutaneous thickness fat, cooling loss, *Longissimus* muscle area, carcass morphometric measurements, and commercial cuts. Higher weight of leg, muscles, fat, bone and other tissues, as well as for the ratio muscle:fat, and muscle:bone was observed in lambs fed 40R:60C. For the meat chemical composition, there was the effect ($p < 0.05$) only for ether extract (EE) for lambs fed 40R:60C ratio. The redness (a*) of meat was greater ($p < 0.05$) for lambs fed 80R:20C. The other physicochemical characteristics were not influenced. The roughage:concentrate ratio of 40:60 improves the carcass traits and commercial cuts, but does not promote changes in meat quality, independent of supplementation with liquid residue of cassava.

Keywords: alternative foods; *Manihot esculenta*; meat; By-products; sustainability.

Received on May 6, 2021.
Accepted on March 7, 2022.

Introduction

Beef sheep in the northeast region of Brazil presents fragile coordination of the links in the production chain, due to seasonality in the roughage supply, different production systems, and genetic pattern, revealing obstacles on the development of the activity regarding the standardization of carcasses, seasonal availability of meat and the valorization of the final product (Oliveira et al., 2018; Lôbo et al., 2018). Despite that, it is necessary to show that beef sheep farming is considered an important local activity, contributing to the growth of the economy and the supply of animal protein for the local population feeding.

The region is marked by severe seasonality of forage production, given that from the nine encompassed states, half of them has more than 85% of its area characterized as semi-arid (Superintendência do Desenvolvimento do Nordeste [SUDENE], 2018). Thus, to minimize fluctuations in the supply of food for animals and, consequently, the supply of meat throughout the year, it is necessary to seek alternative, low-cost food to supply the demand.

In this context, cassava (*Manihot esculenta* Crantz) stands out. It is a root widely cultivated in the region and its processing results in by-products (hay from the aerial part of the plant, root shavings, flour residue, and liquid residue) that hold the potential to be used in animal feed.

The "Manipueira" is a liquid residue of cassava (LCR) with a milky appearance and a light-yellow color, resulting from the pressing of cassava after obtaining the starch or flour. This residue has a high pollutant load that has a toxic effect due to cyanogenic glycoside acid (linamarin) (Aso, Pullammanappallil, Teixeira, & Welt, 2019; Leite et al., 2018).

However, LCR can be used in animal feed without the risk of intoxication, as long as it previously passes through a period of rest (about five days) for acid volatilization, and after that process, it can be administered without risk of intoxication to animals (Silva et al., 2017; Rosales-Soto et al., 2016). Its chemical composition varies according to climate and soil conditions, age of root tuber, and storage time, which implies monitoring its composition for its use as an ingredient in the animal diet.

Few studies are evaluating the use of this by-product and its recommendation is still limited by little knowledge of nutritional characteristics and adequate use (Versino, Lopez, & Garcia, 2015). Cardoso et al. (2016) recommend the use of cassava dregs, a byproduct of cassava similar to LCR, to replace corn in the sheep diet because this by-product does not harm the characteristics of the carcass and non-carcass components. Santos Filho et al. (2015) recommends the use of 25% replacement of corn for LRC because it presents better weight gain, nutrient intake, and carcass characteristics. However, the replacement of corn by LCR can negatively influence the qualitative characteristics of the meat (Urbano et al., 2015). Assessments of the quantitative characteristics of the carcass and qualitative characteristics of the meat can provide important indications for the production process, benefiting the entire chain of sheep meat production.

We hypothesized that liquid residue of cassava can benefit the characteristics of carcasses and meat quality of sheep without causing damage to animal health, contributing also to minimize economic and environmental impacts. Thus, the objective was to evaluate the carcass characteristics, weight and yield of commercial cut, tissue composition of legs, chemical, and physical composition of lambs' meat fed with two roughage:concentrate ratios, with or without liquid residue of cassava supplementation.

Material and methods

The experiment was conducted in the Food Evaluation Laboratory for Small Ruminants III of the Department of Animal Science of the Federal Rural University of Pernambuco (UFRPE) in Recife, Brazil. All procedures were carried out following the guidelines set out by the Ethics Committee on the Use of Animals for Research (CEUA) of the UFRPE.

Forty non-castrated male crossbred Santa Ines lambs with an average initial body weight of 19.5 ± 2.5 kg at 4 months of age were randomly distributed in individual pens that were provided with a feeder and drinker. In the pre-experimental period, all animals were treated against ecto and endoparasites. The experiment lasted for 90 days, with 30 days for adaptation to the diets and installations, and 60 days for data and sample collection, and performance evaluation of the lambs.

Diets were formulated to meet an average daily gain of 150 g according to the National Research Council (NRC, 2007) (Tables 1 and 2).

Table 1. Chemical composition of ingredients used in the diet (g kg^{-1} DM).

Ingredients	DM[1]	Ash	OM	CP	apNDF	EE	NFC
Tifton-85 hay	884	65.7	934	63.9	776	22.5	72.3
Liquid residue of cassava	48.5	8.5	991	16.5	4.30	5.90	965
Soybean meal	874	18.7	981	85.7	131	44.4	720
Ground corn	848	72.4	928	502	180	30.8	215

DM: dry matter; OM: organic matter; CP: crude protein; EE: ether extract; apNDF: neutral detergent fiber assayed with a heat-stable amylase and corrected for ash and nitrogenous compounds; NFC: non-fiber carbohydrates; [1]g kg^{-1}.

The liquid residue of cassava (LRC) was acquired in the city of Glória do Goitá, Pernambuco, Brazil. The LRC was collected during the pressing process of the crushed mass. The LRC was stored in 200-L uncapped plastic drums that were covered with a screen and kept in the shade over an average period of 8 days to allow for the complete volatilization of hydrocyanic acid. It was offered to the lambs after 5 days of storage. LRC was provided *ad libitum* in plastic buckets attached by a bracket outside of the stall, and the quantities supplied and not consumed were recorded daily. Weekly samples were collected by removing an aliquot from each bucket; these were mixed and stored at − 20°C for further analysis. The diets were provided ad libitum as a total mixed ration twice a day, at 8:00 and 15:00h. The amount of feed supplied was corrected daily to generate 10% orts. Further details on the lamb management and feeding systems are given by Leite et al. (2018).

After 90 days of feeding, the animals were slaughtered according to procedures followed by the Regulation on Industrial and Health Inspection of Products of Animal Origin (Brasil, 2000).

After obtaining body weight at slaughter (BWS), bleeding, evisceration, head and limb removal were performed, and the carcass was weighed to obtain the hot carcass weight (HCW). The gastrointestinal tract was weighed full and empty, and it was weighed again to obtain the weight of the contents of the gastrointestinal tract and to calculate the empty body weight (EBW). The yields of the hot (HCY) and biological (BY) carcass were determined using the formulas HCY (%) = (HCW/BWS) × 100 and BY (%) = (HCW/EBW) × 100.

Table 2. Proportion of ingredients and chemical composition of the diet.

Item	Treatments	
	80R: 20C	40R: 60C
Ingredients, g kg^{-1}		
Tifton- 85 hay	800	400
Ground corn	80	460
Soybean meal	110	120
Mineral[1]	10	10
Salt[2]	0	5
Limestone calcitic	-	5
Diet composition, g kg^{-1} of DM		
Dry matter[2]	880	877
Ash	66.2	60.4
Organic matter	934	940
Crude protein	113	125
Ether extract	24.9	33.1
apNDF	687	410
NFC	113	388

DM dry matter, aNDF(n) neutral detergent fiber assayed with a heat-stable amylase and corrected for ash and protein; NFC = non-fiber carbohydrates; [1]Nutrients kg of product^{-1}: Ca = 120 g; P = 87 g; Na = 147 g; Mg = 1320 mg; Co = 40 mg; Mn = 1300 mg; Zn = 3800 mg; I = 80 mg; Se = 15 mg; S = 18 g; F = 870 mg; Fe = 1800 mg; Cu = 590 mg; Mo = 300 mg; Cr = 20 mg. 2 g kg^{-1}.

Subsequently, the carcasses were taken to the cold room with an average temperature of 4°C where they remained for 24 hours, and after the cooling period they were weighed to obtain the cold carcass weight (CCW). Cold carcass yield (CCY) and cooling losses (CL) were determined according to the equations CCY (%) = (CCW / BWS) × 100 and CL (%) = (HCW – CCW / HCW) × 100.

After the cooling period, morphometric measurements were performed on the carcasses. The carcass compactness index (CCI) and the leg compactness index (LCI) were also calculated using the following equations: CCI (kg cm^{-1}) = CCW/internal length carcass; and LCI (cm cm^{-1}) = hind width/leg length. Then each carcass was sagittally divided. The left halves-carcasses were sectioned in six anatomical regions according to the methodology adapted from Cezar and Souza (2007): neck, shoulder, rib, saw, loin, and leg.

In the left half-carcass, a cross-section between the 12 and 13th ribs was performed to measure the *Longissimus* muscle area (LMA) by tracing the muscle contour on a transparent plastic sheet to determine the area using a digital planimeter (HAFF, Digiplan model; Pfronten, Baviera, Germany). Additionally, with the aid of a digital caliper, the subcutaneous thickness fat (STF) was measured in the *Longissimus lumborum*.

The legs were dissected in fat, bone, muscle, and other (vessels, nerves, lymph nodes, tendons, aponeuroses, and fascia) to determine the tissue composition, according to Cezar and Souza (2007).

The loin *(Longissimus lumborum)* of each animal was vacuum packaged in a high-density polyethylene bag and stored at (− 20°C) for further qualitative analyses. The left loin samples were thawed for 24h at 4°C and used in the physicochemical analyses. To evaluate meat color, samples of left loin were cut at a minimum thickness of 15 mm after thawing at 4°C. Next, after exposition to oxygen for 30 min. the fresh meat color was measured. The meat color was evaluated for components such as lightness (L*) 0–100, ranging from black to white, redness (a*) ranging from red to green component, and yellowness (b*) from yellow to blue component. Operating in CIELAB (L* a* b*) color systems were measured using a colorimeter (Minolta Chroma Meter CR-400) calibrated to a white standard, and having an aperture size of 8 mm, using D65 illuminant and 10° standard observer and it was operated using open cone. This colorimeter was calibrated with a white tile (Y= 92.8, x = 0.3160, y = 0.3323) and three replicate measurements were taken at different positions on measured surface and had their average recorded.

The water-holding capacity was determined using the method adapted by Santos-Silva, Mendes, and Bessa (2002). Muscle samples (S) weighing about 300 mg were placed between two filter paper previously weighed (P1) and pressed for 5 min., using a weight of 3.45 kg. The muscle samples were then removed, and the paper was re-weighed (P2). The water holding capacity was calculated according to the following formula: WHC (%) = 100 − (P2/P1)/S × 100.

To measure cooking loss, three 2.54 cm thick steaks were weighed and cooked in an industrial oven preheated to 175°C until the internal temperature of the samples reached 71°C. Cooking loss (CL) was calculated as the difference between the weight of the steaks before and after oven-broiling.

The chemical composition of meat analyzed for crude protein (CP; Method 920.87), ether extract (EE; Method 920.29), and ash (Method 924.05) were determined according to methodologies described by the Association of Official Analytical Chemists (AOAC, 1990).

A completely randomized design was used, following a 2 x 2 factorial arrangement, considering two roughage:concentrate ratios (80: 20 and 40: 60) and inclusion or not of liquid residue cassava, with ten replicates. Data were analyzed using PROC GLM for analysis of variance using SAS software, Version 9.1 (Statistical Analysis System [SAS], 2015), based on the statistical model: $Yijk = \mu + RCi + Mj + RCMij + eijk$, where: Yijk = roughage: concentrate ratio i, with or without RLC j, the effect of the interaction: roughage: concentrate ration × with or without RLC ij; μ = general constant; eijk = random error associated with each observation, with $\alpha = 0.05$ as the critical level of probability for type I error.

Results and discussion

There was no interaction between roughage: concentrate (R:C) ratio and liquid residue of cassava (LRC) for all variables analyzed ($p > 0.05$). The inclusion of LRC had no influence ($p > 0.05$) on carcass characteristics, meat cuts, tissue composition of the leg, and chemical composition of meat (Tables 3, 4, and 5).

There was an effect only on the different roughage: concentrate ratios ($p < 0.05$), on the body weight at slaughter (BWS), where the lambs fed with the 40R: 60C ratio with or without LRC was higher in 27.9 and 24.7%, respectively, and empty body weight (EBW), was 28.3 and 25.2% higher, respectively, compared to animals fed the 80R: 20C ratio. As a result, this 40R: 60C ratio showed higher ($p < 0.05$) weight of left half-carcass reconstituted (LHCR), as well as higher weights of cuts, with emphasis on the shoulder, loin, and leg, with weights of 7.19, 0.70 and 2.24 kg, respectively. The initial and final pH of the carcasses had no influence ($p > 0.05$) by the experimental diets (Table 3).

Table 3. Carcass characteristics and meat cuts of lambs fed different roughage(R): concentrate (C) ratio associated with the liquid residue of cassava (LCR).

p	Treatment				SEM	P-value		
	80:20	40:60	80:20 + LRC	40:60 + LCR		R:C	LCR	R:C x LCR
		Carcass characteristics						
BWS, kg	24.0b	33.3a	24.7b	32.80a	0.365	<.0001	0.903	0.411
EBW, kg	22.5b	31.4a	23.10b	30.9a	0.324	<.0001	0.912	0.442
HCW, kg	9.26b	15.6a	9.83b	15.0a	0.159	<.0001	0.987	0.062
CCW, kg	8.75b	14.9a	9.3b	14.4a	0.098	<.0001	0.948	0.102
HCY, %	38.5b	46.7a	40.2b	45.7a	0.345	<.0001	0.824	0.078
CCY, %	36.6b	45.4a	37.8b	43.9a	0.348	<.0001	0.911	0.089
STF, mm	0.52b	1.28a	0.51b	1.28a	0.052	<.0001	0.367	0.129
LMA, cm²	7.64b	10.55a	8.70b	10.30a	0.234	<.0001	0.395	0.168
LC (%)	5.47a	4.00b	5.71a	3.96b	0.318	<.0001	0.865	0.837
pH, zero h	7.14	6.94	7.04	6.84	0.041	0.052	0.058	0.984
pH, 24 h	5.52	5.55	5.56	5.64	0.042	0.374	0.268	0.837
			Meat cuts					
LHCR	4.27b	7.32a	4.61b	7.07a	0.084	<.0001	0.780	0,093
Neck	0.48b	0.87a	0.55b	0.87a	0.009	<.0001	0.352	0.226
Shoulder	0.74b	1.29a	0.79b	1.21a	0.025	<.0001	0.398	0.127
Rib	0.62b	1.07a	0.67b	1.09a	0.017	<.0001	0.306	0.685
Saw	0.57b	1.10a	0.63b	1.00a	0.025	<.0001	0.745	0.150
Loin	0.41b	0.75a	0.44b	0.67a	0.010	<.0001	0.351	0.021
Leg	1.42b	2.29a	1.53b	2.24a	0.026	<.0001	0.454	0.210

TWG =Total weight gain; BWS = body weight at slaughter; EBW = empty body weight; HCW = hot carcass weight, CCW = cold carcass weight; HCY = hot carcass yield; CCY = cold carcass yield; STF = subcutaneous thickness fat; *Longissimus* muscle area (LMA); LC = loss by cooling; LHCR = left half-carcass reconstituted; SEM = standard error of the mean; Means followed by different lower-case letters in the line, considering the R:C ratio, differ ($p < 0.05$) by F test.

Different nutritional composition of the experimental diets may have influenced the results obtained in the current study. The higher NDF content and lower NFC content of the 80R: 20C diet (Table 1) may have influenced the intake of nutrients as observed by Leite et al. (2018), resulting in lower BWS (Table 1), compared to animals that received a higher concentrate content (40:60). According to Mertens (2002) and Van Soest (1994), high levels of NDF and ADF can cause physical limitation of the rumen and lower rate of passage, promoting the reduction of DM intake and digestibility of nutrients, justifying the result obtained for weight gain reflecting in lower BWS and consequently, in lower carcass characteristics of animals fed with this ratio (80R: 20C).

Although the LRC is rich in starch, supplementation (4.85%) made a small contribution, not influencing the quantitative and qualitative parameters analyzed compared to animals that did not receive LRC in the diet (Tables 3 to 6).

The EBW and CCW of sheep fed 80R: 20C can be explained by the lower response of protein and energy intake of animals in this treatment (Leite et al., 2018) resulting in lower BWS, reflecting in hot and cold carcass yields, as well as biological yield (BY).

The cooling losses (CL) found (3.96 to 5.71%), regardless of diet, showed results close to those recommended (4%) by Carrasco et al. (2009) (Table 3). The lower results obtained for the CL of animals fed with the 80R: 20C ratio are in agreement with the behaviors found for the subcutaneous fat thickness (STF), carcass finish, leg fat content, as well as for the meat's EE content (Tables 3, 4, 5 and 6), because the STF and the carcass finish are parameters that help to assess the level of protection of the carcass during cooling, Fat acts a protection, preventing moisture loss throughout the cooling process. It is also justified by the low EE content observed in the chemical analysis of the meat, showing lower fattening on the carcass. In addition, it is worth noting that the Santa Inês breed is considered to have low external lipid deposition in the carcass (Lima Júnior et al., 2016).

The animals that received the 40R: 60C ratio showed higher values for *Longissimus* muscle area (10.55 cm^2), and leg muscle content (69.2%) (Tables 3 and 5). Due to roughage:concentrate ratio higher energy density was shown (Table 2), mainly in function to the higher values of NFC and lower NDF, favoring the protein intake (172 g day^{-1}) and TDN intake (684 g day^{-1}), observed by Leite et al. (2018), providing a greater protein and energy supply, consequently promoting greater deposition of muscle mass in the carcasses. According to values close to those obtained by Urbano et al. (2015), these authors observed that lambs receiving 25% of LRC in replacement for corn presented 10.40 cm^2 for LMA.

The lower weights of meat cuts observed for sheep fed 80% roughage can be related to the lower intake of TDN (445 g day^{-1}) (Leite et al., 2018) and consequently lower BWS 24.33 kg). According to Costa et al. (2010), the efficiency of the use of nutrients for muscle development depends on the energy concentration of the diet (Tables 2 and 4). In addition, diets with a high fiber content cause a slow passage rate, influencing the intake and deposition of muscles in the carcass (Asadollahi, Erafanimajd, & Ponnampalam, 2017). Silva Sobrinho, Purcha, Kadim, and Yamamoto (2005) affirm that the yields of the main cuts (leg, loin, and shoulder) must be above 60%. In the present work, a yield of 59.41% was found, a value close to that recommended by these authors, reinforcing that the LRC did not influence the quality of the noble cuts.

Animals fed with the 40R: 60C ratio showed higher morphometric measurements and subjective carcass evaluations ($p < 0.05$) compared to those that received the 80R: 20C ratio, with the carcass compactness index (CCI), conformation, finishing, and perirenal fat, which were 6.98, 43.9, 37.0 and 47.3% higher, respectively (Table 4).

Table 4. Carcass morphometric measurements and subjective evaluations of lambs fed different roughage: concentrate (R: C) ratios associated with the liquid residue of cassava (LCR).

Item	Treatment				SEM	P-value		
	80:20	40:60	80:20 + LCR	40:60 + LRC		R:C	LCR	R:C x LCR
			Measurements, cm					
CCI, km cm^{-1}	0.157b	0.241a	0.159b	0.237a	0.507	<.0001	0.369	0.081
Thoracic width	20.20 b	22.25a	20.42b	21.87a	0.260	<.0001	0.878	0.568
Hind perimeter	49.63b	57.62a	50.45b	58.35a	0.837	<.0001	0.646	0.979
Hind width	19.20b	21.40a	18.90b	21.03a	0.220	<.0001	0.452	0.938
Leg length	35.70b	40.85a	38.45b	38.75a	0.483	<.0001	0.739	0.069
Leg perimeter	34.41b	39.30a	34.75b	38.80a	0.273	<.0001	0.447	0.884
Thoracic depth	24.60b	27.60a	25.75b	27.90a	0.439	<.0001	0.415	0.632
Thoracic perimeter	59.70b	68.50a	60.85b	68.35a	0.301	<.0001	0.412	0.288
			Subjective evaluations, points					
Conformation (1 to 5)	1.60b	2.75a	1.45b	2.80a	0.076	<.0001	0.900	0.262
Finishing (1 to5)	1.70b	2.85a	1.75b	2.80a	0.065	<.0001	0.627	0.871
Perirenal fat (1 to 3)	1.40b	2.70a	1.50b	2.80a	0.045	<.0001	0.288	1.000

SEM = standard error of the mean; CCI = carcass compactness index; Means followed by different lower-case letters in the line, considering the R:C ratio, differ ($p < 0.05$) by F test.

Higher weights of leg, muscles, fat, bone, and others tissues, as well as a higher muscle: fat and muscle: bone ratio was observed in lambs that received the 40R: 60C ratio in the diet ($p < 0.05$). Yields followed the same behavior, except for bone yield, which was higher for animals fed with the 80R: 20C ratio (Table 5).

As for the chemical composition of meat, there was a difference (p < 0.05) only for the ether extract, with higher values for animals fed with the ratio 40R: 60C (2.21 g 100 g^{-1}) compared to the ratio 80R: 20C (1.38 g 100g^{-1}, Table 6). However, the animals fed with the highest ratio of 80R: 20C showed higher values for redness (a*) (Table 6). The water-holding capacity (WHC) was influenced (p < 0.05) by the inclusion of the LRC and by the different roughage: concentrate ratios, observing greater losses (29.47%) for meat from animals fed with 40R: 60C and which did not receive LRC, compared to the other treatments (Table 6). The lightness (L*), yellowness (b*), and cooking losses (CL) were not influenced by the experimental diets (Table 6).

Table 5. Leg characteristics of lambs fed different roughage: concentrate (R: C) ratios associated with the liquid residue of cassava (LCR).

Item	Treatment				SEM	P-value		
	80:20	40:60	80:20 + LCR	40:60 + LCR		R:C	LCR	R:C x LCR
			Leg characteristics (g)					
Leg	1410.4b	2236.2a	1508.4b	2217.6a	24.863	<.0001	0.445	0.258
Muscle	912.6b	1504.2a	1090.4b	1492.0a	21.177	<.0001	0.067	0.287
Fat	64.4b	158.2a	85.6b	180.4a	8.170	<.0001	0.110	0.970
Bone	327.6b	437.6a	383.6b	438.4a	6.499	<.0001	0.063	0.149
Other tissues	32.2b	60.8a	26.2b	52.0a	2.454	<.0001	0.108	0.757
			Leg characteristics (%)					
Muscle	67.17	69.42	67.24	68.86	0.491	0.065	0.838	0.787
Fat	4.82b	7.24a	5.68b	8.32a	0.293	<.0001	0.130	0.865
Bone	24.15a	20.19b	26.88a	20.34b	0.356	<.0001	0.149	0.211
Other tissues	2.36b	2.80ª	1.74b	2.42a	0.111	<.0001	0.067	0.622
Relations								
M:B	2.81b	3.46ª	2.59b	3.43a	0.059	0.010	0.373	0.488
M:F	15.15a	10.15b	13.55a	8.62b	0.489	0.001	0.208	0.975

SEM = standard error of the mean; Means followed by different lower-case letters in the line, considering the R:C ratio, differ (p < 0.05) by F test; M:B = Muscle: Bone ration; M:F = Muscle: Fat ratio.

Table 6. Chemical composition, and *Longissimus lumborum* muscle physical-chemical parameters of lambs fed different roughage: concentrate (R: C) ratios associated with the liquid residue of cassava (LCR).

Item	Treatment				SEM	P-value		
	80:20	40:60	80:20 + LCR	40:60 + LCR		R:C	LRC	R:C x LRC
		Chemical composition						
Moisture, %	78.73	76.96	78.63	78.02	0.324	0.150	0.611	0.518
Crude Protein, %	15.47	16.19	15.06	15.66	0.284	0.286	0.527	0.872
Ether extract, %	1.52b	2.18a	1.34b	2.25a	0.078	<.0001	0.943	0.648
Ash, %	0.93	1.10	1.05	1.16	0.086	0.040	0.536	0.974
		Physical-chemical parameters						
L*	44.81	42.84	44.40	43.27	0.310	0.212	0.989	0.570
a*	15.29a	14.66b	16.02a	14.20b	0.160	0.003	0.736	0.132
b*	7.10	6.68	7.28	7.34	0.121	0.520	0.150	0.418
CL, %	27.16	27.59	26.10	25.98	0.073	0.123	0.222	0.232
WHC, %	25.28 b	29.47a	21.96 a	23.34b	0.126	0.013	<.001	0.200

SEM = standard error of the mean; L*= lightness; a*= redness; b*= yellowness; CL= cooking loss (g 100 g^{-1}); WHC = water holding capacity.

The average pH value (24 hours after slaughter) found (5.58) can be considered normal, indicating an adequate glycogen reserve, adequate lactic acid production, and pH decline, transforming the muscle into the meat. According to Della Malva et al. (2016) pH values between the range of 5.5 to 5.8 indicate the absence of pre-slaughter stress, consequently, not influencing the other parameters of meat quality (color, WHC, CL, and tenderness).

The higher ether extract (EE) value of the meat's observed in this treatment can be explained by the higher intake of TDN (Leite et al., 2018) and the consequent higher lipid deposition in the carcass and the meat.

The higher red (a*) content in the meat of animals fed with the 80R: 20C ratio indicates a higher muscle myoglobin content (Kilhiji, van de Ven, Lamb, Lanza, & Hopkins, 2010) (Table 6). However, the meat evaluated in the present study is within the range recommended by Sañudo et al. (2000). According to these authors the sheep meat presents a variation for lightness (L*) of 30.0 to 49.5 (versus 42.84 to 44.81 in this study), for the redness (a*) of 8.2 to 23.5 (versus 14.43 to 15.65 in this study), and yellowness (b*) of 7.01 to 11.1 (versus 6.68 to 7.34 in this study).

The lower water retention capacity of the meat of animals fed with a higher proportion of concentrate (40R: 60C) and LRC supplementation can be explained by the higher BWS of the animals related to higher lipid deposition in the carcass (Karaka, Erdogan, & Kor, 2016; Ricardo et al., 2015; Madruga et al., 2008).

Conclusion

The 40:60 roughage:concentrate (R:C) ratio improves the carcass traits and meat cuts, but does not promote changes in meat quality, regardless of supplementation with liquid residue of cassava, thus this residue can be used in the sheep diet.

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