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Physicochemical characteristics of lamb meat fed with cottonseed associated with calcium lignosulphonate

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ABSTRACT. The physicochemical characteristics of the meat from lambs fed diets containing whole or disintegrated cottonseed, associated or not with calcium lignosulfonate (LignoCaSO_3), were evaluated. Thirty non-castrated Dorper x Santa Inês lambs, with an average of 24.9 ± 3.6 kg and four months of age were confined for 60 days in collective stalls and distributed in a completely randomized design with six replications. After slaughter, by means of contrasts, the averages of the parameters of the semimembranous and semitendinosus muscles were analyzed. The cottonseed increased cooking loss and ash, and reduced muscle weight, water holding capacity and red intensity. The disintegration of the cottonseed reduced the shear force in diets without LignoCaSO_3, increased the protein and the loss by cooking and reduced the pH in the diets with the additive. The luminosity values increased with the disintegration of the cottonseed in diets with and without LignoCaSO_3. The addition of LignoCaSO_3 increased the weight of the muscle, protein, ash, pH, shear strength and the intensity of red. Moisture, lipids and yellow intensity were not influenced by the diets. Even changing the physical-chemical characteristics, the cottonseed with or without LignoCaSO_3 does not change the quality of the meat.

Keywords: Concentrate; feedlot; sheep; quality; semimembranosus; semitendinosus.

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Introduction

Sheep meat has beneficial properties for the human organism, especially when it comes from lambs. Thus, there is a potential for the expansion of the activity (Venturini et al., 2016), so that the increasing demand for quality sheep meat in the Brazilian market induces the intensification of this production system (Urbano et al., 2016).

The sheep confinement aims to increase productivity without damaging the quality of the meat (Moura Neto et al., 2014), however, it has a high cost. In order to reduce expenses with the components of the diets, the use of co-products from the regional agroindustry is indicated (Manera, Voltolini, Yamamoto, Araújo, & Souza, 2014), which increases the viability of the system (Borghi et al., 2016). Because it is a food containing protein of high biological value and energy content, cottonseed and its co-products are an interesting alternative to use in the confinement of lambs.

According to Carvalho et al. (2015), the use of confinement with high concentrate diets brings several advantages ranging from the lack of need for using an area for plantation crops to the reduction of labor. Rufino Júnior et al. (2015) observed that in the literature, there are no studies that have evaluated, so far, the inclusion of cottonseed in lamb diets composed only of concentrated foods.

Lignosulphonate is a binder additive that can be used to improve the physical characteristics of the diet (Khitrin, Fuks, Khitrin, Kazienkov, & Meteleva, 2012) and may act to reduce ruminal degradation of grain protein because it can protect the true protein from the action of ruminal microorganisms, increasing the concentration of non-degradable protein in the rumen (Petit et al., 2002). It also reduces the availability of lipids and protein for ruminal bacteria and, consequently, minimizes the negative effects of lipids on ruminal fermentation (Wernersbach Filho et al., 2006).

Therefore, the provision of high concentrate diets containing cottonseed, or their co-products treated with lignosulfonate for lambs finished in confinement can provide benefits to the production system and maintain the quality of the meat produced. In this way, the aim is to obtain quality sheep meat based on its physical-chemical characteristics, using diets containing a regional co-product, to reduce costs, and an additive that aims to improve digestive parameters.

Material and methods

The experiment was carried out in Guanambi-BA, located in the northeastern region of Brazil at 14°13' S and 42°46'51"W, with an average elevation of 525m.

Thirty F1 Dorper x Santa Inês male lambs, non-castrated, with a mean initial body weight of 24.9 ± 3.6 kg and four months of age were distributed in a completely randomized design and confined in collective stalls. The lambs were distributed in five treatments consisting of 100% concentrate diets, being four experimental diets and one control, with six replicates.

The experimental treatments corresponded to the following diets: whole cottonseed (CAI); disintegrated cottonseed (CAD); whole cottonseed with lignosulfonate (CAIL) 100 g kg^{-1} of cottonseed natural matter (MN); disintegrated cottonseed with lignosulfonate (CADL) 100 g kg^{-1} of cottonseed MN; and the control diet, elaborated without cottonseed (CONT). The diets were formulated (Table 1) as recommended by the National Research Council (NRC, 1985), supplied twice a day to meet the daily requirements for an average gain of 300g day^{-1}. The chemical composition of calcium lignosulfonate ($LignoCaSO_3$) is presented in Table 2.

The experiment lasted 60 days, being the first 12 of adaptation. The animal research was conducted in accordance with the institutional committee for animal use (protocol nº 042/2013). At the end of the experimental period, the lambs were slaughtered under veterinary inspection, according to the current regulations at the RIISPOA (Brazil, 1997). The semimembranosus (SM) and semitendinosus (ST) muscles were removed from the leg and immediately weighed. The determination of the physicochemical parameters occurred subsequently in the logical order of analysis.

For color determination, the Miniscan EZ colorimeter, Hunterlab Brand, Model 4500 L, was used through the CIELAB scale system L* (lightness), a* (redness) and b* (yellowness).

Table 1. Proportions, chemical-bromatological composition of diet ingredients.

Item	Experimental diets[1]				
	CONT	CAI	CAD	CAIL	CADL
	Proportions of ingredients (g kg^{-1} DM)				
Corn	680	580	580	580	580
Soybeanmeal	190	40	40	40	40
Cottonseed	--	340	340	340	340
Cotton pie	100	--	--	--	--
Urea	--	10	10	10	10
Vitamin-mineral premix[2]	30	30	30	30	30
	Chemical-bromatological composition				
Dry matter (g kg^{-1} NM)	877.7	885.5	885.3	884.2	877.2
Organic matter[3]	96.3	96.7	96.69	95.98	95.81
Protein[3]	180.4	182.6	168.8	171.5	168.0
Ethereal extract[3]	26.9	83.5	71.5	74.0	67.4
Neutral detergent fiber[3]	232.8	310.1	305.9	313.8	314.6
Acid detergent fiber[3]	108.0	157.7	141.8	134.6	154.6
Cellulose[3]	86.3	104.3	89.7	86.6	112.1
Hemicelullose[3]	124.8	152.5	164.0	179.0	160.0
Lignin[3]	21.6	53.4	52.1	48.0	42.5
Ash[3]	36.5	32.6	33.1	40.2	42.0

[1]CONT - Control diet; CAI - whole cottonseed; CAD - Disintegrated cottonseed; CAIL - Calcium lignosulfonate treated whole cottonseed (100 g kg^{-1}); CADL –Disintegrated cottonseed treated with calcium lignosulfonate (100 g kg^{-1}). Composition: (Purgante Saline UCB® - 16.7%; Vitamin Complex ADE powder - 16.7%; Mineral Supplement - 66.7%). [3]Values in g kg^{-1} DM.

For cooking loss (CL) analysis, the samples were weighed and cooked on a Quimis hot plate 0313F21, preheated at a temperature of 150°C. When internal temperature reached 75°C, heating was interrupted, and the samples were weighed again, at room temperature, for the percent calculation. Subsequently, for determination of the shear force (SF), the cooked samples were subjected to a cross-sectionedof the muscle fibers by the CT3 Texture Analyzer Brookfield texturometer of Braseq, with a Warner Bratzler blade. To classify the meat texture, the interpretation of Cezar and Sousa (2007) was used, in which the SF analysis classified it as tender (22.36 to 35.60 N), of intermediate tenderness (35.70 a 53.35 N), tough, and extremely tough (above 53.35 N).

Table 2. Chemical composition of calcium lignosulfonate.

Item	Calcium Lignosulfonate
Dry matter, %	100.0
Protein[1]	0.67
Neutral detergent fiber[1]	0.46
Acid detergent fiber[1]	2.01
Etherealextract[1]	0.25
Ash[1]	17.5
Calcium[1]	3.53
Total phosphorus[1]	0.02

[1]Dry matter values in %.

The water holding capacity (WHC) was calculated according to Nakamura and Katoh (1981), with a Centribrio centrifuge, in which one gram of ground sample was weighed in filter paper and placed in the centrifuge for 4 minutes at 1500 x G, after drying in an oven (70°C) for 12 hours. The WCR was then determined by the following formula: WHC % = (centrifuged sample weight – dry sample weight)/sample initial weight before centrifugation.

The pH determination was performed in triplicate, with the aid of a benchtop pH meter of the brand Quimis 0400MT.

The protein, moisture and ash contents were analyzed according to the Association of Official Analytical Chemists (AOAC, 2000) using samples ground in an electric mill.

Extraction of the lipid fraction was performed with a mixture of chloroform, methanol and water, respectively (2:2:1.8 v v v^{-1}), according to Bligh and Dyer (1959).

In other stages of the research project, some performance parameters that are worth mentioning and informing in this study (Table 3) were determined by specific methodologies.

Table 3. Performance of lambs fed high concentrate diets with cottonseed associated with calcium lignosulfonate.

Performance parameters	Diets					SEM	Contrasts	
	CONT	CAI	CAD	CAIL	CADL			
PC,g animal/day	143.5	83.4	123.0	173.9	137.6	10.783	ns	
LC,g animal/day	23.4	49,01	41.09	52.4	57.9	3.117	C3 (*)	C4 (*)
LWS, kg	39.5	36.7	34.2	40.4	36.8	0.981	ns	
HCW, kg	18.0	16.3	14.5	18.7	16.7	0.535	C1 (*)	

PC- Protein consumption; LC- Lipids consumption; LWS- Live weight at slaughter; HCW-Hot carcass weight; ns: non-significant contrast and (*) significant contrast at 5% probability level. CONT: Control diet without cottonseed in its formulation; CAI = Whole cottonseed; CAD = Disintegrated cottonseed; CAIL = Whole cottonseed treated with calcium lignosulfonate; CADL = Disintegrated cottonseed treated with calcium lignosulfonate; C1 (CONT vs CAI, CAD, CAIL, CADL); C2 (CAI, CAD vs. CAIL, CADL); C3 (CAI vs CAD) and C4 (CAIL vs CADL).

A split plot scheme in space was used, with the experimental diets (A_i) completely randomized into plots, and the muscle (B_j) and the interaction (AB_{ij}) in the subplots, with 5 replicates, as follows: $Yijk = \mu + Ai + \delta ik + Bj + (AB)ij + eijk$

The mean values obtained for the studied parameters of the SM and ST muscles were analyzed by the decomposition of sum of squares related to the use of cottonseed and calcium lignosulfonate by orthogonal contrasts (Table 4). Statistical procedures were performed using the (Statistical Analysis System [SAS], 2001) software, adopting 0.05 as the critical probability level.

Table 4. Distribution of the coefficients for the orthogonal contrasts used in the decomposition of the sum of squares.

Contrasts	Diets				CADL
	CONT	CAI	CAD	CAIL	
C1	+4	-1	-1	-1	-1
C2	0	+1	+1	-1	-1
C3	0	+1	-1	0	0
C4	0	0	0	+1	-1

CONT: Control diet without cottonseed in its formulation; CAI = Whole cottonseed; CAD = Disintegrated cottonseed; CAIL = Whole cottonseed treated with calcium lignosulfonate; CADL = Disintegrated cottonseed treated with calcium lignosulfonate; C1 (CONT vs CAI, CAD, CAIL, CADL); C2 (CAI, CAD vs. CAIL, CADL); C3 (CAI vs CAD) and C4 (CAIL vs CADL).

Results and discussion

No effect of the diets ($p > 0.05$) on the mean values of total lipids and moisture (Table 5) was observed. However, it was verified that among the mean values of the moisture of the muscles there was a significant difference ($p < 0.05$). All experimental diets presented lower MW mean values ($p < 0.05$) than the one in the CONT diet (CONT vs CAD, CAI, CAIL, CADL). The diets with $LignoCaSO_3$ addition resulted in higher MW mean values compared to the ones of the diets without the additive (CAI, CAD vs CAIL, CADL). There was significance ($p < 0.05$) between the mean values of muscle weight.

The lower muscle weight (MW) values of the experimental diets (Table 5), in relation to the control diet, are due to the fact that the absolute weight of the carcass decreased in the same way in the respective treatments (Table 3), which directly reflected the muscle weight contained in it. The higher MW values of the diets with the addition of $LignoCaSO_3$ were due to the chemical and structural alterations that the additive may have caused in the diets, improving the use of the protein fraction, resulting in a greater deposition of muscle tissue.

The ST was 17.50% heavier than the SM ($p < 0.05$). The maintenance in confinement and the early age of the animals in the present study may justify the smaller weight difference between the muscles.

Table 5. Weight and chemical composition of semimembranosus (SM) and semitendinosus (ST) muscles of lambs fed with high concentrate diets containing whole or disintegrated cottonseed, treated or not with calcium lignosulfonate.

Parameter	Muscles	Diets								Pr>F		
		CONT	CAI	CAD	CAIL	CADL	Mean	SEM	Contrasts	Diet	Muscle	Diet x Muscle
Muscle weight (kg)	SM	0.127	0.110	0.095	0.125	0.117	0.115	0.01	C1 (*)	0.0018	0.0014	0.9824
	ST	0.142	0.125	0.115	0.134	0.132	0.130	0.01				
	Mean	0.134	0.118	0.105	0.131	0.124	0.122		C2 (*)			
	SEM	0.01	0.01	0.01	0.01	0.01						
Moisture (%)	SM	68.91	68.09	69.69	70.32	68.47	69.10	0.56	ns	0.1023	0.0002	0.9281
	ST	70.81	70.53	71.50	72.99	71.64	71.49	0.35				
	Mean	69.86	69.31	70.59	71.65	70.05	70.29					
	SEM	0.91	0.53	1.08	0.69	0.73						
Protein (%)	SM	18.50	18.00	18.12	18.54	21.02	18.84	0.50	C2 (*)	0.0362	0.6500	0.9150
	ST	16.93	18.43	17.71	18.41	21.09	18.52	0.47				
	Mean	17.72	18.22	17.92	18.48	21.06	18.68		C4 (*)			
	SEM	0.55	0.69	0.44	0.28	1.35						
Lipids (%)	SM	5.52	4.85	4.24	4.02	4.44	4.61	0.32	ns	0.8424	0.1055	0.3192
	ST	3.22	4.37	3.73	4.13	4.38	3.96	0.23				
	Mean	4.37	4.61	3.98	4.07	4.41	4.29					
	SEM	0.62	0.50	0.39	0.36	0.38						
Ash (%)	SM	1.10	1.15	1.10	1.34	1.29	1.20	0.03	C1 (*)	<0.001	<0.001	0.9173
	ST	0.97	1.05	1.00	1.15	1.17	1.07	0.02				
	Mean	1.04	1.10	1.05	1.25	1.23	1.13		C2 (*)			
	SEM	0.03	0.04	0.03	0.07	0.04						

CONT: Control diet without cottonseed in its formulation; CAI = Whole cottonseed; CAD = Disintegrated cottonseed; CAIL = Whole cottonseed treated with calcium lignosulfonate; CADL = Disintegrated cottonseed treated with calcium lignosulfonate; SEM = Standard error of the mean; Pr> F - probability obtained from the study of plot subdivided in space; ns: non-significant contrast and (*) significant contrast at 5% probability level. C1 (CONT vs CAI, CAD, CAIL, CADL); C2 (CAI, CAD vs. CAIL, CADL); C3 (CAI vs CAD) and C4 (CAIL vs CADL). N = 30.

The muscles moisture was not influenced by the diets ($p > 0.05$), resulting in a mean value of 70.29%, which was close to the ones reported by Homem Júnior et al. (2015), that when evaluating different sources of lipids in Santa Inês x Dorper lambs, found moisture content ranging from 72.3 to 73.6%. Farias et al. (2015) also found no effect of the diet on the percentages of meat moisture, when evaluating the characteristics of the carcasses and meat quality of crossbred Suffolk lambs fed diets containing protected lipid. It was verified that between the mean values of the muscles there is a significant difference ($p < 0.05$), the ST muscle having the highest mean moisture, which is justified by its greater motor function.

For the protein, there was no difference between the CONT diet and the experimental diets, however, a significant effect ($p < 0.05$) was observed among the mean values of the experimental diets. There was superiority in the mean values of protein in the diets with the addition of $LignoCaSO_3$ over the other experimental diets. Through interpretation of the contrasts, it was found that the disintegration of cottonseed with the addition of $LignoCaSO_3$ (CAIL vs CADL) provided a higher deposition of protein.

The superiority of the protein values in the diets with the addition of $LignoCaSO_3$ on the other experimental diets confirms what was expected as a function of the higher MW mean values. This effect can be attributed to the action of LignoCaSO$_3$which possibly caused the reduction of ruminal degradation and a greater protein absorption by the animals through the improvement of enzyme activity in the intestine, increasing digestibility of true protein. The disintegration of cottonseed with the addition of LignoCaSO$_3$ resulted in a greater deposition of protein in the muscles, probably due to the greater availability of this nutrient for intestinal absorption, and consequently a greater partition of this nutrient for muscle deposition.

The protein mean values found for the four experimental diets ranged from 17.92 to 21.06%, close to those reported by Senegalhe, Burin, Fuzikawa, Penha, and Leonardo (2014), who obtained protein mean values of 22.72% for ½ Dorper x Santa Inês lambs, considered within the normal parameters and of good nutritional quality.

Lipids have a significant role in some desirable sensory attributes such as tenderness and succulence of the meat, and the maintenance of similar lipids levels between control and experimental diets leads to the assumption that all the obtained meats are within the normal standards. The lipids mean values ranged from 3.68 to 4.02% and are close to those reported by Leão et al. (2011), when evaluating the nutritional characteristics of the meat of lambs finished in confinement with diets containing sugarcane or corn silage in two bulky÷concentrate ratios (60:40 or 40:60). The variation in protein levels and the absence of variation in the lipids indicate that, because they are young animals, the nutrients ingested were destined to the formation of muscle tissue and not to the deposition of lipids.

Contrasting the CONT diet with the experimental diets, it was verified that the addition of cottonseed to the diet of lambs promotes a greater ($p < 0.05$) deposition of ash. The addition of LignoCaSO$_3$ to any of the physical forms of the cottonseed further accentuates the ash deposition, when compared to the diets without LignoCaSO$_3$.

The cottonseed peel presents itself as a source of macrominerals, with emphasis on the phosphorus, calcium and sulfur contents (Silva, Sousa, Silva Neta, Inácio, & Muniz, 2013), which may justify the greater deposition of ash found in the muscles of the animals that were fed with the experimental diets. The accentuation of the deposition of minerals to the muscles by the addition of LignoCaSO$_3$ is due to the composition of this additive (Table 2), which promoted a substantial increase of minerals to the diets that contained it. The average contents of ash ranged from 1.04 to 1.25% (mean of 1.13%), similar to those found by Menezes Junior et al. (2014) and considered within the expected values for lamb meat. The difference between the ash mean values in the muscles is probably related to the different muscle functions and activities.

The absence of significant differences for some of the chemical parameters of sheep meat, especially lipids, can be attributed to the short confinement period (60 days) and the live weight at slaughter (Table 3), which were not sufficient for lipids deposition, especially intramuscularly, not allowing the lambs to reach physiological maturity.

For the pH values, no differences were observed between the mean values of the CONT diet and the experimental diets, however, differences ($p < 0.05$) were found between the mean pH values of the experimental diets (Table 6). The addition of LignoCaSO$_3$ to the CAI or CAD diets promoted an increase in the pH of the meat. There was also a significant difference ($p < 0.05$) between the mean values of the SM and ST muscles. This study did not aim to determine which diets promoted higher or lower pH values, but to demonstrate those that presented ideal pH providing high quality meat.

The pH values, even if different between diets and muscles, are satisfactory since no factors that could disqualify them for quality parameters were found (Table 6). The pH values are within the standard parameters for lamb meat, as recently reported in the literature (Rego et al., 2019, Mora et al., 2015, Farias et al., 2015).

For the shear force (SF), the experimental diets did not differ from the CONT, but the contrasts showed that there wasa difference ($p < 0.05$) between the mean values of the experimental diets. The addition of LignoCaSO$_3$ promoted increases in the SF, therefore a less tender meat. The disintegration of cottonseed promoted a reduction in the SF among the mean values of the diets without LignoCaSO$_3$ (CAI vs CAD).

Although the animals were conditioned to produce less tender meat, the inclusion of LignoCaSO$_3$ in the diet containing CAI or CAD kept the average SF values close to those considered desirable, probably due to the interactions between the collagen and fat deposition rates in animal muscle. The disintegration of SC facilitated the digestion of the fiber present in the shell and resulted in the production of a softer flesh.

According to the method used to classify meat texture (Cezar & Sousa, 2007), the mean value obtained for the different diets (44.33 N) characterizes a meat of intermediate tenderness. The acceptable values of tenderness found in this study can be explained by the fact that the animals remained in confinement during the whole experimental period and because they were slaughtered at an age suitable for the production of less tough meat.

Table 6. Physicochemical parameters of semimembranosus (SM) and semitendinosus (ST) muscles of lambs fed diets with high concentrate containing whole or disintegrated cottonseed, treated or not with calcium lignosulfonate.

Parameter	Muscles	Diets								Pr>F		
		CONT	CAI	CAD	CAIL	CADL	Mean	SEM	Contrasts	Diet	Muscle	Diet x Muscle
pH	SM	5.77	5.59	5.66	5.94	5.79	5.75	0.05	C2 (*)	<0.001	0.0024	0.7257
	ST	5.87	5.72	5.81	5.97	5.87	5.85	0.04				
	Mean	5.82	5.65	5.74	5.96	5.83	5.80		C4 (*)			
	SEM	0.06	0.04	0.11	0.08	0.03						
Shear force (N)	SM	43.25	42.66	32.17	54.13	55.60	45.60	0.33	C2 (*) C3 (*)	0.0062	0.5036	0.7277
	ST	45.11	48.25	26.87	47.86	47.37	43.05	0.32				
	Mean	44.13	45.50	29.52	50.99	51.58	44.33					
	SEM	0.52	0.44	0.23	0.52	0.56						
Water holding capacity (%)	SM	48.10	43.77	44.99	41.89	46.31	45.01	0.94	C1 (*)	0.0203	0.0039	0.3785
	ST	49.24	45.87	47.24	47.52	47.58	47.49	0.52				
	Mean	48.67	44.82	46.11	44.70	46.94	46.25					
	SEM	0.60	1.56	0.90	1.47	1.25						
Cooking loss (g)	SM	30.48	33.60	36.84	33.57	33.32	33.56	0.76	C1 (*)	<0.001	0.0975	0.0473
	ST	29.49	29.77	35.46	29.70	36.65	32.21	1.00	C3 (*)			
	Mean	29.99	31.69	36.15	31.64	34.99	32.89					
	SEM	1.16	1.91	1.04	0.69	1.30			C4 (*)(**)			

CONT: Diet control without cottonseed in its formulation; CAI = Whole cottonseed; CAD = Disintegrated cottonseed; CAIL = Whole cottonseed treated with calcium lignosulfonate; CADL = Disintegrated cottonseed treated with calcium lignosulfonate; SEM = Standard error of the mean; Pr> F - probability obtained from the study of plot subdivided in space; ns: non-significant contrast, (*) significant contrast at 5% probability level, and (**) significant contrast for the diet interaction in ST muscle. C1 (CONT vs CAI, CAD, CAIL, CADL); C2 (CAI, CAD vs. CAIL, CADL); C3 (CAI vs CAD) and C4 (CAIL vs CADL). N = 30.

The CONT diet provided a higher mean water holding capacity (WHC) value ($p < 0.05$) in contrast to the experimental diets. A statistical difference for WHC was also observed between the mean values of muscles. The increase in proprionate, which is the main source of glucose for ruminants, inside the rumen occurs by increasing the amount of non-fibrous carbohydrates present mainly in concentrates, which can influence the drop in pH when establishing rigor mortis. Thus, the denaturation and loss of solubility of proteins increases negative charges, which do not attract water, reducing WHC. Therefore, higher WHC values are obtained with diets with higher amounts of non-fibrous carbohydrates.

Generally, lower WHC values are associated with lower fat content in the flesh. However, the WHC variation in this study cannot be attributed to the fat present in the muscles of the animals, since this trait did not change as a result of the diets. It is observed in this study that the inclusion of cottonseed, regardless of its physical form, results in muscles with lower WHC. Vieira et al. (2010), when evaluating the effect of termination diets containing different levels (0, 20, 30 and 40%) of the cottonseed identified in absolute terms the reduction of WHC lamb meat with the highest level of inclusion of cottonseed.

The SM muscle has a lower WHC compared to the ST muscle, which is directly related to the lower percentage of SM moisture in relation to ST (Table 5).

The experimental diets promoted an increase in cooking loss (CL) ($p < 0.05$) when compared to the control diet. When comparing the mean values of the CAI diets with the ones of the diets with CAD (CAI vs CAD and CAIL vs CADL) it was noted that the cottonseed disintegration process promotes increases in CL. There was also an effect of the diet x muscle interaction ($p < 0.05$), where even though there was no difference between the mean values of the muscles ($p > 0.05$), there was a difference in the mean values of the muscles within the diets. The unfolding of the mean values and contrasts made it possible to observe that the disintegration of cottonseed in the diets with $LignoCaSO_3$ addition increased the CL of the ST muscle.

According to Menezes Junior et al. (2014), the highest fiber content in the diet is related to meat with higher CL values. This way, it is possible to attribute the increase of the CL in the meat of the animals that received the experimental diets to the increase of the fiber contents of the diets resulting from the presence of cottonseed. It was noted that the cottonseed disintegration process promotes increases in the CL, probably due to the greater availability of the fiber present in the peel. The parameter that varied and may be related to the differences between the characteristic of CL among the diets is the percentage of protein. It is possible that the cooking process may have promoted the denaturation of proteins and led to greater weight losses during the heating process.

Among the coloring parameters (Table 7), only b* was not affected by the diets ($p > 0.05$). For the mean values of the muscle, variation of b* ($p < 0.05$) was observed.

Table 7. Coloring of semimembranosus (SM) and semitendinosus (ST) muscles of lambs fed diets with high concentrate containing whole or disintegrated cottonseed, treated or not with calcium lignosulfonate.

Parameter	Muscles	Diets								Pr>F		
		CONT	CAI	CAD	CAIL	CADL	Mean	SEM	Contrasts	Diet	Muscle	Diet x Muscle
L*	SM	42.16	40.68	43.86	38.43	45.35	42.10	0.71	C3 (*)	0.0025	0.3428	0.0060
	ST	42.38	39.80	42.75	44.59	44.11	42.73	0.85				
	Mean	42.27	40.24	43.31	41.51	44.73	42.41		C4 (*)(**)			
	SEM	1.04	0.88	0.82	1.77	1.17						
a*	SM	11.09	7.93	8.54	9.18	10.37	9.42	0.34	C1 (*)	0.0015	<0.001	0.7329
	ST	7.95	6.10	6.52	6.73	7.36	6.93	0.38				
	Mean	9.52	7.02	7.53	7.95	8.87	8.18		C2 (*)			
	SEM	0.88	0.50	0.68	0.42	0.65						
b*	SM	6.60	7.74	6.60	6.67	6.75	6.88	0.32	ns	0.4982	<0.001	0.9755
	ST	4.94	5.40	4.37	4.61	4.23	4.71	0.22				
	Mean	5.77	6.57	5.49	5.64	5.50	5.79					
	SEM	0.32	0.48	0.57	0.77	0.45						

L* = percentage of reflectance or lightness; a* = variation of color red to green; b* = variation of color yellow to blue. Parameters according to the International Commission L'Eclairage - CIE L*a*b*;. CONT: Diet control without cottonseed in its formulation; CAI = Whole cottonseed; CAD = Disintegrated cottonseed; CAIL = Whole cottonseed treated with calcium lignosulfonate; CADL = Disintegrated cottonseed treated with calcium lignosulfonate; SEM = Standard error of the mean; Pr> F - probability obtained from the study of plot subdivided in space; ns: non-significant contrast, (*) significant contrast at 5% probability level, and (**) significant contrast to the diet interaction in SM muscle. C1 (CONT vs CAI, CAD, CAIL, CADL); C2 (CAI, CAD vs. CAIL, CADL); C3 (CAI vs CAD) and C4 (CAIL vs CADL). N = 30.

The contrasts did not express L* differences between the CONT diet and the experimental ones. However, the physical form of the cottonseed interfered ($p < 0.05$) in the mean values of L*, with the highest values being found in the diets with CAD. The L* presented no difference between the means of the muscles ($p > 0.05$), but it was significant for the diet x muscle interaction, which means that even though they did not differ, the muscles showed significant differences individually in the diets. The unfolding of the mean values and contrasts made it possible to identify that among the diets containing $LignoCaSO_3$ the disintegration of the cottonseed promoted an increase of the L* of the SM muscle.

The similarity of the L* values between the CONT and the experimental diets is due to the fact that the percentages of moisture also remained unchanged, because the greater the presence of water in the animal meat, the more reflected is the light, thus increasing the value of L*.

According to Rech et al. (2014), several factors can influence the color of the meat, being among them the pigment contents of the food. In this regard, by observing the contrasts that compare the physical forms of cottonseed, it was noted that cottonseed disintegration made some pigment compounds more available for absorption and subsequent deposition in the muscles, influencing the variations of the mean values of L* between the experimental diets.

The pH acts directly on the meat color, and when a reduction in the amount of muscle glycogen occurs, it results in a high pH level (close to or above 6.0). Thus, an increase in oxygen consumption may increase the concentration of deoxygenated myoglobin, resulting in dark-colored meats. This behavior was observed when the mean values of the diets with $LignoCaSO_3$ addition (CAIL vs CADL) were compared since the CAIL presented a higher pH in comparison to the CADL, and darker meat. This argument is corroborated by Calnan, Jacob, Pethick, and Gardner (2014), who stated that high pH values in the *Longissimus dorsi* muscle drastically reduced the light reflectance index, darkening the lamb meat as a consequence of the reduction of the oxygen capacity to penetrate the surface of the muscle.

The unfolding of the mean values and contrasts made it possible to identify that, among the diets containing calcium lignosulfonate (CAIL vs CADL), the disintegration of cottonseed resulted in an increase in SM L*.

The addition of cottonseed promoted a reduction of a* mean values ($p < 0.05$). When comparing the mean values of the diets with or without $LignoCaSO_3$, it is verified that the additive promotes an increase in the a* values. Statistical difference of a* between the SM and ST muscle mean values was also identified.

As the animals in the present study were slaughtered at the same average age and finished in confinement, the inclusion of cottonseed was not expected to influence the a* of the meat of the animals, since this characteristic is influenced by the amount of myoglobin present in animal muscle, which in turn is influenced by age or production system (Juárez et al., 2009; Lima Júnior et al., 2016). In the present study, it was observed that the a* values of the muscles of the animals that received the experimental diets were lower than those observed in the control group. The observed changes may have occurred due to the presence of some component present in the cottonseed that resulted in lower reflectivity of the red pigments in the evaluated muscle meat.

$LignoCaSO_3$ increased a* values, compared to diets without the additive, probably due to increased protein deposition, which proportionally increased myoglobin deposition. The difference in a* between muscles can be attributed to differences in anatomical functionality. According to Silva, Palezi, and Carli (2014), the greater the muscle activity, the higher the myoglobin content and the darker the meat; thus, the highest mean of a* can be attributed to the SM muscle due to its higher activity.

The absence of effect of the diets on lipids content may have favored the absence of difference observed in b*, since, according to Rech et al. (2014), b* can be affected by subcutaneous and intramuscular lipid content.

According to Fernandes, Orrico Junior, Orrico, Vargas Junior, and Oliveira (2011), b* can be influenced by both the lipid concentration and the ingestion of carotenoid pigments contained in the diet. The animals in this study received all diets rich in energy and carotenoids, which may have acted on b* and maintained their similar values. The difference in the deposition of yellow pigments between the evaluated muscles may have also been due to the difference in function, anatomical location and muscular activity.

The pH is the main indicator of the final quality of the meat (Gomide, Ramos, & Fontes, 2013). As this parameter was not influenced by the inclusion of cottonseed, varied according to the physical form of the cottonseed and the presence of $LignoCaSO_3$, and remained within the acceptable values for meat considered good quality, it corroborates with the values considered acceptable for SF, WHC, CL and color, since the pH influences these characteristics.

Conclusion

The inclusion of whole or crumbled cottonseed with or without calcium lignosulphonate in the diet of feedlot lambs changes the physical and chemical properties of the meat, but does not negatively affect it.

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