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Meat quality of lambs fed diets with peanut cake

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ABSTRACT

Replacement of soybean meal by peanut cake was evaluated on the meat quality of 45 Dorper × Santa Inês crossbred lambs. Animals were distributed in a completely randomized design, with five treatments and nine repetitions, and fed Tifton-85 hay and a concentrate mixed with 0.0%, 25.0%, 50.0%, 75.0% or 100.0% peanut cake based on the dry mass of the complete diet. The *longissimus lumborum* muscle was used to determine the proximate composition, physical–chemical characteristics and fatty acid profile. Significant differences ($P < 0.05$) were found for the crude protein and ether extract levels, with average values of 23.38% and 2.15% in the sheep meat, respectively. The physical–chemical characteristics of the loin were not affected ($P > 0.05$) by the diets. The fatty acid profile was affected by peanut cake supplementation for myristic, myristoleic, palmitoleic, linolenic and arachidonic fatty acids. Peanut cake can be added in the diet of lambs no effect on physical–chemical characteristics. However, the total replacement of the soybean meal altered the proximate composition and fatty acid profile of the meat.

1. Introduction

Alternative feed sources for sheep in finishing that may be used to promote decreased production costs and to improve profitability of producers, and sustainable animal production systems are in demand mainly because of the high feed prices that can account for up to 70% of production costs in lamb production (Moreno et al., 2010; Paim et al., 2011).Thus, according to Pereira et al. (2016), the search for alternative food sources for nutritional management that enable decrease costs in production systems without affecting the performance of animals in feedlot is relevant.

Biodiesel by-products, which have become a relevant economic alternative replacing soybean meal and corn, have been tested for use in animal nutrition. Their effects on carcass traits and meat quality were evaluated when soybean meal were replaced by cakes from oilseeds such as cottonseed (Pereira et al., 2016) and sunflower cake (Oliveira et al., 2015), and also using glycerin replacing ground corn (Barros et al., 2015; Strada et al., 2015; Eiras et al., 2014; Ribeiro, Messana, José Neto, Fiorentini, & Berchielli, 2016).

Beyond the by-products of biodiesel production described above, it is possible to emphasize the use of peanut cake, which is a good source of protein, energy and fat (Aletor and Ojelabi, 2007; Ezekiel, Alabi, Anokwuru, & Oginni, 2011). Its use in animal nutrition may be relevant because it has a chemical composition similar to soybean meal. It has a protein content that can range from 41% to 45%, a fat content ranging from 8% to 9% (Abdalla, Silva Filho, Godoi, Carmo, & Eduardo, 2008) and a fatty acid composition that has a greater proportion of palmitic acid, oleic acid and myristic acid, at 38.74%, 23.10% and 15.35%, respectively, according to Oliveira et al. (2012).

The metabolic profile and the histopathological evaluation of the hepatic and renal tissues were evaluated by Araujo et al. (2014) in lambs fed diets containing peanut cake. The authors concluded that this biodiesel by-product can be used as an alternative protein source up to 100% since it does not affect the metabolic, protein or liver and kidney functions of lambs finished in feedlot.

As mentioned by Johnson and Mcgowan (1998), Geay, Bauchart, Hocquette, and Culioli (2001) and Batista et al. (2010), nutrition is important because dietary changes can improve both the quantity and quality of the final product, providing standardized housing and better quality meat. Moreover, in recent years, the fat content and fatty acid composition of food has been closely observed by consumers who have become more aware of the relationship between dietary fat and

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the incidence of illnesses linked to coronary heart disease, cancer and arthritis (Corpet, 2011; Wood et al., 1999). Thus, the production of foods containing a high proportion of fatty acids that are beneficial to human health has been encouraged (McAfee et al., 2010).

Replacing the soybean meal by peanut cake for Nellore young bulls on beef production and beef quality, Correia et al. (2016) concluded that although no alterations occurred in the physicochemical characteristics, diets affected the *longissimus thoracis* fatty acid profile. Despite this, peanut cake at levels up to 100% in the diet of had a beneficial improve in the levels of poliunsaturated fatty acids and nutraceutical compounds, such as conjugated linoleic acid and omega-3 and 6 fatty acids.

Given the benefits of cattle nutrition described above, the impact of peanut cake on lamb meat finished in feedlot is not mentioned in scientific literature yet. However, it emphasized the importance of evaluating its effect as an alternative food source in order to determine the impact on lamb meat quality, in which comsumption is improving nowadays, thus proving its potential of use in small ruminants nutrition.

In this context, the objective of this study was to evaluate the effect of the replacement of soybean meal with peanut cake on the proximate composition, physicochemical characteristics and fatty acid profile of meat from crossbred lambs (Dorper × Santa Inês) finished in a feedlot.

2. Material and methods

This study was approved by the ethics committee of the Ethics of Animal Experiments of the Federal University of Bahia, Bahia State, Brazil, under permit number 08-2013.

The experiment was performed at the Experimental Farm of the Federal University of Bahia in the municipality of São Gonçalo dos Campos, Bahia. The experimental site is characterized by an average annual temperature of 26 °C, an 85% relative humidity and an annual rainfall of approximately 1.200 mm.

A total of 45 5-month-old, non-castrated, male crossbred Dorper × Santa Inês lambs with average initial weight of 24.49 ± 5.27 kg were used. The animals were arranged in a covered area and individually allotted on a suspended slatted floor into individual pens with free access to feed and water in a feedlot system.

The experiment lasted for 84 days and was preceded by a 21-day adaptation period, during which lambs were weighed, identified, vaccinated against clostridial diseases and treated for ecto- and endoparasites, and diet adaptation was performed.

The experimental design was completely randomized, with five treatments and nine repetitions (nine animals in each treatment). Thus, lambs were weighed at the beginning of the experiment and randomly assigned to treatments consisting of diets with various levels of peanut cake replacing soybean meal in the concentrate (0.0%, 25.0%, 50.0%, 75.0% and 100%).

The diets were formulated in order to be isonitrogenous, on the basis of the National Research Council (NRC 1985) recommendations for an average daily weight gain of 200 g/day. The concentrates consisted of ground corn, soybean meal, peanut cake and mineral salt. Tifton-85 hay (ground into approximately 5 cm particles) was provided at a forage:concentrate ratio of 50:50 (DM basis) (Tables 1 and 2). The diets were fed twice daily (09 and 16 h) and were offered as a total mixed ration. The leftovers were weighed daily, and the amount of supplied feed was adjusted to allow for leftovers of 10 to 20% refusal.

Samples of the complete diet ingredients and the leftovers were individually placed in plastic bags. At the end of each collection period, a sample by animal and by treatment was taken. These samples were defrosted at room temperature for 4 h and pre-dried in a forced-air circulation oven at 55 °C for 72 h, and then, they were processed using a Willey cutting mill with a 1 mm sieve.

The dry matter (DM), mineral matter (MM), crude protein (CP) and ether extract (EE) contents of the ingredients of the experimental diets were determined according to the method of the AOAC (1990). The analyses for determining the neutral detergent fiber (NDF) and acid detergent fiber (ADF) levels were performed according to the method described by Van Soest, Robertson, and Lewis (1991).

The neutral detergent insoluble protein (NDIP) and acid detergent insoluble protein (ADIP) concentrations were determined as described by Licitra et al. (1996). For the analysis of lignin, the fiber residue was treated in acid detergent with 72% sulfuric acid (Silva & Queiroz, 2002).

Table 1
Chemical composition of the ingredients used in the experimental diets.

Items	Ingredients			
	Tifton-85 hay	Ground Corn	Soybean meal	Peanut cake
Dry matter	857.0	929.1	892.5	890.7
Organic matter[a]	931.1	985.5	935.3	949.5
Mineral matter[a]	68.9	14.5	64.7	50.5
Crude protein[a]	38.9	59.4	406.2	386.9
Ether extract[a]	10.7	40.6	19.1	99.5
NIDP (% CP)[b]	679.0	169.0	61.9	54.2
ADIP (% CP)[c]	142.0	89.0	31.9	19.4
Neutral detergent fiber[a]	738.7	153.3	131.9	140.3
Acid detergent fiber[a]	405.1	34.6	80.0	85.8
Lignin[a]	50.0	23.7	16.3	43.0
Cellulose[a]	355.1	10.9	63.7	42.8
Hemicellulose[a]	333.6	118.7	51.9	54.5
Non-fibrous carbohydrates[a]	142.8	732.2	378.1	322.8

[a] g kg^{-1}as fed.
[b] Neutral detergent insoluble protein.
[c] Acid detergent insoluble protein

Table 2
Proportion of ingredients and chemical composition of experimental diets.

Ingredient (g kg^{-1}of DM)	Level of replacement (% DM)				
	0	25	50	75	100
Ground corn	281.0	281.0	281.0	281.0	281.0
Soybean meal	200.0	150.0	100.0	50.0	0.00
Peanut cake	0.00	50.00	100.0	150.0	200.0
Premix mineral[a]	14.0	14.0	14.0	14.0	14.0
Urea	4.50	4.50	4.50	4.50	4.50
Ammonium sulfate	0.05	0.05	0.05	0.05	0.05
Tifton-85 hay	500.0	500.0	500.0	500.0	500.0
Chemical composition					
Dry matter	871.2	888.2	889.9	889.0	897.4
Organic matter[b]	941.0	937.1	940.8	940.7	941.8
Mineral matter[b]	64.0	62.9	64.1	64.0	63.6
Crude protein[b]	126.0	124.0	124.9	124.4	118.7
Ether extract[b]	19.9	27.3	36.0	44.0	55.5
Neutral DIP[c] (% total CP)	277.3	276.7	275.4	275.1	274.4
Acid DIP[c] (% total CP)	81.7	79.2	78.9	78.6	76.4
Neutral detergent fiber[b]	445.0	441.9	441.7	428.4	426.2
Acid detergent fiber[b]	238.7	237.8	237.0	227.7	232.9
Lignin[b]	36.4	37.8	38.1	31.1	37.3
Cellulose[b]	202.3	200.0	198.9	196.6	195.6
Hemicellulose[b]	206.3	204.1	204.7	200.7	193.3
Non-fibrous carbohydrates[b]	345.1	343.9	333.3	339.2	336.0
Total digestible nutrients[d]	671.5	671.9	672.4	673.0	676.1
Fatty acid profile					
16:0	8.04	12.88	10.84	11.51	10.39
18:0	6.85	2.71	2.83	3.15	2.91
18:1	33.91	40.20	44.47	44.36	49.30
18:2n-6	43.93	38.59	33.82	31.77	28.95
18:3n-6	1.40	0.52	0.09	0.02	0.06
18:3n-3	0.61	0.95	0.58	0.38	0.17
20:0	0.98	1.00	1.25	1.50	1.47

[1] Guaranteed levels (per kg in active elements): calcium, 120.00 g; phosphorus, 87.00 g; sodium, 147.00 g; sulfur, 18.00 g; copper, 590.00 mg; cobalt, 40.00 mg; chromium, 20.00 mg; iron, 1800.00 mg; iodine, 80.00 mg; manganese, 1300.00 mg; selenium, 15.00 mg; zinc, 3800.00 mg; and molybdenum, 300.00 mg. Maximum fluoride, 870.00 mg; solubility of phosphorus (P) in citric acid at 2%- minimum-95%.
[b] g kg^{-1}of DM.
[c] Detergent insoluble protein.
[d] Estimated by the equations of Detmann et al. (2006a, 2006b, 2006c, 2007).

The total carbohydrates (TC) were obtained by using the following equation: TC = 100 − (% CP + % EE + %ASH) (Sniffen, O'Connor, Van Soest, Fox, & Russell, 1992). Non-fiber carbohydrates (NFC) were determined by the difference between the TC and the NDF (Mertens, 1997). The concentration of the total digestive nutrients (TDN) was estimated using the formula proposed by Weiss (1999).

At the end of the experiment, lambs were weighed after a 16-h solid fast. Then, when they were transported to the commercial slaughterhouse, they were weighed to determine the body weight at slaughter (BWS).

2.1. Slaughter and sample collection

Pre-harvest handling was in accordance with good animal welfare practices, and the slaughtering procedures followed the Sanitary and Industrial Inspection Regulation for Animal Origin Products (Brasil, Ministério Pecuária e Abastecimento, 2000). After dressing and evisceration, the head (section in atlanto-occipital joint) and legs (section in carpal and tarsal-metatarsal joints) from the hot carcasses were refrigerated at 4 °C for approximately 24 h and then taken from the cooling chambers.

Afterwards, the carcasses were split into two identical longitudinal halves and sectioned into five regions (neck, shoulder, ribs, loin and leg), as presented by Colomer-Rocher (1986). The left half-carcass was cross-sectioned between the 12th and 13th thoracic vertebra. The *longissimus lumborum* (*L. lumborum*) muscle was completely removed from each carcass until the analysis was performed.

The texture, color and marbling of the *L. lumborum* muscle were determined using nine scores ranging from one to five with 0.5 intervals, yielding five categories according to Osório and Osório (2005). The texture was classified as very coarse, coarse, slightly coarse, fine or very fine. The color was classified as clear pink, pink, light red, red or dark red.

Texture, color and marbling were measured in the *L. lumborum* between the 12th and 13th ribs, using scores ranging from one to five with 0.5 intervals, yielding five categories according to Osório and Osório (2005). Texture was assessed by size of the bundles of fibers lying lengthwise by dividing the muscle by the perimysial septa of connective tissue and evaluated subjectively on a point scale (1.0 to 1.5—very coarse; 2.0 to 2.5—coarse; 3.0 to 3.5—slightly coarse; 4.0 to 4.5—fine; 4.5 to 5.0—very fine). The *L. lumborum* color was determined by visual assessment of the meat color, also according to a point scale (1.0 to 1.5—clear pink; 2.0 to 2.5—pink; 3.0 to 3.5—light red; 4.0 to 4.5—red; 4.5 to 5.0—dark red). Marbling was evaluated by visual evaluation of the amount of intramuscular fat in the presented muscle (1.0 to 1.5—nonexistent; 2.0 to 2.5—little; 3.0 to 3.5—good; 4.0 to 4.5—much; 4.5 to 5.0—excessive).

2.2. Proximate composition analysis and physical–chemical characteristics

Analyses on the *L. lumborum* samples were carried out three months after sampling, using samples on the right side of the carcass, after a cross-section cut was made between the 12th and 13th ribs.

To determine the proximate composition, each *L. lumborum* sample was analyzed for crude protein (CP; Method 920.87—AOAC, 1990), ether extract (EE; Method 920.29—AOAC, 1990) and ash (MM, Method 924.05—AOAC, 1990).

The pH of the meat was measured when the physical–chemical analysis was carried out, using a Testo 205 pH meter (Testo InstrumentCo. LTD., Germany) with an automatic endpoint and buffer recognition, as well as temperature compensation, equipped with a penetrating electrode. The pH-meter was calibrated before use to pH 7.0 and 4.01. The pH was measured at approximately 4 cm deep in the *L. lumborum* muscle on the left side of each carcass (12th rib). We performed pH readings in triplicate at three different points in the *L. lumborum* muscle.

The water-holding capacity was calculated using the method described by Hamm (1986), with slight modifications. Meat samples weighing 500 ± 20 mg were placed on filter paper between two acrylic plates, and a 10 kg weight was placed on top of the plates for 5 min. The results are expressed as percentages compared to the initial weight, as follows: WHC = 100 − ((IW − FW) / IW × 100), where WHC is the water-holding capacity, IW is the initial weight and FW is the final weight.

To measure cooking loss, the samples were weighed and cooked in an industrial oven preheated to 175 °C until the internal temperature of the samples reached 72 °C, according to Felicio (1999). Cooking loss was calculated as the difference between the weight of the steaks before and after oven-broiling. Subsequently, six round cores were removed from each steak, parallel to the long axis of the muscle fibers.

Instrumental measurement of texture was assessed following the methods described by Lyon, Lyon, and Dickens (1998), using a TA-XT2 texture analyzer (MultiTest 1-i, Mecmesin, UK) equipped with a Warner–Bratzler (WB) shearing device. Shear force was recorded and expressed in Newtons as the average of four to six measurements per sample.

2.3. Fatty acid profile

L. lumborum samples were packed and frozen to allow timely analysis in regards to the fatty acid composition. The assays were carried out at the Chromatographic Assay Center (CEACROM) of the Universidade Estadual do Sudoeste da Bahia. The total lipids were determined by the method from Bligh and Dyer (1959). The transesterification of triacylglycerols (TAGs) to obtain fatty acid methyl esters was performed according to the 5509 ISO (1978).

The chromatographic assay was carried out using a Thermo-Finnigan Trace-GC-Ultra gas chromatographer equipped with a flame ionization detector (FID) and a BPX-70 fused-silica capillary column (120 m, 0.25 mm i.d.). The operation parameters established after the verification of the best resolution conditions were injector and detector temperatures of 250 °C and 280 °C, respectively.

The column temperature was programmed to 140 °C for 10 min, proceeding through a first ramp of 15 °C min^{-1} until it reached 200 °C for 1 min. The second ramp was 10 °C min^{-1} until 230 °C was reached for 1 min. The third ramp was 0.4 °C min^{-1} until it reached 233 °C for 3 min. The fourth ramp was 0.5 °C min^{-1} until it reached 238 °C for 2 min. The total assay time amounted to 41.50 min. The gas flow rates (White Martins , São Paulo, Brazil) used were 30 mL min^{-1} for hydrogen, 30 mL min^{-1} for nitrogen and 250 mL min^{-1} for synthetic air. Injections (1.2 μL) were carried out in duplicate, and the fatty acid methyl ester peak areas were determined with the software ChromQuest 4.1.

Fatty acid (FA) identification was carried out after verification of the peak equivalent chain length and comparison of the sample retention times with a standard sample containing a mixture of fatty acid methyl esters (189-19, O-5632 and O-5626, from Sigma Company, St Louis, MO, USA) as described by Simionato et al. (2010).

The quantification of fatty acids in mg g^{-1} of total lipids was carried out in relation to the internal standard, methyl tricosanoate (23:0) (Sigma, St. Louis, MO, EUA). The verifying agreement among the theoretical and experimental response factors was performed as described by Costa et al. (2011). The calculation of the FA concentrations in the samples was carried out according to Joseph and Ackman (1992). The verification of the agreement between the theoretical response and the experimental factors was carried out as described by Simionato et al. (2010) and Costa et al. (2011).

From the identified fatty acid profile, the sum of saturated (SFA), unsaturated (UFA), monounsaturated (MUFA), polyunsaturated (PUFA), omega-6 (n-6), omega-3(n-3), medium chain (MCFA), long chain (LCFA) and desirable (DFA; DFA = MUFA + PUFA + C18:0) fatty acids were taken to determine the PUFA relationships: PUFA:SFA, n6:n3 and SFAT/UFA. We also calculated the atherogenicity index (AI)

and the thrombogenic index (TI) as proposed by Ulbricht and Southgate (1991). These indices were used to relate the fatty acid profile with the risk of cardiovascular disorders, using the equation, and the ratio between the hypocholesterolemic fatty acids/hypercholesterolemic fatty acids,(h/H ratio) = (C18:1cis9 + C18:2n6 + 20:4n6 + C 18:3n3 + C20:5n3 + C22:5n3 + C22:6n3) / (C14:0 + C16:0), as well as the correlations among them, according to Santos-Silva, Bessa, and Mendes (2002).

2.4. Statistical analysis

Data for the chemical composition, the physical–chemical characteristics and the fatty acid profile were analyzed as a completely random design, using 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 ($i = 1$ to 5), and e_{ij} = experimental error. An analysis of variance (ANOVA) and a regression set at 5% probability were used to analyze the results.

The relationships between the composition of consumed fatty acids and the intramuscular fatty acid content were calculated using Pearson's correlation coefficients.Variable r assumes values between −1 (negative linear association) and 1 (positive linear association). The significance of the correlation coefficient was tested by the "t" test at 1% probability (H_0: corr = 0). All statistical analyses were conducted using SAS 9.0 (SAS Institute, 2002).

3. Results and discussion

The proximate composition of the *L. lumborum* muscle was not influenced ($P > 0.05$) by the replacement of soybean meal with peanut cake in terms of moisture and ash contents (Table 3). The ash content, the moisture and the protein values obtained were similar to those found in the literature for sheep meat (Prata, 1999; Geay et al., 2001; Zapata, Nogueira, & Sabra, 2001) and varied by only 0.79% to 1.68% of the 70.80 to 80.25 and 18.50% to 23.39%, respectively, which were values indicative of good quality meat.

The total lipid content showed a linear effect ($P < 0.05$) and increased in proportion to the energy density of the provided diets. According to Lushbough and Urbin (1963), the fat content can be influenced by the nature of the diet. Increased dietary energy density increases the percentage of fat and decreases the percentage of moisture in the meat (Lawrie, 2005). With regards to the crude protein in the meat (Table 3), we observed an effect of peanut cake levels ($P < 0.05$), which may be related to muscle protein deposition in growing animals. However, the protein content was consistent with the results described in the literature for sheep meat.

The fat content in the *L. lumborum* muscle was influenced by the diets (Table 3); however, the meat was considered lean because its content was less than 5% fat (Gurtler, Ketz, Kolb, Schroder, & Seidel, 1987). Another justification for the fat content from the *L. lumborum* was that the animals were young. As such, the time when the lambs were confined was potentially sufficient to influence the deposition of adipose tissue, in addition to increasing the energy density of the diet.

Qualitative characteristics evaluated in the *L. lumborum* were not influenced ($P > 0.05$) by peanut cake levels (Table 4). The meat of the lambs had average values for texture (3.41 points), a light red color (3.25 points) and marbling that was considered good (2.75 points). Taken together, these data show that the meat presented satisfactory features characteristic of young lambs with adequate intramuscular fat deposition.

In addition, feedlot animals are generally slaughtered earlier. Lawrie (2005) explains that because the animals are young, the meat of male lambs has a rose color; the increase in myoglobin concentration occurs as the animals become adults or with physiological maturity.

Peanut cake levels did not affect ($P > 0.05$) the texture and marbling of the meat (Table 4). The similarity between the values found for the texture can be attributed to the fact that diets do not have an influence on the marbling of the meat. Therefore, the lambs were slaughtered at a similar weight resulting in a similar deposition of intramuscular fat in the carcasses and a similar tenderness of the meat.

The pH was not affected ($P > 0.05$) by the substitution of peanut cake for soybean meal in the diets (Table 6), and these findings are similar to those found in literature for sheep meat, which correspond to a pH range of 5.5 to 5.8 (Silva Sobrinho, Purchas, Kadim, & Yamamoto, 2005). Importantly, the finding of normal values of a decreased pH in the carcasses shows that the quality parameter indicators, such as the water-holding capacity, the taste, the color and the texture, are satisfactory. This can be justified because during the development of rigor mortis, the pH influences contraction, proteolysis and protein denaturation, leading to changes in the structure and quality of meat (Ramos & Gomide, 2007). Thus, pH is one of the main parameters of meat quality; meats with a pH within the normal range have more desirable properties.

The water-holding capacity also did not differ ($P > 0.05$) between the evaluated diets (Table 5) and is in accordance with the values recommended for sheep meat (Sañudo et al., 1997; Perez, Maino, & Tomic, 2002; Silva Sobrinho et al., 2005). This variable did not affect the diets because the pH values in the meat samples were similar.

The cooking losses were not affected ($P > 0.05$) by the diets (Table 5). According to Sañudo et al. (1997) and Bressan, Prado, Pérez, and Lemos (2001), the cooking losses of the meats are related to the losses during the process of preparation for consumption and are influenced by genetics, diet, slaughter weight, water-holding capacity and fat. Among these factors, the diet was the only factor among the studied treatments that was different, and despite the increased energy density of the diets (Table 2), it did not interfere with the deposition of fat in the meat, which is important to prevent the loss of nutrients during the cooking of the meat.

In addition to other physical and chemical characteristics of meat, the Warner–Braztler shear force also did not differ ($P > 0.05$) between diets (Table 5), with an average value of 21.40 N. Thus, the meat of lambs in this study were classified as soft because sheep meat presenting shear strength values below 22.26 N, 22.36 to 35.60 N, 35.70 to 53.

Table 3
Proximate composition in the *L. lumborum* muscle of lambs.

Variables (%)	Level of replacement with peanut cake (% DM)					SEM[a]	*P*-value[b]	
	0	25	50	75	100		Linear	Quadratic
Moisture	73.78	73.88	73.35	73.93	73.78	0.16	0.2126	0.8234
Ash	1.20	1.23	1.07	1.15	1.07	0.03	0.4253	0.2607
Protein	23.95	22.78	23.76	22.65	23.78	0.20	0.4801	0.0328
Total lipids	2.08	1.80	2.15	2.24	2.48	0.09	0.0019	0.6647

[a] Standard error of the mean.
[b] $P \leq 0.05$.

Table 4
Subjective characteristics in the *L. lumborum* muscle of lambs.

Characteristics	Level of replacement peanut cake (% DM)					SEM[a]	*P*-value[b]	
	0	25	50	75	100		Linear	Quadratic
Color (1 to 5)	3.14	3.20	3.50	3.41	3.00	0.072	0.9501	0.1106
Texture (1 to 5)	3.35	3.20	3.62	3.41	3.50	0.051	0.3081	0.9647
Marbling (1 to 5)	3.00	2.60	3.00	2.66	2.70	0.098	0.4768	0.7895

[a] Standard error of the mean.
[b] $P \leq 0.05$.

Table 5
Mean values of the pH, the water-holding capacity (WHC), the cook losses and the Warner–Bratzler shear force (WBSF) in the *L. lumborum* muscle of lambs.

Variable	Level of replacement with peanut cake (% DM)					SEM[a]	*P*-value[b]	
	0	25	50	75	100		Linear	Quadratic
pH	5.70	5.69	5.70	5.84	5.72	0.019	0.0955	0.9645
WHC (%)	63.41	60.33	61.00	59.86	61.28	0.444	0.0826	0.1020
Cook losses (%)	26.39	26.02	29.08	26.71	23.57	0.774	0.7561	0.1616
WBSF (N)	20.22	19.42	23.44	21.43	22.48	0.929	0.1688	0.2230
Color								
L*(lightness)	40.06	42.47	40.80	39.57	39.00	0.353	0.1357	0.0649
a* (yellowness)	19.58	19.37	19.80	19.11	19.98	0.239	1.000	0.7573
b* (redness)	8.51	9.43	8.61	8.07	7.82	0.178	0.0851	0.1578

[a] Standard error of the mean.
[b] P ≤ 0.05.

35 N and above 53.35 N, respectively, can be classified as soft, mid softness, tough and extremely hard (Cezar & Sousa, 2007).

Silva Sobrinho et al. (2005) noted that sheep meat was traditionally classified as hard compared to meat from the current early races because the animals were raised in an extensive system and were slaughtered late from breeds producing wool. However, according to Sañudo (2002), increasing or decreasing values for the Warner–Braztler shear force can be found in young animals according to slaughter age, perhaps due to the interactions between different collagen deposition rates and fat in the animal muscle.

The replacement of soybean meal by peanut cake did not influence ($P > 0.05$) the following variables: lightness (L*), redness (a*) and yellowness (b*) of meat (Table 5). The findings corroborate those in the literature for lamb meat because the results are considered normal variations from 30.03 to 49.47, from 8.24 to 23.53 and from 3.38 to 11.10 for L *, a * and b *, respectively (Warris, 2003).

Similarly, the redness can be influenced not only by the slaughter weight (Martínez-Cerezo, Sañudo, Panea, & Olleta, 2005; Werdi Pratiwi, Murray, & Taylor, 2007) but also by pH (Priolo, Micol, Agabriel, Prache, & Dranfield, 2002). Because we did not observe an effect of diet on the pH values of the meat (Table 5), this behavior justifies the similarity in this coloring index of animal meat. The yellowness of lamb meat was not influenced ($P > 0.05$) by the diets (Table 5). This result was expected because soybean and peanut cake have inherent carotene deficiency in their composition (Lana, 2003; Peres, Freitas Junior, & Gazzoni, 2005).

According to Voltolini et al. (2009), cottonseed cake could be used in different ruminant feeding systems in order to replace the protein-concentrate in the traditional diets, composed of soybean meal. Similarly as this study, Pereira et al. (2016) replaced the soybean meal by cottonseed cake and mentioned that physicochemical characteristics of lamb's meat were not affected ($P > 0.05$) by the diets.

The same behavior was described by Correia et al. (2016) when fed Nellore young bulls with diets containing by peanut cake. The authors noticed that diets did not affect shear force, weight loss by cooking, water-holding capacity and pH further demonstrating the potential for replacing soybean meal with peanut cake.

The fatty acids found in greater proportion in the lamb meat were oleic (42.15%), stearic (26.58%) and palmitic (25.05%) fatty acids (Table 6). The fatty acid profile was influenced by peanut cake ($P < 0.05$) for myristic (C14:0) and myristoleic (C14:1n-7) fatty acids; we observed a quadratic effect with the replacement of soybean meal with peanut cake.

According to Moloney, Mooney, Kerry, and Troy (2001), myristic acid (14:0) and palmitic acid (16:0) are considered hypercholesterolemic fatty acids and thereby increase the synthesis of cholesterol, promoting the accumulation of low density lipoprotein, which is a risk factor for cardiovascular diseases. According to French et al. (2003), C14:0 is the most undesirable fatty acid; however, according to the found content, the effect of myristic acid on lamb meat does not imply high cholesterol levels.

However, stearic fatty acid (C18:0), which is considered neutral, represents 10 to 20% of the fats produced by ruminants and does not have this property. Instead, the saturated, mono- and polyunsaturated fatty acids are considered hypocholesterolemic fatty acids (Williams, 2000; Valsta, Tapanainen, & Männistö, 2005). As a result, the meat of lambs fed diets containing peanut cake can be considered a healthy food for humans, given the low amounts of C14:0 and the high amounts of C18:1. This notion was confirmed by Wang, Raymer, Chinnan, and Pittman (2012) by comparing peanut cake to soybean meal and reporting that this cake has a high content of oleic fatty acid (C18:1) compared to soybeans, which have the highest concentration of linoleic acid (C18:2).

There was a linear increasing effect ($P < 0.05$) for C16: 1 (palmitoleic acid). This fatty acid originates from the unsaturation of palmitic fatty acid through the desaturation process via ruminal bacteria, which introduces a *cis* double bond between carbon 9 and 10 by an oxidative

Table 6
Fatty acid composition in the *L. lumborum* muscle of lambs.

Fatty acid	Level of replacement with peanut cake (% DM)					SEM[a]	*P*-value[b]	
	0	25	50	75	100		Linear	Quadratic
14:0	1.85	1.36	1.55	1.50	1.92	0.197	0.6517	0.0393
14:1	0.13	0.11	0.11	0.092	0.13	0.013	0.6444	0.0342
15:0	0.23	0.18	0.25	0.22	0.31	0.030	0.0529	0.1048
15:1	0.19	0.16	0.19	0.15	0.16	0.024	0.4577	0.9827
16:0	27.09	23.47	25.22	25.31	24.16	1.405	0.3773	0.5386
16:1	1.07	0.98	1.34	1.16	1.32	0.096	0.0308	0.9138
17:0	0.83	0.81	0.80	0.90	0.99	0.075	0.1109	0.2424
17:1	0.60	0.42	0.53	0.55	0.56	0.057	0.7857	0.1749
18:0	23.29	25.77	32.66	25.36	25.83	3.755	0.6945	0.2055
18:1n-7 t	1.29	1.18	1.24	0.80	1.08	0.139	0.0725	0.6044
18:1n-9c	41.82	44.64	44.12	39.92	40.24	2.685	0.3588	0.4041
18:2n-6	3.18	2.61	2.63	2.37	2.68	0.282	0.1688	0.1742
18:3n-6	0.22	0.28	0.28	0.17	0.20	0.028	0.0987	0.1234
20:0	0.24	0.16	0.18	0.19	0.24	0.029	0.7638	0.0198
18:3n-3	0.29	0.21	0.23	0.19	0.29	0.037	0.9089	0.0434
CLAc9t11	0.11	0.10	0.12	0.11	0.12	0.018	0.7535	0.7927
21:0	0.34	0.37	0.36	0.27	0.30	0.050	0.3213	0.6312
22:0	0.93	0.96	0.80	0.70	0.83	0.117	0.2365	0.5542
23:0	0.19	0.15	0.16	0.13	0.17	0.024	0.4707	0.1570
22:2n-6	0.02	0.03	0.01	0.02	0.02	0.003	0.0527	0.2657
EPA	0.01	0.02	0.01	0.01	0.03	0.004	0.0360	0.0519
	Regression equation							
14:0	$\hat{Y} = 1.81142 - 0.01707X + 0.00018245X^2$							($R^2 = 0.89$)
14:1	$\hat{Y} = 0.13434 - 0.00123X + 0.00001144X^2$							($R^2 = 0.69$)
20:0	$\hat{Y} = 0.23554 - 0.00300X + 0.00003109X^2$							($R^2 = 0.89$)
18:3n-3	$\hat{Y} = 0.28444 - 0.00336X + 0.00003302X^2$							($R^2 = 0.74$)

[a] Standard error of the mean.
[b] $P \leq 0.05$.

Table 7
Sums and ratios of major fatty acids in the *L. lumborum* muscle of lambs.

Item	Level of replacement with peanut cake (% DM)					SEM[a]	*P*-value[b]	
	0	25	50	75	100		Linear	Quadratic
SFA	54.78	52.25	49.11	54.40	47.29	4.100	0.3134	0.9630
MUFA	44.84	47.34	47.47	42.74	41.30	2.889	0.2032	0.2545
PUFA	4.21	2.96	3.81	2.82	3.07	0.429	0.0796	0.4808
PUFA/SFA	0.08	0.06	0.07	0.05	0.13	0.034	0.3369	0.1607
n-6	3.77	2.66	3.06	2.52	2.61	0.197	0.0854	0.3813
n-3	0.31	0.25	0.28	0.18	0.30	0.764	0.1916	0.2461
n-6/n-3	13.89	14.70	14.12	11.77	8.71	0.993	0.1745	0.4108
SFA	48.92	47.75	50.83	45.57	49.18	2.100	0.8002	0.8782
SFA/UFA	1.59	1.05	2.01	1.23	1.20	0.405	0.6440	0.6404
DFA	68.33	73.63	70.31	70.80	64.82	4.030	0.4389	0.2234
MCFA	30.51	25.04	28.84	28.44	24.34	2.174	0.2029	0.8591
LCFA	69.52	74.94	73.32	71.59	65.61	4.055	0.3898	0.1390
AI	0.63	0.55	0.59	0.67	0.91	0.143	0.1410	0.2036
TI	35.27	33.63	32.89	28.46	21.87	5.595	0.0776	0.5131
h/H	1.81	1.93	1.98	1.75	1.59	0.135	0.1579	0.1102

Saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), ômega-6 (n-6), ômega-3(n-3), unsaturated (UFA), desirable fatty acids (DFA), medium chain fatty acids (MCFA), long chain (LCFA), atherogenicity index (AI), trombogenic index, hypocholesterolemic fatty acids/hypercholesterolemic fatty acids ratio (h/H ratio).
[a] Standard error of the mean.
[b] $P \leq 0.05$.

reaction that is catalyzed by acyl-CoA desaturase (Visentainer, Franco, & Visentainer, 2003).

Furthermore, palmitic fatty acid (C16:0) may act as a precursor for long chain saturated fatty acids through the successive insertion of two carbon atoms, which gives rise to saturated fatty acids, such as stearic (18:0), arachidonic (20:0), etc. Arachidonic acid (C20:0) also showed a quadratic effect ($P < 0.05$) with the replacement of soybean meal by peanut cake. This fatty acid is essential in the diet of mammals because it is a precursor in the biosynthesis of prostaglandins, thromboxanes and leukotrienes.

Among the total identified fatty acids, the monounsaturated fatty acid, oleic acid (C18:1 cis-9), known for its cholesterol-lowering properties, was not affected by diet ($P > 0.05$) but showed higher values (42.15%). This result is close to the levels obtained by Barros et al. (2015), when lambs were fed diets with glycerin levels, and found average value of 36% of this fatty acid.

Sañudo et al. (2000) reported that ruminant meat has a high content of this fatty acid in the intramuscular fat. This fatty acid is synthesized from stearic acid by the Δ9-dessaturase enzyme, which is also involved in the synthesis of conjugated linoleic acid (CLA) (Wood et al., 2008). It is possible that the C18: 1 cis-9 did not differ between treatments because the concentrations of its precursor, C18: 0, were also not affected.

Linolenic acid (C18:3n-3) showed a quadratic effect ($P < 0.05$) and was found in low concentrations in the meat of lambs (0.24%). This finding is due to the biohydrogenation process where, according Doreau and Ferlay (1994), approximately 85 to 100% of the C18:3 acids are biohydrogenated by ruminal bacteria; thus, very little is available for tissue incorporation. These acids are considered to be essential and important precursors of the n-3 series family of acids, such as EPA and DHA. The difference ($P < 0.05$) in the EPA content of the meat from these animals was due to differences in their precursors.

According Emken, Adlof, and Gulley (1994), the fatty acids of the n-6 and n-3 families compete for the enzymes involved in the desaturation and chain elongation reactions. Although these enzymes have greater affinity for the n-3 family acids, conversion of alpha-linolenic acid to long chain fatty acids is greatly influenced by the linoleic fatty acid content in the diet.

The conjugated linoleic acid (CLA) levels were not affected by the diets (Table 6). CLA is an intermediate from the process of biohydrogenation of linoleic acid by rumen bacteria (Beaulieu, Drackley, & Merchen, 2002).

The sum of the saturated, monounsaturated and polyunsaturated fatty acids was not influenced by treatments ($P > 0.05$) (Table 7). The composition of dietary lipids influences the fat from the carcass profile in most species; however, for ruminants, dietary lipids are extensively modified in the rumen, especially with regards to polyunsaturated fatty acids that affect the content and composition of fatty acids in skeletal muscle (Arruda et al., 2012). (See Table 8.)

In a healthy diet, it is recommended that the ratio of PUFA:SFA should be greater than 0.4 (Wood et al., 2003). However, according to Scollan, Murphy, Moloney, Dewhurst, and McGilloway (2005), the relationship between PUFA: SFA in meat is generally low, approximately 0.1, which was observed in this study, even though there was no difference ($P > 0.05$). However, in very thin animals, this ratio is approximately 0.5–0.7 (<1% intramuscular fat), and they have double the muscle tissue. In general, nutritional manipulation does not increase this relationship above normal levels, ranging from 0.06 to 0.15 due to rumen biohydrogenation. The mean value found in this study was 0.08, which is considered within the range of that observed by Scollan et al. (2005).

With regards to the n-6 and n-3 levels and the n-6/n-3 ratio, there was no effect on the concentrations of these variables in lamb meat, and they did not interfere with the quality of the meat product. According to Fagundes (2002), a new parameter for the nutritional quality of food is the proportion of the polyunsaturated fatty acids omega-6 (n-6) and omega-3 (n-3) because n-3 deficiency and n-6 excess characterizes a Western diet and can induce the onset of degenerative diseases and cancer.

In diets rich in n-6, the body produces inflammatory and carcinogenic eicosanoids. On the other hand, n-3 are *anti*-inflammatory, reduce blood lipids and have vasodilatory properties that are beneficial for preventing heart diseases, hypertension and diabetes. Therefore, the ratio n-6:n-3 appears to be of great importance, and it is recommended that diets have a 4:1 or 5:1 ratio of n-6:n-3 (Holman, 1998; Wood et al.,

Table 8
Correlation among the saturated and unsaturated fatty acids of the diets with fatty acids in the meat.

Fatty acids in the meat	Fatty acids in the diets													
	C16:0		C18:0		C20:0		C18:1		C18:2 n-6		C18:3 n-3		C18:3n-6	
	r^1	P^2	r	P	r	P	r	P	r	P	r	P	r	P
C16:0	–	–	–	–	–	–	–	–	–	–	–	–	0.64	<0.0001
C18:0	–	–	–	–	–	–	–	–	–	–	–	–	−0.57	0.0002
C18:1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
C18:2 n-6	–	–	0.40	0.01	–	–	–	–	–	–	–	–	–	–
C18:3 n-3	0.51	0.0014	0.47	0.0041	–	–	0.46	0.0043	–	–	–	–	0.62	<0.0001
C18:3 n-6	–	–	0.44	0.0055	–	–	–	–	–	–	–	–	–	–
C20:0	–	–	0.50	0.001	–	–	–	–	–	–	–	–	0.55	0.0002

r^1 = Pearson correlation coefficients; P^2 = test at 1% probability.

2003). Lamb meat, due to its low n-6:n-3 (2:1) ratio, is more favorable to human health (Wood et al., 2003). Thus, ratios between 2:1 and 4:1 are important for individuals with eating habits that result in a low intake of EPA and DHA. However, diets based on n-6:n-3 ratios of less than 1:1 are not recommended because they inhibit the conversion of linoleic acid to long chain fatty acids.

There was no significant effect ($P > 0.05$) on the atherogenicity index, thrombogenicity and hypocholesterolemic:hypercholesterolemic ratio of fatty acids due to the replacement of soybean meal by peanut cake. Atherogenicity index (IA) and thrombogenicity (IT) indicate the stimulus potential for platelet aggregation; therefore, the smaller the AI and TI values, the greater the amount of anti-atherogenic fatty acids present in a given oil/fat, which consequently leads to greater potential for preventing the onset of coronary heart disease (Turan, Sönmez, & Kaya, 2007).

Saturated fatty acids from the diet correlated with the following meat fatty acids: palmitic acid (C16:0) positively and moderately correlated with linolenic acid (C18:3 n-3) in the meat (Table 8). Stearic fatty acid (C18:0) showed a moderate positive correlation with linoleic (C18:2n-6), α linolenic (C18:3 n-3), γ linolenic (C18: 3 n-6) and arachidonic (20:0) acids, which may have contributed to the deposition of these fatty acids in the meat. This correlation was possibly because palmitic and stearic fatty acids are precursors to unsaturated fatty acids (C18: 2n-6, C18: 3 n-3, C18: 3 n-6) and C20:0; therefore, a high concentration of these fatty acids in the diet can favor the production of their derivatives. This process occurs through the actions of elongase and dessaturase enzymes; elongase acts by adding two carbon atoms to the initial part of the chain, and desaturases act by oxidizing two carbons in the chain, yielding a double bond with a cis configuration (Martin et al., 2006).

There was a moderate and positive correlation between oleic fatty acid (C18:1) and α linolenic acid (C18: 3 n-3) deposited in the meat (Table 8). Oleic acid may compete with α linolenic acid and their intermediate products in reactions carried out by dessaturase and elongase enzymes (Woutersen, Appel, Van Garderen-Hoetmer, & Wijnands, 1999). Additionally, α linolenic acid can be converted to EPA and DHA by these enzymes.

The γ linolenic fatty acid C18:3 n-6 was positively and moderately correlated with palmitic acid (C16:0) due to the process of ruminal biohydrogenation, which consists of the saturation of unsaturated fatty acids and their incorporation into animal muscle. This was observed by Strada et al. (2015).

The γ linolenic acid fatty acid C18:3 n-6 in the diets also negatively and moderately correlated with stearic fatty acid (C18:0). This correlation likely occurs because there is not a final reduction of γ linolenic to stearic fatty acid; when there is complete biohydrogenation, γ linolenic acid is converted to stearic fatty acid. However, the γ linolenic fatty acid C18:3 n-6 levels in the diets positively and moderately correlated with α linolenic acid (C18:3 n-3) and moderately and positively correlated with arachidonic acid (C20:0).

According to the results mentioned above, it is possible to notice the importance of being evaluated the correlation between fatty acids supplied in the diet and deposition of these into the meat since they are influenced by ruminal biohydrogenation and, consequently, can affect the quality of the final product.

Similarly to this work, Strada et al. (2015), using glycerin low purity derived from biodiesel production, aimed to determine the existing linear correlation between consumed fatty acids and deposited in the L. dorsi muscle of Nellore bovines. The authors concluded that the fatty acids present in the diet showed correlations with the majority of fatty acids in meat and modified the fatty acid profile deposited of them. Thus, a decrease of the deposition of monounsaturated fatty acids and higher fatty acids of the ω-6 series, and the ratio between the fatty acids of the series ω-ω 6 and the series -3. On the other hand, no change was noticed in the deposition of lauric, myristic and palmitic fatty acids, considered to be hypercholesterolemic.

4. Conclusions

Peanut cake can be added in the diet of lambs no effect on physical–chemical characteristics. However, the total replacement of the soybean meal altered the proximate composition and fatty acid profile of the meat. As such, its use as an alternative protein source in sheep diets is recommended.

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