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NUTRITIONAL CHARACTERISTICS OF LAMBS MEAT FED DIETS WITH COTTON CAKE

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ABSTRACT

This study aimed to evaluate the nutritional quality of meat of lambs fed with cake originating from cotton production of biodiesel. Forty noncastrated lambs, crossbred Dorper versus Santa Inês from 20.9 to 36.7 kg of body weight finished in feedlot of 99 days and fed diets containing levels of cotton cake (0, 33, 66 and 100%) replacing soybean meal. The chemical composition and physicochemical characteristics were not influenced ($P > 0.05$) by the levels of cotton cake in the concentrate. Regarding the fatty acids found in the meat, there were no differences attributable to diet composition. The fatty acid found in the highest concentration ($P < 0.05$) of cotton cake was the mono-unsaturated oleic acid (49.7%), followed by saturated palmitic acid (23.6%) and stearic acid (18.5%), unsatured poly-linolenic acid (1.93%), saturated myristic (1.58%) and the mono-unsaturated palmitoleic (1.45%).

PRACTICAL APPLICATIONS

In diets for feedlot lambs, the cotton cake can replace soybean meal in the concentrate, corresponding to 120 g/kg of the total diet, and it does not change the nutritional characteristics of meat. Thus, cotton cake, with low cost ingredients, if used in diets for the production of lambs, provides good nutritional quality meat.

INTRODUCTION

The feed habits of meat consumers make them the most demanding consumer in relation to the nutritional quality of foods. Several factors may affect the quality of lamb meat and animal nutrition might have an influence on the meat composition (Ribeiro *et al.* 2011). The elevated costs of concentrate feed used in animal nutrition have presented an impediment to productions systems. Therefore, the search for alternatives for nutritional management that might reduce the productive systems costs without affecting the animal performance in feedlot is imperative.

Furthermore, the utilization of agro-industrial subproducts could be a viable food source from the nutritional and economic point since the subproducts might reduce the costs and the oscillations of productions. The cotton cake is a product of biodiesel industry obtained by pressing the grain during the extraction of the oil (Abdalla *et al.* 2008). Cotton cake might be an efficient ingredient for animal feeding with high protein and energy levels, and yet is a considerable nutritional source (Bomfim *et al.* 2009). According to Voltolini *et al.* (2009), cotton cake could be utilized in different ruminant feeding systems to replace the protein-concentrate in the traditional diets (soybean).

Oilseeds have been utilized as an alternative to decrease saturated fatty acids and to increase polyunsaturated fatty acids with the intent to improve food and nutritional compounds, mainly the animal products. Fatty acid profiles have an importance on meat chemical quality, not quantity,

but food lipid compositions have greater human health influences (Nuernberg *et al.* 2008).

Animals that are fed high-grains diets present uniform carcass with higher marbling and better color fat in meat (Aferri *et al.* 2005). Meats have a great significance on human nutrition, whether for the amino acids, minerals, water, lipids or vitamins. The physicochemical characteristics of meat determine the quality and acceptability (Martínez-Cerezo *et al.* 2005).

Given the above, to include a co-product of low cost in the diet of lambs to provide good quality meat production for human consumption is a major challenge. Due to its nutritional characteristics and the profile of unsaturated fatty acids, cotton cake has that potential. The objective of the current study was to evaluate the nutritional quality of lambs' meat from lambs that are fed diets containing cotton cake from of biodiesel production.

MATERIAL AND METHODS

Animals, Housing and Diets

The experiment was conducted at the Experimental Farm of Federal University of Bahia in São Gonçalo dos Campos, Bahia State, Brazil.

Forty noncastrated lambs (Santa Inês versus Dorper) were used in a completely randomized design. After a 15-day diet, feedlot and management adaptations period, lambs were weighed and presented an initial average body weight of 20.9 ± 2.5 kg. The lambs were distributed into groups, with four diets and 10 replications. Lambs were allocated into individual pens with trough and drinkers with *ad libitum* watering in a feedlot system.

The experimental period lasted 99 days and the body weights were recorded each 28 days. The lambs were fed twice a day (09:00 and 16:00 h) with diets formulated as isonitrogenous (140 g/kg CP [crude protein]) to provide a daily weight gain of 0.2 kg/day, according to NRC (2007) estimates. Diets were supplied as total mixed rations with forage : concentrate ratio of 50% hay (Tifton 85 hay) and 50% concentrate (Table 1). The lambs were randomly assigned to one of the four diets containing 0, 40, 80 and 120 g/kg of cotton cake on dry matter basis which replaced 33, 66 and 100% of the soybean meal (Table 2).

TABLE 1. COMPOSITION (G/KG ON DRY MATTER) OF THE NUTRIENTS AND DIETS FED TO DORPER VERSUS SANTA INÊS LAMBS FROM 20.9 TO 36.7 KG OF BODY WEIGHT

	Cotton cake levels (g/kg DM)			
Ingredients	0.0	40	80	120
Corn grain	349	347	345	343
Soybean meal	120	80.0	40.0	0.00
Cotton cake	0.00	40.0	80.0	120
Mineral salt†	15.0	15.0	15.0	15.0
Urea	16.0	18.0	20.0	22.0
Tifton 85 hay	50.0	50.0	50.0	50.0

† Per kg: calcium, 120 g; phosphorus, 87 g; sodium, 147 g; sulfur, 18 g; copper, 590 mg; cobalt, 40 mg; chrome, 20 mg; iron 1.800 mg; iodine, 80 mg; manganese, 1.300 mg; selenium, 15 mg; zinc, 3.800 mg; molybdenum, 300 mg; fluorine (maximum), 870 mg.
DM, dry matter.

Nutrient and Diet Analyses

DM content of the ingredients (Tifton 85 hay, concentrate mix) was determined by method 934.01 (AOAC 1990). Ash content was measured by method 942.05 (AOAC 1990) to determine the organic matter. Nitrogen concentration was determined by the Kjeldahl method (AOAC 1990; ID 920.87). After, the CP was calculated by N content multiplied by a factor of 6.25. Ether extract (EE) content was determined by method 920.85 (AOAC 1990). Neutral detergent fiber (NDF) content was measured according to the recommendations of Mertens (2002) using α-amylase and expressed inclusive of residual ash. The acid detergent fiber was measured using the method 973.18 (AOAC 1990), and expressed inclusive of residual ash. Total carbohydrates (TC) were estimated by the equation according to Sniffen *et al.* (1992). Nonfibrous carbohydrate was determined as: NFC = 100 (CP + NDF + EE + ash). Total digestible nutrient content of diets was obtained by the methodology described by NRC (2007). The samples were analyzed in the Laboratory of Feed Analyses and Animal Nutrition at the Federal University of Bahia.

Sampling and Meat Quality

Lambs were slaughtered (36.7 ± 3.71 kg BW) according to industrial practices in Brazil at a commercial slaughterhouse located at 116 km from the Experimental Farm of Federal University of Bahia. The carcasses were chilled for 24 h at 4C. After chilling, the left side of the carcass was used to determine quantitative characteristics (Haruyoshi *et al.* 2012).

The samples of Longissimus muscle were identified and excised 24 h postmortem and the pH24h was determine using a pH Meter Text Model (Tradelab, Contagem – MG – Brazil) with a penetration pH-electrode to average three points over the Longissimusthoracis et lumborum. Muscle color was evaluated according to a point scale at 30 min after a cross-sectional cut was made on the Longissimus muscle between the 10th and 11th ribs (cherry red: 1.0–1.5, slightly cherry red: 2.0–2.5, slightly red: 3.0–3.5, red: 4.0–4.5 and dark red: 4.5–5.0). The samples were individually placed in unsealed plastic bags and frozen (−18C) immediately, to be analyzed later.

TABLE 2. COMPOSITION (G/KG DRY MATTER) OF THE NUTRIENTS AND DIETS FED TO DORPER VERSUS. SANTA INÊS LAMBS FROM 20.9 TO 36.7 KG OF BODY WEIGHT

		g/kg DM								
	DM	OM	Ash	CP	EE	TC	NFC	NDF	ADF	TDN
Ingredients										
Corn grain	887	854	14.6	644	45.0	876	756	120	48.0	871
Soybean meal	902	266	73.4	390	19.3	517	362	155	111	787
Cotton cake	926	512	48.8	240	75.6	636	192	443	650	333
Mineral salt	980	–	–	–	–	–	–	–	–	–
Urea	990	–	–	2620	–	–	–	–	–	–
Tifton 85 hay	911	319	68.1	50.0	13.7	868	147	721	402	562
Diets										
0.0†	874	521	47.9	137	24.9	819	397	421	229	692
40‡	873	531	46.9	137	27.0	822	389	433	238	694
80§	872	541	45.9	136	29.2	825	381	444	247	635
120¶	871	551	44.9	136	31.3	828	372	455	255	650

† Without cotton cake.

‡ 40 g/kg of cotton cake on DM basis.

§ 80 g/kg of cotton cake on DM basis.

¶ 120 g/kg of cotton cake on DM basis

ADF, acid detergent fiber; CP, crude Protein; DM, dry matter; EE, ether extract; NDF, neutral detergent fiber; NFC, nonfiber carbohydrates; OM, organic matter; TC, total carbohydrates; TDN, total digestible nutrients.

At the moment of laboratory analysis, the samples were thawed at 10C for 20 h in a refrigerator and the *Longissimus thoraciset lumborum* were dissected. All the samples were freeze-dried for 72 h to obtain the centesimal composition. The moisture, protein, fat and ash contents were analyzed in triplicate according to standardized protocols (ISO-R-1442, ISO-R-937, ISO-R-1443 and ISO-R-1998), respectively (AOAC 1990).

The water-holding capacity was determined based on the technique described by Hamm (1960). Approximately 500 mg of samples was weighed, placed between two filter papers and then left under 10.0 kg weight for 5 min. The samples were weighed and water holding capacity was determined by the exudated water weight through the following formula: 100 – [(initial weight – final weight)/(initial weight)].

Cooking loss was determined by weight after cooking. The muscle samples were separated into individual standardized thick slices, placed in an electric oven and cooked at a defined internal temperature (72C). When the endpoint temperature was reached, the samples were removed from the electric oven and maintained at room condition until they equilibrated and were weighed. Cooking loss is the ratio of sample weight before and after being cooking, multiplied by 100.

Warner-Bratzler shear force (WBSF) was performed after cooking loss. The WBSF mechanical properties of the meats were obtained using a texture analyzer (Stable Micro Systems TA-TX^2 Plus; Texture Technologies Corp., Surrey, U.K.) with a 5.0-kg load cell (Lyon *et al.* 1998).

Total lipids were extracted using the Bligh and Dyer (1959) method with a chloroform/methanol mixture. Fatty acid methyl esters (FAME) were prepared by triacyl glycerine methylation according to ISO (1978) method. FAME were analyzed in a gas chromatograph (Thermo–Finnigan Trace, GC Ultra, Waltham, MA), equipped with a flame ionization detector and a fused silica capillary column BPX-70 (120 m, 0.25 mmi. d). The column temperature was programmed at 140C for 10 min, 200C (15C/min) for 1 min, 230C (10C/min) for 1 min, 233C (0.4C/min) for 3 min and 238C (0.5C/min) for 2 min. Gas flows (White Martins, São Paulo, Brazil) were 30 mL/min for carrier gas (H_2); 30 mL/min for make-up gas (N_2); and 250 mL/min for carrier synthetic flame gas. The injection volume was 1.2 μL. Peak areas were determined by the method of normalization, using the software ChromQuest 4.1 (Thermo Electron, Italy). The quantification of the fatty acids was performed after normalization of areas. The peaks were identified by comparing retention times of standard methyl esters of fatty acids (189-19, O-5632 and O-5626, Sigma, St. Louis, MO) and after checking the equivalent chain length. Data were expressed as percentages of the normalized area of fatty acids (Table 3).

The saturated fatty acids (SFA), mono-unsaturated fatty acids (MUFA), poly-unsaturated fatty acids (PUFA), $n-3$ and $n-6$ fatty acids were calculated by sum of respective fatty acids group. The PUFA : SFA and $n-3$ $n-6$ ratios were determined by ratio of categories. The fatty acids wanted (FAW) was obtained to FAW = MUFA + PUFA + C18:0. Atherogenicity index (AI) was calculated by the equation: AI = (C14:0 × 4) + C16:0 / (MUFA + Σn6 + Σn3). The thrombogenicity index (TI) were determined as TI = (C14:0 + C16:0 + C18:0) / [(0.5 × ΣMUFA) + (0.5 × Σn6 + (3 × Σn3) + (Σn3 / Σn6)] (Ulbricht and Southgate

TABLE 3. FATTY ACIDS COMPOSITION ON DIETS CONTAINING DIFFERENT COTTON CAKE LEVELS FED TO DORPER VERSUS SANTA INÊS LAMBS FROM 20.9 TO 36.7 KG OF BODY WEIGHT

		Cotton cake levels (g/kg DM)			
Fatty acids, %	HAY	0	40	80	120
SFA	33.6	21.2	21.3	21.4	21.6
MUFA	8.70	22.5	22.6	22.6	22.6
PUFA	57.7	52.8	52.4	52.0	51.7
n – 6	18.3	32.1	31.9	31.8	31.6
n – 3	39.4	20.7	20.5	20.2	20.0
PUFA : SFA	1.72	2.49	2.46	2.43	2.40
n – 6 : *n* – 3	0.46	1.55	1.56	1.57	1.58
FAW	70.0	78.8	78.5	78.1	77.7
IA	2.89	1.49	1.58	1.66	1.79
IT	0.23	0.22	0.23	0.23	0.23
h : H	2.38	4.55	4.48	4.41	4.33
14:0	0.62	0.32	0.34	0.36	0.39
15:0	0.22	0.11	0.11	0.11	0.11
16:0	27.3	16.2	16.4	16.6	16.8
16:1	0.11	0.10	0.11	0.12	0.13
17:0	0.44	0.28	0.28	0.28	0.27
17:1	0.08	0.06	0.07	0.07	0.07
18:0	3.60	3.53	3.45	3.38	3.31
18:1 *n* – 9C	7.60	21.7	21.8	21.8	21.8
18:2 *n* – 6	16.7	31.0	30.9	30.8	30.7
18:3 *n* – 3	39.4	20.7	20.5	20.3	20.0
20:0	1.00	0.51	0.51	0.51	0.51
20:3 *n* – 6	1.57	1.02	1.00	0.98	0.97
22:0	0.40	0.23	0.23	0.22	0.22
24:1	0.91	0.63	0.63	0.62	0.61

FAW, fatty acids wanted; HAY, Tifton 85 hay; h : H, hypo : hypercholesterolemic fatty acids; IA, index of atherogenicity; IT, index of thrombogenicity; MUFA, mono-unsaturated fatty acids; n – 3, fatty acids n – 3; n – 6, fatty acids n – 6; PUFA, poly-unsaturated fatty acids; SFA, saturated fatty acids; DM, dry matter.

1991). By Santos-Silva *et al.* (2002), the hypo: hypercholesterolemic fatty acids were classified to hypocholesterolemic and hypercholesterolemic ratio (h : H = (MUFA + PUFA) / (C14:0 + C16:0).

The fatty acid composition on *Longissimus* muscle of Dorper verus Santa Inês lambs from 20.9 to 36.7 kg of BW finished in feedlot and fed on diets containing different cotton cake levels to replace the soybean meal consisted of multivariate data sets that were interpreted using principal component (PC) analysis.

Statistical Analysis

The experimental design was completely randomized with four treatments and 10 replications. All characteristics under study were tested for normality. Those that showed normal distribution were analyzed using MIXED procedure (SAS 2004) to determine the effect of cotton cake concentration in the diet. Those characteristics that did not show normal distribution where analyzed by the generalized linear models method (Nelder and Wedderburn 1972), using the GENMOD procedure (SAS 2004). In these cases, the gamma distribution and the reciprocal link function were used. All treatments means were evaluated by Chi-square test using LSMEANS option (SAS 2004). The principal component analysis was conducted using SAS (2004) software for multivariate calibration.

RESULTS AND DISCUSSION

Cotton cake from biodiesel production which replaced soybean meal did not change the meat pH values ($P > 0.05$) in all diets (Table 4). The pH values observed were considered normal (5.82) for lamb's meat when no stress pre-slaughter happened. According to Sañudo (1992) the pH means would be 5.6–5.9 after 24 h. The pH presented high correlation with the iso-electric point of muscular proteins producing lactic acid and presenting influence on water activity (Huff-Lonergan and Lonergan 2005). On other hand, the diets with high crude protein would influence the water-holding capacity due the higher formation of myofibrillar proteins in meat.

Water-holding capacity and thawing losses were similar ($P > 0.05$) when the cotton cake was added to the diets. The lower water-holding capacity on meat would result in an increase of meat exudation and a reduction of nutritional composition (Sañudo 1992). According to Vieira *et al.*

TABLE 4. MEAT CHARACTERISTICS OF DORPER VERSUS SANTA INÊS LAMBS FROM 20.9 TO 36.7 KG OF BODY WEIGHT FINISHED IN FEEDLOT AND FED ON DIETS CONTAINING DIFFERENT COTTON CAKE LEVELS ON REPLACEMENT THE SOYBEAN MEAL

	Cotton cake levels (g/kg DM)					*P*-value		
Items	0	40	80	120	SEM	L	Q	S versus cotton
pH	5.88	5.82	5.78	5.80	0.06	0.86	0.83	0.54
Water holding capacity, %	63.7	62.2	61.5	63.2	0.51	0.49	0.36	0.24
Thawing loss, %	23.5	25.2	26.1	26.0	0.79	0.71	0.78	0.22
Shear force, kgf/cm^2	1.93	2.14	2.20	2.25	0.13	0.77	0.97	0.36
Color, points	2.90	2.70	2.80	2.60	0.09	0.31	0.33	0.31

SEM, standard error of mean; S versus cotton, soybean meal versus Cotton cake; L, linear effect; Q, quadratic effect.

TABLE 5. CHEMICAL COMPOSITION ON *LONGISSIMUS* MUSCLE OF DORPER VERSUS SANTA INÊS LAMBS FROM 20.9 TO 36.7 KG OF BODY WEIGHT FINISHED IN FEEDLOT AND FED ON DIETS CONTAINING DIFFERENT COTTON CAKE LEVELS ON REPLACEMENT THE SOYBEAN MEAL

	Cotton cake levels (g/ kg DM)				*P*-value			
Items	0	40	80	120	SEM	L	Q	S versus Cotton
Moisture, g/kg	73.27	73.22	72.73	72.98	0.29	0.12	0.80	0.49
Ash, g/kg	1.10	1.10	1.09	1.08	<0.01	0.37	0.51	0.27
Crude protein, g/kg	22.42	22.57	23.12	22.78	0.34	0.50	0.38	0.29
Total lipids, g/kg	3.20	3.11	3.06	3.16	0.14	0.66	0.79	0.93

SEM, standard error of mean; S versus cotton, soybean meal versus Cotton cake; L, linear effect; Q, quadratic effect.

(2010) the thawing loss could be attributed to the genotypic characteristics of animals, handling pre and post-slaughter conditions and the methodology utilized to evaluate the samples.

The variation observed on thawing loss (26.1%) was considered normal for cross-bread lambs (Zapata *et al.* 2000). Probably, the similar genotypic characteristics and handling conditions contributed to the observed a no-difference.

No differences ($P > 0.05$) were observed for WBSF and Longissimus color when soybean meal was replaced by cotton cake in the diets of lambs from 20.9 to 36.7 kg BW finished in feedlot.

The shear force was not affected by replacing soybean meal by cotton cake levels of lambs finished in feedlot. The result for shear force (2.13 kgf/cm^2) was considered very good for lamb's meat (Lepetit 2008; Osório *et al.* 2009). According to Monte *et al.* (2012) the shear force values until 8.0 kgf/cm^2 could be classified as soft and should result in high consumer acceptance. Tenderness of meat has been associated with intramuscular fat content (Purchas *et al.* 2002). On the other hand, meat tenderness might be due to the quantity, solubility and space organization of collagen (Sañudo *et al.* 2000a). Thus, the similar average daily gain (0.186 kg/day), age of slaughter (0.9 ± 1.0 months) and final BW (36.7 ± 3.71 kg) of Dorper versus Santa Inês lambs fed with cotton cake replacing soybean meal could explain the means observed.

The meat color is influenced by the amount of water on the meat surface and is a consequence of pH and water-holding capacity (Pearce *et al.* 2011). Likewise, it is an important commercial characteristic that influences consumer behavior (Mancini and Hunt 2005). According to Silva Sobrinho *et al.* (2005) the meat color of sheep must be between "cherry" to "slightly dark red", depending on animals' age. In the current study, the color was considered good (2.75 points), ranging between "pink" and "slightly red" (Osório *et al.* 2009). Adequate nutrition, low age of animals and handling pre or post-slaughter conditions may have affected meat color (Mancini and Hunt 2005).

There were no differences ($P > 0.05$) with regard to moisture, ash, crude protein and total lipids in *Longissimus* muscle when feeding different amounts of cotton cake (Table 5).

The chemical compositions of meat were considered normal to Dorper versus Santa Inês lambs slaughtered at a similar final BW (36.7 ± 3.71 kg). According to Madruga *et al.* (2008), the sheep meat could present 75% moisture, 1.1% ash, 23% crude protein and 4% total lipids. Likewise, the chemical compositions could be influenced by the diets and by animal fatness (Zeola *et al.* 2004). In the current experiment, the diets were formulated as iso-nitrogenous to allow a similar average daily gain (0.186 kg/day). Thus, the soybean meal replaced by cotton cake levels did not alter the chemical composition on meat of lambs finished in feedlot by 99 days.

SFA, MUFA and PUFA fatty acids were not affected ($P > 0.05$) by cotton cake levels (Table 6). Amounts of $n-6$ and the PUFA : SFA were similar ($P > 0.05$) in all diets. However, the $n-3$ presented quadratic effect ($P < 0.05$). The $n-6 : n-3$ ratio was increased ($P < 0.05$) with cotton cake added in the diets. The FAW, AI, TI and hypo : hypercholesterolemic fatty acids (h : H) were similar ($P > 0.05$) among all cotton cake levels in diets.

SFA represented approximately 43.4% of total FA in the meat of lambs fed cotton cake levels. According to Costa *et al.* (2012), the meat of lambs could present high concentrations of saturated, mono-unsaturated and poly-unsaturated fatty acids. However, the soybean meal replaced by cotton cake demonstrated higher concentrations of mono-unsaturated fatty acids (52.5%) of total FA. The MUFA intake is beneficial to the human health by decreasing the low-density lipoprotein (LDL) without influencing the high-density lipoprotein (HDL) concentration (Kinsella *et al.* 1990). According to Valsta *et al.* (2005), the SFA are involved on cholesterol levels in human blood, while the unsaturated FA are considered to be hypocholesterolemic FA.

The cotton cake levels in the diets did not influence the poly-unsaturated fatty acids (4.26%) of Dorper versus Santa Inês lambs meat from 20.9 to 36.7 kg of BW. According to De Smet *et al.* (2004), the PUFA is mainly influenced by genetics and, principally, by animal fatness, and less by

TABLE 6. FATTY ACIDS COMPOSITION ON *LONGISSIMUS* MUSCLE OF DORPER VERSUS SANTA INÊS LAMBS FROM 20.9 TO 36.7 KG OF BODY WEIGHT FINISHED IN FEEDLOT AND FED ON DIETS CONTAINING DIFFERENT COTTON CAKE LEVELS ON REPLACEMENT THE SOYBEAN MEAL

	Cotton cake levels					*P*-value		
Fatty acids, %	0.0	40	80	120	SEM[1]	L	Q	S versus Cotton[2]
SFA[3]	44.2	42.3	43.8	43.3	1.37	0.75	0.98	0.82
MUFA[4]	51.8	52.7	53.6	51.2	1.29	0.20	0.67	0.79
PUFA[5]	4.07	4.19	4.34	4.46	2.84	0.80	0.50	0.33
n – 6[6]	2.33	2.62	2.57	2.65	0.18	0.08	0.15	0.05
n – 3[7]	1.22	1.32	1.30	1.12	0.06	0.96	0.0009	0.01
PUFA : SFA[8]	0.09	0.09	0.11	0.10	0.01	0.35	0.83	0.32
n – 6:*n* – 3[9]	1.87	2.07	1.94	2.83	0.18	0.0007	0.06	0.02
FAW[10]	73.4	73.1	74.1	74.3	0.68	0.20	0.58	0.59
AI[11]	0.54	0.54	0.51	0.52	0.02	0.26	0.45	0.46
TI[12]	8.23	8.61	8.25	8.81	0.33	0.93	0.17	0.32
h : H[13]	2.27	2.22	2.34	2.33	0.07	0.31	0.45	0.75
Saturated fatty acids								
14:0[14]	1.70	1.65	1.45	1.53	0.06	0.28	0.04	0.03
15:0	0.23	0.24	0.24	0.25	0.01	0.92	0.48	0.33
16:0	23.8	24.2	23.3	23.2	0.61	0.27	0.59	0.72
17:0	0.92	0.82	0.90	0.95	0.02	0.01	0.70	0.52
18:0	17.8	18.6	18.1	19.4	0.95	0.60	0.47	0.40
20:0	0.09	0.10	0.08	0.17	0.03	0.09	0.05	0.98
22:0	0.07	0.07	0.11	0.02	<0.01	0.0001	0.0001	0.01
Mono-unsaturated fatty acids								
14:1[15]	0.06	0.07	0.07	0.08	<0.01	0.03	0.31	0.01
15:1[16]	0.04	0.03	0.03	0.04	<0.01	0.0001	0.86	0.01
16:1[17]	1.52	1.53	1.54	1.21	0.08	0.0059	0.09	0.03
17:1	0.73	0.65	0.70	0.69	0.03	0.31	0.26	0.13
18:1 *trans*	49.6	50.2	50.3	48.6	0.94	0.44	0.58	0.80
22:1 *n* – 9[18]	0.11	0.13	0.14	0.12	<0.01	0.19	0.0077	0.02
24:1[19]	0.02	0.05	0.03	0.04	2.70	0.0069	0.0003	0.0001
Poly-unsaturated fatty acids								
18:2 *n* – 6	1.88	2.02	1.98	1.83	0.15	0.99	0.81	0.36
18:2 *cis* 9 *trans* 11 – CLA	0.38	0.37	0.37	0.36	0.03	0.26	0.48	0.98
18:2 *cis* 12 *trans* 10 – CLA	0.13	0.12	0.13	0.11	<0.01	0.35	0.41	0.19
18:3 *n* – 3	0.30	0.30	0.27	0.28	0.01	0.08	0.46	0.15
18:3 *n* – 6[20]	0.10	0.10	0.09	0.30	0.01	0.0001	0.0001	0.0001
20:3 *n* – 3[21]	0.72	0.94	0.71	0.55	0.05	0.0001	0.0069	0.0002
20:3 *n* – 6[22]	0.06	0.12	0.08	0.39	0.02	0.0001	0.0001	0.0001
20:4 *n* – 6[23]	0.10	0.14	0.12	0.09	0.006	0.0001	0.004	0.03
20:5 *n* – 3 – EPA[24]	0.12	0.11	0.09	0.08	0.01	0.0001	0.22	0.0014
20:5 *n* – 6[25]	0.16	0.22	0.21	0.14	0.01	0.0016	0.02	0.0015
22:6 *n* – 3 – DHA[26]	0.09	0.04	0.17	0.21	0.02	0.0001	0.03	0.0001

[1] Standard error of mean. [2] Soybean meal versus Cotton cake. [3] Saturated fatty acids. [4] Mono-unsaturated fatty acids. [5] Poly-unsaturated fatty acids. [6] Fatty acids *n* – 6. [7] Fatty acids *n* – 3 – $\hat{Y} = 1.88818 - 0.00573x + 0.00011221x^2$ ($r^2 = 0.37$). [8] PUFA : SFA ratio. [9] *n* – 6:*n* – 3 ratio – $\hat{Y} = 1.93881 - 0.00648x + 0.00014614x^2$ ($r^2 = 0.95$). [10] Fatty acids wanted. [11] Atherogenicity index. [12] Thrombogenicity index. [13] Hypo : hypercholesterolemic fatty acids. [14] $\hat{Y} = 1.71907 - 0.00532x + 0.00003341x^2$ ($r^2 = 0.16$). [15] $\hat{Y} = 0.12338 - 0.00056888x$ ($r^2 = 0.45$). [16] $\hat{Y} = 0.18997 + 0.00008513x$ ($r^2 = 0.98$). [17] $\hat{Y} = 1.50085 + 0.00492x$ ($r^2 = 0.94$). [18] $\hat{Y} = 0.07762 - 0.00110x + 0.00002856x^2$ ($r^2 = 0.72$). [19] $\hat{Y} = 0.02408 + 0.00060982x - 0.00000494x^2$ ($r^2 = 0.25$). [20] $\hat{Y} = 0.13311 - 0.00018406x$ ($r^2 = 0.10$). [21] $\hat{Y} = 0.30728 - 0.00034640x + 8.98208x^2$ ($r^2 = 0.13$). [22] $\hat{Y} = 0.11421 - 0.00332x + 0.00005336$ ($r^2 = 0.85$). [23] $\hat{Y} = 0.09625 - 0.00000623x - 0.00000623x^2$ ($r^2 = 0.20$). [24] $\hat{Y} = 0.83572 - 0.00228x$ ($r^2 = 0.16$). [25] $\hat{Y} = 0.08092 - 0.00307x + 0.00006262x^2$ ($r^2 = 0.81$). [26] $\hat{Y} = 0.12172 - 0.00015275x$ ($r^2 = 0.2$).

L, linear effect; Q, quadratic effect.

nutrition. To compare the diet intakes of the lambs, the level of 100% soybean meal presented a higher PUFA ratio (52.8%), with a decrease in PUFA ratio with an increase in cotton cake levels (Table 3 – 52.4, 52.0 and 51.7%). Still, cotton cake as a replacement to soybean meal in diets did not affect the FA involved with cardiovascular risks (Ribeiro *et al.* 2011).

FA myristic (14:0) was lower ($P < 0.05$) in meat of lambs fed with cotton cake added on a diet (Table 6). Levels of tetradecanoic acid (14:1) and pentadecanoic acid (15:1) were increased ($P < 0.05$) with soybean meal being replaced by cotton cake in the diets. However, the hexadecanoic acid (16:1) decreased ($P < 0.05$) with inclusion of cotton cake in the diets. The erucic acid (22:1 $n-9$) and nervonic acid (24:1) were higher ($P < 0.05$) with addition of cotton cake in the diets.

The concentration of the sum $n-3$ FA presented a quadratic effect reaching a maximum level of 42.4% cotton cake in the diet. The sum $n-3$ FA could be represented for linolenic acid (18:3 $n-3$), eicosapentaenoic acid (20:5 $n-3$ – EPA) and docosahexaenoic acid (22:6 $n-3$ – docosahexaenoic (DHA)). Increases in sum $n-$ FA would reduce then $-6/n-3$ ratio (Wood *et al.* 2004).

The PUFA : SFA ratio (0.10%) is below the recommended rate which is considered beneficial (0.42) to human health (HMSO 1994). According to Wood *et al.* (2004), the level normally seen in lamb meat should be 0.10%.

The soybean meal replacement to cotton cake increased ($P < 0.05$) the γ-linolenic acid (18:3 $n-6$), dihomo-γ-linolenicacid (20:3 $n-6$) and docosahexaenoic acid (22:6 $n-3$ – DHA). However, the cotton cake addition reduced ($P < 0.05$) the levels of eicosatrien acid (20:3 $n-3$), arachidonic acid (20:4 $n-6$), eicosapentaenoic acid (20:5 $n-3$ – EPA) and eicosanoic acid (20:5 $n-6$).

The values of $n-6 : n-3$ ratio from 1.87 (0.0) to 2.83 (120) were considered healthy and lower than four are indicated as the most favorable in order to prevent some human cardiovascular diseases (Scollan *et al.* 2006). The meat of lambs that were fed with cotton cake replacing soybean meal presented higher values when compared with results by other authors (Wood *et al.* 2008; Paim *et al.* 2014).

The levels of FAW were considered higher than those obtained by other researchers (Banskalieva *et al.* 2000; Madruga *et al.* 2005). The elevated concentration of FAW (73.7%) could be explained by the high MUFA values on meat lambs.

The AI and TI presents high correlation with LDL and HDL in human serum concentrations (Chardigny *et al.* 2008). The soybean meal replaced by cotton cake levels could reduce the index of atherogenicity ratio (3.70%) due the decrease of 14:0 and 16:0 FA. According to Turan *et al.* (2007), the lower levels of atherogenic FA are better to human health.

According to Banskalieva *et al.* (2000) the ratio hypo : hypercholesterolemic FA represents the beneficial lipids encountered in meat of lambs (2.45%). The ratio h : H could represent the functional effects of fatty acids about the metabolism of cholesterol transported by lipoproteins influencing the cardiovascular risks. In this study, the means of h : H on meat lambs were considered satisfactory (2.29%) to human health.

The FA oleic (49.7%), palmitic (23.6%) and stearic (18.5%) presented higher concentration on total FA. This fact has been corroborated by Demirel *et al.* (2006), Nuernberg *et al.* (2008) and Leão *et al.* (2011) who reported differences on FA compositions of lambs fed different diets.

According to Bonanome and Grundy (1988), the oleic FA should decrease LDL concentrations on human serum that would be better to human health. The adequate oleic FA concentrations on meat lambs are related to ruminal biohydrogenation of stearic FA (Wood *et al.* 2008).

On the other hand, the palmitic FA it is considered adverse to HDL serum and would be favorable to increase human cardiovascular diseases (Moloney *et al.* 2001). However, palmitic FA values obtained were lower than those observed by Sañudo *et al.* (2000b) when evaluated different sheep breeds.

According to Paim *et al.* (2014), the fatty acids in whole cottonseed have a greater protection from rumen microorganisms than other diets that has lipids directly exposed to biohydrogenation. Biohydrogenation of unsaturated FA from the diet occurs slowly, resulting in an increased concentration of these acids in the rumen, making it available for absorption in the intestinal tract (Bauman *et al.* 2011). In this study, the increase of cotton cake levels on diets probably influenced the saturation of unsaturated FA on ruminal ambiance. Thus, the myristic acid (14:0) reduced (10%) with total replacement of soybean meal by cotton cake. According to Cater and Denke (2001) the 14:0 FA present on lamb's meat do not affect the human cholesterol serum.

Likewise, the potential effects of cotton co-products on reduction of biohydrogenation process (Paim *et al.* 2014) could explain the increase on MUFA concentrations (tetradecanoic acid – 33.3%, pentadecanoic acid – 0.12%, erucic acid – 9.09% and nervonic acid – 100%). However, the hexadecanoic acid (16:1) decreased (20.4%) with 120 g/kg of cotton cake inclusion on the diets. The hexadecanoic acid effects on human health were not totally elucidated, but this FA has been associated to hepatic metabolism presenting influence on LDL concentrations in human serum (Fernandes *et al.* 2009).

The FA linoleic (1.93%) and α-linolenic (0.29%) presented higher concentration on PUFA. According to Doreau and Ferlay (1994), minor concentrations of these FA are available for absorption in the intestinal tract; however, they

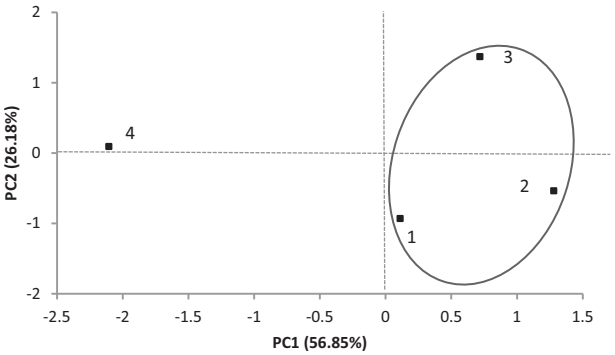

FIG. 1. THE FIRST TWO PRINCIPAL COMPONENTS FOR WHOLE MILK POWDER FATTY ACIDS COMPOSITION ON LONGISSIMUS MUSCLE OF DORPER VERSUS SANTA INÊS LAMBS FROM 20.9 TO 36.7 KG OF BODY WEIGHT FINISHED IN FEEDLOT AND FED ON DIETS CONTAINING DIFFERENT COTTON CAKE LEVELS ON REPLACEMENT OF THE SOYBEAN MEAL

1 = Diet without cotton cake; 2 = 40 g/kg of cotton cake on dry matter basis; 3 = 80 g/kg of cotton cake on dry matter basis and 4 = 120 g/kg of cotton cake on dry matter basis.

are considered essential compounds $n-6$ and $n-3$ (Wood *et al.* 2008).

The soybean meal replacement to cotton cake increased the γ-linolenic acid (200%), dihomo-γ-linolenic acid (550%) and docosahexaenoic acid (133%). These compounds could decrease cardiovascular disease risk in humans (Wood *et al.* 2008). However, the cotton cake addition reduced the levels of eicosatrien acid (23.6%), arachidonic acid (10%), eicosapentaenoic acid (33.3%) and eicosanoic acid (12.5%).

The discrimination of treatments, depending on the fatty acid composition by principal component analysis, is shown in Fig. 1.

The score portion on PC1 versus PC2, with a cumulative contribution of 83.03%, was the easiest way to visualize the main trends defined in the samples of the different treatments. There was a tendency of separation between the samples according to the increased cotton cake level of the treatments.

According to the principal component analysis, the increasing addition of cotton cake in the diets of sheep was distinguished depending on the composition of fatty acids in two different groups (Fig. 1). It was found that the samples could be discriminated by treatment along the PC1. The sample with high levels of cotton cake is located on the negative extreme of the PC1, while the samples with cotton cake replacement level of 0, 33 and 66% were classified into only one group.

Thus, given the above, it can be concluded that in diets for feedlot lambs, the cotton cake can replace soybean meal in the concentrate, corresponding to 120 g/kg of the total diet, because it does not change the nutritional characteristics of meat.

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