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Cottonseed cake in substitution of soybean meal in diets for finishing lambs

Rosani Valéria Marcelina Matoso Silva[a], Gleidson Giordano Pinto de Carvalho[a,*], Aureliano José Vieira Pires[b], Mara Lúcia Alburquerque Pereira[b], Luana Pereira[a], Fleming Sena Campos[a], Alexandre Fernandes Perazzo[a], Maria Leonor Gomes Melo Lopes de Araújo[a], Camila de Oliveira Nascimento[a], Stefanie Alvarenga Santos[a], Manuela Silva Libânio Tosto[a], Luana Marta de Almeida Rufino[a], Bruna Mara Aparecida de Carvalho[c]

[a] Federal University of Bahia, School of Veterinary Medicine and Animal Science, Animal Production Department, Salvador, Bahia, 40170-110, Brazil
[b] Southwest State University of Bahia, Rural and Animal Technology Department, Itapetinga, Bahia, 45700-000, Brazil
[c] Federal University of Minas Gerais, Agricultural Sciences Institute, Montes Claros, Minas Gerais, 39400-000, Brazil

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ABSTRACT

The objective of this study was to evaluate nutrient intake, diet digestibility, performance and carcass characteristics of Santa Inês crossbred lambs fed diets cottonseed cake in substitution of soybean meal. Forty Santa Inês × Dorper crossbred noncastrated rams with average initial weight of 20.9 ± 2.5 kg were distributed in a completely randomized design with four treatments and ten replicates. The diets were composed of Tifton 85 (*Cyndon dactylon* cv. Tifton-85) hay as roughage and cottonseed cake replacing 0, 33, 66 and 100% of soybean meal, in a roughage-to-concentrate ratio of 50:50. At the end of the experiment, the lambs were slaughtered and their carcasses were evaluated. Except for crude protein and ether extract, overall, the digestibility coefficients of the nutrients decreased linearly ($P < 0.05$) as the levels of cottonseed cake in the diets were elevated. The cottonseed cake levels in substitution of soybean meal also did not affect final body weight, daily weight gain and total weight gain of the lambs ($P > 0.05$). The qualitative and quantitative carcass characteristics did not differ ($P > 0.05$) among the levels of cottonseed cake in substitution of soybean meal. Although the hot and cold carcass yields decreased ($P < 0.05$) as the cottonseed cake increased its participation in the diet, these variables remained within the levels considered satisfactory. Cottonseed cake can replace up to 100% of soybean meal in the concentrate, which corresponds to 12% of the total diet for lambs, representing an important food alternative to substitute soybean meal.

1. Introduction

Studies have proven that some byproducts from biodiesel production may contain satisfactory protein and energy levels, which meet the requirements of animals and which can replace commonly utilized ingredients, such as soybean meal (Abdalla et al., 2008; Ward et al., 2008; Nicory et al., 2015; Silva et al., 2015).

Cottonseed meal is a by-product already used in ruminant feeding. According to NRC (2001), soybean meal can be replaced by cottonseed meal in ruminant diets without major performance losses, provided that the nutritional requirements are maintained. The great novelty of the present work is the use of cottonseed cake in total substitution of soybean meal, since the cake still little studied in concentrates for ruminants.

The cottonseed cake is a by-product from the biodiesel industry obtained through the extraction of the oil contained in the cottonseed, by pressing. One of the most remarkable characteristics of cakes obtained from biodiesel production is their chemical heterogeneity, which may vary according to the species and/or cultivar, the extraction methods used (chemical or mechanical), and the efficiency of processing (Oliveira et al., 2012).

The cottonseed cake has a high nutritional value, particularly in terms of protein (20–46%) (Ramachandran et al., 2006; Abdalla et al., 2008; Kanyinji and Sichangwa, 2014), ether extract (5.4–14.1)

* Corresponding author.
E-mail address: gleidsongiordano@yahoo.com.br (G.G.P.d. Carvalho).

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Table 1
Chemical composition of ingredients in experimental diets (%DM).

Nutritional component	Tifton-85 hay	Ground corn	Soybean meal	Cottonseed cake
Dry matter[a]	91.2	88.7	90.2	92.6
Organic matter	84.4	87.2	82.9	87.7
Crude protein	5.0	6.4	39.0	24.0
Ether extract	1.4	4.5	1.9	7.6
Neutral detergent fiber (NDF)[b]	72.2	12.0	15.6	44.3
Indigestible NDF	15.1	14.3	1.0	15.0
Acid detergent fiber	40.2	4.8	11.1	33.3
Cellulose	34.7	3.7	10.9	22.7
Hemicellulose	31.9	7.8	4.4	11.0
Lignin	5.5	0.5	0.3	10.6
Non-fibrous carbohydrates	14.7	75.6	36.2	19.2
Total digestible nutrients	56.2	87.2	78.7	65.0

[a] %Of fresh matter.
[b] Corrected for ash and protein.

(Jabbar et al., 2006), and neutral detergent fiber (13.3–32.5) (Pousga et al., 2007) contents.

Our hypothesis is that cottonseed cake can replace up to 100% soybean meal in diets for lambs in feedlot. Thus, the aim of this study was to evaluate the nutritional and growth performance and carcass characteristics of feedlot lambs fed diets containing cottonseed cake replacing soybean meal.

2. Material and methods

The experiment was conducted on the Experimental Farm of São Gonçalo dos Campos, at the Federal University of Bahia (12°23′49.5″S, 38°52′43.5″W), from July to September 2011. The experimental site is characterized by average annual temperature of 26 °C, 85% relative humidity, and annual precipitation of approximately 1200 mm.

Forty Santa Inês × Dorper crossbred, noncastrated males with initial body weight of 20.9 ± 2.5 kg (mean ± SD) were distributed in a completely randomized design with ten replicates per treatment, and housed in individual pens with slatted floor provided with feeding and drinking troughs.

The diets, formulated based on the NRC (2007) for 4-month-old, late-maturing lambs at 0.3% of maturity weight, for an average daily gain of 200 g and supplied as a complete mix, were composed of corn, soybean meal, mineral supplement, urea; and cottonseed cake (Table 1) substituting 0, 33, 66 and 100% of the soybean meal, corresponding to 0, 40, 80 and 120 g of cottonseed cake per kg of diet, respectively (Table 2). The roughage used was hay of Tifton 85 (*Cynodon* sp) grass, at a roughage-to-concentrate ratio of 50:50. Diets were iso-nitrogenous (14% crude protein on a dry matter basis) to meet the nutritional requirements of growing lambs. The experimental assay lasted 99 days, and was preceded by a 15-day adaptation period, during which vaccination, deworming, management, and diet adaptation procedures were performed. The animals were weighed after the 15 days of adaptation, and at the end of every 28-day period. Feed conversion was calculated as the ratio between intake and average daily gain (ADG) during the experiment. Lambs were fed twice daily, at 7:00 and 16:00 h. Feed and orts were weighted every day. The amount of feed was adjusted daily to allow between 10 and 20% as orts to ensure ad libitum intake conditions.

The individual intake of the lambs was assessed throughout the 84 days of experiment. Samples of the ingredients, diets provided, and orts were collected for analysis of dry matter (DM; Method 967.03—Association of Official Analytical Chemists (AOAC, 1990), organic matter (OM; Method 942.05—AOAC, 1990), crude protein

Table 2
Proportions and chemical composition of experimental diets.

Ingredient	Level of cottonseed cake in substitution of soybean meal (% of dietary DM)			
	0	33	66	100
Cottonseed cake	0.0	4.0	8.0	12.0
Minerals	1.5	1.5	1.5	1.5
Soybean meal	12.0	8.0	4.0	0.0
Ground corn	34.9	34.7	34.5	34.3
Urea	1.6	1.8	2.0	2.2
Tifton-85 hay	50.0	50.0	50.0	50.0
Item (% of dietary DM)	Chemical composition of experimental diets			
Dry matter[a]	87.4	87.3	87.2	87.1
Organic matter	82.6	82.6	82.6	82.6
Crude protein	13.7	13.7	13.6	13.6
Ether extract	2.5	2.7	2.9	3.1
Neutral detergent fiber (NDF)[b]	42.1	43.3	44.4	45.5
Indigestible NDF	22.9	23.8	24.7	25.5
Acid detergent fiber	9.8	10.4	11.1	11.7
Cellulose	19.9	20.4	20.9	21.3
Hemicellulose	19.2	19.5	19.7	20.0
Lignin	3,0	3.4	3.7	4.2
Non-fibrous carbohydrates	39.7	38.9	38.1	37.2
Total digestible nutrients	69.2	69.4	63.5	65.0
Gossypol content[c]	–	340	680	1020

[a] g/kg Of fresh matter.
[b] Corrected for ash and protein.
[c] Parts per million (ppm).

Table 3
Intakes of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE) neutral detergent fiber corrected for ash and protein (NDFap), non-fibrous carbohydrates (NFC), total digestible nutrients (TDN), and metabolizable energy (ME) according to the inclusion of cottonseed cake in the diets.

	Level of cottonseed cake in substitution of soybean meal (% of dietary DM)				SEM[a]	P-value
	0	33	66	100		
	Intake (kg/day)					
DM	1.14	1.13	1.16	1.16	0.022	0.72
OM	1.07	1.06	1.08	1.09	0.020	0.73
CP	0.17	0.17	0.17	0.17	0.003	0.85
EE	0.03	0.03	0.03	0.03	0.001	0.01
NDFap	0.44	0.43	0.45	0.46	0.009	0.20
NFC	0.50	0.50	0.49	0.48	0.009	0.60
TDN	0.66	0.71	0.62	0.69	0.004	0.08
ME (Mcal/d)	2.18	2.37	2.14	2.07	0.183	0.08
	Intake (% $BW^{0.75}$)					
DM	7.6	7.7	7.7	7.8	0.752	0.43
	Intake (% BW)					
DM	3.1	3.1	3.1	3.2	0.260	0.33
NDFap	1.2	1.2	1.2	1.3	0.100	<0.01

[a] standard error of the mean.

(CP; Method 981.10—AOAC, 1990), and ether extract (EE; Method 920.29—AOAC, 1990), and lignin (Gomes et al., 2011), in which the ADF residue was treated with 72% sulfuric acid. Neutral detergent fiber (NDF) was obtained according to Mertens (2002) recommendations, and corrections for protein contaminants and ash were carried out as described by Licitra et al. (1996) and Mertens (2002), respectively. The concentration of non-fibrous carbohydrates (NFC) was obtained according to Detmann and Valadares Filho (2010). The TDN of diet was initially in accordance with the estimation equation described in NRC (2001).

To evaluate the iNDF (indigestible neutral detergent fiber) fraction, pre-dried composite samples of ingredients and experimental diets were ground through a 2-mm sieve and packed individually in TNT (nonwoven fabric) bags with a surface ratio of 20 mg DM cm^{2-1}. The bags were subsequently incubated for 240 h (Casali et al., 2008).

The gossypol content in the cottonseed cake used in the experiment was analyzed at the Center for Chromatographic Studies and Analyses (CEACRON, *Centro de Estudos e Análises Cromatográficas*), at the Southwest State University of Bahia (UESB), Itapetininga campus, BA, Brazil, according to the methodology of Ribani et al. (2004).

The digestibility coefficients of DM, OM, CP, EE, NDF, NFC and TDN were obtained by the method of total feces collection. Composite samples were conditioned in labeled plastic bags and stored in a freezer at −20 °C for further analysis. To calculate the digestibility, samples of the feed supplied, leftovers and feces were collected in the same period.

Once the fecal excretion of dry matter was determined, the apparent digestibility coefficients (DC) of the other nutritional components were calculated by dividing the amount of nutrient ingested and its respective fecal excretion, and the result was multiplied by 100. The total digestible nutrient concentration (%) was calculated based on the equations of Weiss (1999): TDN = DCP + 2.25 × DEE + DNFC + DNDF, in which DCP, DEE, DNFC and DNDF represent the digestible fractions of crude protein, ether extract, non-fibrous carbohydrates, and neutral detergent fiber, respectively.

At 99 days of confinement, the animals were slaughtered according to the current norms of the Normative Instruction of the Ministry of Agriculture and Food Supply—Agriculture Defense Department of Brazil, and their carcasses were trimmed and weighed to determine the hot carcass weight.

Lambs were slaughtered in a commercial abattoir and the following data were recorded: body weight at slaughter (BWS), hot carcass weight (HCW), cold carcass weight (CCW), cooling losses (CL), hot dressing percentage (HDP) and cold dressing percentage (CDP).

Adopting the methodology described by Osório et al. (1998), the following morphometric measurements of the carcass were evaluated: carcass length, leg length, leg depth, leg width, and chest depth. All measurements of length and height were taken using a tape measure, whereas the width and depth were obtained with the aid of a compass, whose registered opening was measured with a ruler.

The carcasses were divided longitudinally into two half carcasses, and the left half carcass was sectioned into five anatomical regions: neck, shoulder, ribs, loin and leg. As they were obtained, the commercial cuts were weighed individually. Afterwards, the weights of the five commercial cuts were summed to determine the reconstituted cold-half-carcass weight (RCHCW), as proposed by Cezar and Sousa (2007).

Table 4
Apparent digestibility coefficients of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), non-fibrous carbohydrates (NFC), and total digestible nutrients (TDN) according to the inclusion of cottonseed cake in the diets.

	Level of cottonseed cake in substitution of soybean meal (% of dietary DM)				SEM[a]	*P*-value
	0	33	66	100		
DM[b]	69.9	70.4	64.4	65.0	5.53	0.03
OM	71.8	72.1	66.0	67.3	5.01	0.01
CP	70.7	71.0	64.6	66.5	6.70	0.06
EE	74.8	75.1	72.7	76.6	4.55	0.60
NDFap	61.9	62.0	53.9	55.1	6.93	0.01
NFC	72.7	72.9	67.0	68.0	4.82	0.09
TDN	68.7	69.5	64.2	64.9	4.69	0.02

[a] Standard error of the mean.
[b] g/kg Of fresh matter.

Table 5
Final body weight (FBW), total weight gain (TWG), average daily gain (ADG), and feed conversion (FC) according to the inclusion of cottonseed cake in the diets.

	Level of cottonseed cake in substitution of soybean meal (% of dietary DM)				SEM[a]	*P*-value
	0	33	66	100		
FBW(kg)	37.14	36.09	37.04	36.40	0.573	0.83
TWG (kg)	15.97	15.35	15.96	15.50	0.422	0.86
ADG (kg)	0.19	0.19	0.19	0.19	0.005	0.86
FC (kg/kg)	6.30	6.55	6.31	6.46	0.136	0.87

[a] Standard error of the mean.

The loin-eye area and the subcutaneous fat thickness were evaluated by making a cross section between the 13th thoracic vertebra and the first lumbar vertebra, allowing the exposure of the cross-section of the loin from the right half-carcass. The loin-eye area was measured with a transparency with transparent, gridded standard template, in which each square corresponded to 1 cm^2 (Cunha et al., 2001). The degree of fat cover was determined using a caliper rule.

The variables were analyzed in a completely randomized design, according to the following model: $Y_{ij} = \mu + T_i + e_{ij}$, where Y_{ij} = observed value of the dependent variable; μ = overall mean; T_i = effect of treatment i (i = 1–5); and e_{ij} = experimental error.

The obtained data were interpreted statistically by analyses of variance (ANOVA) and regression adopting 0.05 as the critical level of probability of type-I error, on SAEG (Statistics and Genetics Analysis System) software version 9.1, developed in Viçosa, MG, Brazil (SAEG, 2007).

3. Results

There was no significant quadratic effect (P > 0.05) for any of the variables studied. The effects of increasing levels of CSC on DM, OM, CP, NDF and NFC intakes were not significant (P > 0.05). There was an increasing linear effect in the levels of cottonseed cake on the EE intake in kg/d ($\hat{Y} = 0.0270593 + 0.0000444462x$) and NDF in% body weight ($\hat{Y} = 1.16528 + 0.000947600x$) (Table 3).

Substitution of SBM for CSC caused the digestibility coefficients of the nutritional components to decrease linearly, except for the CP and EE (Table 4). The digestibility of DM decreased (P < 0.05) linearly ($\hat{Y} = 70.3880–0.054178x$), although no differences were verified among diets (Table 4). The digestibility of OM ($\hat{Y} = 72.2914–0.0592423x$), NDF ($\hat{Y} = 62.5617–0.0864741x$) and NDT ($\hat{Y} = 69.4127–0.0510350x$) decreased as the cottonseed cake levels in the diets were increased (P < 0.05).

Increasing levels of cottonseed cake did not affect final body weight, daily weight gain, or total weight gain of the lambs (Table 5). Live weight at slaughter, hot and cold carcass weights, and cooling loss were not affected (P > 0.05).

Cooling losses were not affected (P > 0.05) by the concentrations of CSC in the diets, but were related to the subcutaneous fat thickness of the animals. Cold ($\hat{Y} = 43.3371–0.020793x$) and hot ($\hat{Y} = 42.9255–0.0199003x$) carcass yields decreased linearly (P < 0.05) as the SCS levels in the diets were increased (Table 6).

The commercial carcass cuts and their percentages did not differ (P > 0.05) among the cottonseed cake levels included in the diet in substitution of soybean meal (Table 7). No effect of CSC substitution for SBM was observed on any of the morphometric measurements of the carcasses (Table 8).

4. Discussion

The dry matter intake, as g day^{-1}, for all diets, was above the 1000 g DM day^{-1} recommended for growing lambs with 20 kg body weight (NRC, 2007). The constitution of the fiber content of the diets was similar, and did not affect DM intake. Van Soest (1965) asserted that NDF levels ranging from 55 to 60% of the DM may limit forage intake due to the filling effect, which was not observed in this study. The linear increase in the EE content of the diets caused by the cake levels was not sufficient to affect DM intake, since the EE content in the diets were lower than the range of 50–70 g kg DM^{-1}, considered by some authors as the maximum for ruminants, because levels above these have detrimental effects to the ruminal microbiota (Palmquist and Jenkins, 1980; Church, 1988).

Additionally, the linear increase in EE content of the diets elevated the intake of this nutrient. The levels of cottonseed cake in the diets had no effect on the intake of total digestible nutrients (TDN), and this result can be explained by the lack of effects also on the intake of the digestible fractions of CP, NDF, and NFC. However, the cottonseed cake levels in the diet had a positive linear effect on EE intake, but this effect was not sufficient to provide an increase in TDN intake, whose mean values were lower than the 750 and 1000 g day^{-1} recommended by NRC (2007) for animals weighing 15 and 30 kg, respectively.

The NDF intakes expressed as%BW are in agreement with the values cited by Van Soest (1994), who suggested that ruminants should have an NDF intake between 0.8 and 2.2% of their BW.

The same is true for the increase observed in NDF intake in relation to metabolic weight. The reduction of DMD resulting from the substitution of SBM for CSC might be related to a possible increase in passage rate. In addition, the lignin concentration of the diets increased along with the cottonseed cake levels, because this by-product has 10.6% lignin, and soybean meal only 0.30, which probably contributed to the decrease in the DM digestibility coefficient. It is possible that the quantity and quality of the NDF from the cake provoked a drop in DM digestibility and that the other

Table 6
Body weight at slaughter (BWS), hot carcass weight (HCW), cold carcass weight (CCW), cooling losses (CL), hot dressing percentage (HDP), and cold dressing percentage (CDP) according to the inclusion of cottonseed cake in the diets.

	Level of cottonseed cake in substitution of soybean meal (% of dietary DM)				SEM[a]	*P*-value
	0	33	66	100		
BWS (kg)	36.34	35.87	35.29	36.03	0.591	0.94
HCW (kg)	16.06	15.58	15.73	14.90	0.300	0.30
CCW(kg)	15.96	15.43	15.59	14.80	0.295	0.30
CL (%)	0.6	0.9	0.9	0.6	0.077	0.99
HDP (%)	44.1	43.5	42.1	41.3	0.308	<0.01
CDP (%)	43.8	43.1	41.8	41.0	0.295	<0.01

[a] Standard error of the mean.

Table 7
Mean weights and yields of commercial carcass cuts and reconstituted cold-half-carcass weight (RCHCW) according to the inclusion of cottonseed cake in the diets.

	Level of cottonseed cake in substitution of soybean meal (% of dietary DM)				SEM[a]	*P*-value
	0	33	66	100		
	Weight (kg)					
Neck	1.55	1.44	1.19	1.44	0.046	0.60
Shoulder	1.44	1.44	1.43	1.34	0.028	0.30
Ribs	1.94	2.01	2.03	1.87	0.050	0.66
Loin	1.09	1.06	1.08	1.05	0.022	0.60
Leg	2.48	2.28	2.30	2.22	0.038	0.09
RCHCW	8.50	8.23	8.33	7.92	0.3645	0.84
	Yield (%)					
Neck	29.3	27.7	27.7	28.1	0.235	0.22
Shoulder	12.9	13.0	13.0	13.2	0.125	0.46
Ribs	21.8	23.7	23.7	22.9	0.390	0.42
Loin	13.1	13.0	13.1	13.3	0.124	0.65
Leg	29.2	28.2	28.1	28.3	0.266	0.30

[a] Standard error of the mean.

Table 8
Morphometric measurements of the carcass according to the inclusion of cottonseed cake in the diets.

	Level of cottonseed cake in substitution of soybean meal (% of dietary DM)				SEM[a]	*P*-value
	0	33	66	100		
Carcass length (cm)	65.2	64.3	63.7	63.9	0.340	0.24
Leg length (cm)	38.6	37.9	37.5	37.5	0.180	0.08
Leg width (cm)	9.4	9.4	9.1	9.4	0.126	0.86
Leg depth (cm)	12.1	11.5	12.2	11.5	0.196	0.66
Breast depth (cm)	27.3	28.0	27.4	27.3	0.181	0.64
Loin-eye area (cm^2)	12.9	10.5	11.8	11.2	0.254	0.25
Fat thickness (mm)	2.3	1.2	1.9	1.1	0.141	0.08

[a] Standard error of the mean.

fractions followed this behavior. Silva et al. (2015) evaluated the replacement of soybean meal by peanut cake in diets for goats, no observed effect on total digestible nutrient content of diets (Table 8).

The substitution of SBM for CSC also did not affect final body weight, daily weight gain and total weight gain of the lambs, and the similarity in productive performance can be explained by the dry matter intake, which was similar among the diets and which is the nutritional factor of greatest influence on weight gain. Silva et al. (2015) observed that because of the decrease in the dry matter intake, animals fed peanut cake in replacement of soybean meal also showed lower weight gains.

The results obtained in this study for daily weight gain are in agreement with those in literature (Souza et al., 2015; Guimarães et al., 2014), in which crossbred lambs were subjected to the feedlot and achieved a daily weight gain above 150 g.

The total gossypol values obtained in the concentrates utilized were 0, 340, 680 and 1020 ppm in the diets containing, respectively, 0, 33, 66 and 100% cottonseed cake in substitution of soybean meal. The maximum level of 100% cottonseed cake replacing soybean meal corresponded to 12% of the total diet.

Although the experimental diets were fed for only 99 days, there were no signs of toxicity by gossypol nor was the productive performance of the animals compromised. There were no alterations in health or performance, not even at the highest level of gossypol. Moreover, gossypol is known for its toxic effects, including reproductive toxicity (Gadelha et al., 2014).

The results obtained for the hot and cold carcass weights are possibly related to the live weight at slaughter, which was similar among the animals. The dry matter intake also was not affected by the levels of cottonseed cake in substitution of soybean meal, which also contributed to the similarity of the carcass weights (Table 2).

Cooling losses were not affected by the concentrations of CSC in the diets, and they are related to the similarity in the subcutaneous fat thickness observed in these animals. A decrease in hot carcass yield can be attributed to an increase in NDF intake as grams of metabolic weight and as percentage of body weight, which was observed in the animals that consumed lower levels of cottonseed cake; this contributes to increasing the gastrointestinal content and consequently reduction of the hot and cold carcass yields.

The cuts that make up the sheep carcass have different economic values and their proportion is an important parameter for the evaluation of the carcass commercial quality. No effect of levels of cottonseed cake in substitution of soybean meal was verified in any of the morphometric measurements of the carcasses. These results can be explained by the fact that the animals received the experimental diets only in the finishing phase, when the development of the bone tissue was practically over, compared with that of other tissues.

The results regarding loin-eye area were not influenced by the diets, because of the ingestion of crude protein and total digestible nutrients, which also did not differ among the diets, promoting an even growth of the animals among the groups. It is worth remarking that this muscle is important because it is part of the set of cuts of high commercial value. Therefore, carcasses with larger loin-eye area are more valued.

5. Conclusion

Cottonseed cake can replace up to 100% of soybean meal in the concentrate, which corresponds to 12% of the total diet for lambs, representing an important food alternative to substitute soybean meal.

Conflict of interest

The authors declare that they have no conflict of interest.

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