Rev. Bras. Saúde Prod. Anim., Salvador, v.23, 01 - 23, e202100082022, 2022
http://dx.doi.org/10.1590/S1519-9940202100082022

Animal Nutrition
Received on: 24/02/2021
Accepted on: 27/05/2022

Cottonseed and Soy-bean agro-industrial by-products used in feedlot cattle diet: effects on beef fatty acid profile and quality parameters

Subprodutos agroindustriais de caroço de algodão e soja utilizados na dieta de bovinos confinados: efeitos no perfil de ácidos graxos e parâmetros de qualidade da carne bovina

Polizel Neto, Angelo
https://orcid.org/0000-0003-1983-2723

Roça, Roberto de Oliveira
https://orcid.org/0000-0002-1776-2066

Arnandes, Renata Helena Branco
https://orcid.org/0000-0001-7034-5993

Bonilha, Sarah Martins
https://orcid.org/0000-0002-8055-4112

Araújo, Claudio Vieira de
https://orcid.org/0000-0001-9378-7348

Gomes, Helen Fernanda Barros
https://orcid.org/0000-0003-1168-0999

Bento, Felipe Cecconelo
https://orcid.org/0000-0003-1586-7355

Universidade Federal de Mato Grosso-UFMT, Campus Universitário de Rondonópolis Rodovia MT 270, n. 5.055, Bairro: Área Interna. CEP: 78735-910 – Rondonópolis/MT, Brasil
Universidade Estadual Paulista – UNESP, Faculdade de Ciências Agronômicas - Câmpus de Botucatu, Acessos: Av. Universitária, 3780 - Altos do Paraíso, R. José Barbosa de Barros, 1780, CEP 18610-034, Botucatu/SP, Brasil
Instituto de Zootecnia - IZ/APTA/SAA-SP, Rua Heitor Penteado, 56, CEP: 13460-000, Nova Odessa/SP, Brasil
Universidade Federal de Mato Grosso - UFMT Campus Universitário de Sinop, Avenida. Alexandre Ferronato, 1.200 - Bairro: Setor Industrial, CEP: 78550-000 – Sinop/MT, Brasil
Universidade Federal de Mato Grosso-UFMT - Campus Universitário de Cuiabá, Av. Fernando Correa da Costa, 2.367 – Bairro: Boa Esperança, CEP: 78060-900, Cuiabá/MT, Brasil

*Mail for correspondence: gomeshfb@gmail.com

ABSTRACT

Beef composition are directly influenced by the dietary fat, particularly in ruminants, due to rumen biohydrogenation, which promotes alterations in the dietary fatty acid (FA) profile and affects the meat quality. Beef sensorial, chemical, and FA compositions of intramuscular and subcutaneous fat were evaluated, from 40 Nellore males finished on feedlot diet based, containing cottonseed (CSB) and soybean by-product (SOB) as agro-industrial by-product fat sources. CSB as a fat source, did not alter the beef pH, shear force, chemical composition, or subcutaneous FA profile compared with the SOB diet. Differences were observed at yellow and red beef color, with low and high CSB diet inclusion; on the contrary, inclusion of SOB in the diet led to an intensely unpleasant aroma in aged and cooked meats. Regarding beef FA profile, CSB with 3% dietary fat

ISSN 1519 9940

produced steaks with a lower proportion of $C_{17:0}$, having 1.359 and 3.238 g/100 g of intramuscular FA, whereas CSB with 5% dietary fat led to an increase in $C_{18:2n\text{-}6}$, with 0.298 and 0.132 g/100 g of intramuscular FA in steaks from animals fed with CSB and SOB, respectively. CSB produced more intense red beef color, unpleasant aroma, and higher linoleic acid content; however, the color and aroma of the meat produced from cattle fed with CSB in the diet were less intense and were like those observed in cattle fed with SOB; these could therefore be recommended for use as agro-industrial by-products in beef cattle diet.
Keywords: cottonseed, fat source, meat quality, soybean

RESUMO

A composição da carne bovina é influenciada diretamente pela gordura da dieta, principalmente em ruminantes, devido à biohidrogenação ruminal, que promove alterações no perfil de ácidos graxos dietéticos e afeta a qualidade da carne. Foram avaliadas às composições sensoriais, químicas e de ácido graxo da carne, da gordura intramuscular e subcutânea, de 40 machos Nelore terminados em dieta de confinamento contendo caroço de algodão (CSB) e subproduto de soja (SOB) como fontes de gordura de subprodutos agroindustriais. CSB, não alterou o pH da carne, força de cisalhamento, composição química ou perfil de ácido graxo subcutâneo em comparação com a dieta SOB. Diferenças foram observadas na cor amarela e vermelha da carne bovina, com baixa e alta inclusão de CSB na dieta; a inclusão de SOB na dieta levou a um aroma intensamente desagradável em carnes envelhecidas e cozidas. Em relação ao perfil de ácido graxo da carne bovina, CSB com 3% de gordura dietética produziu bifes com menor proporção de $C_{17:0}$, tendo 1.359 e 3.238 g / 100 g de ácido graxo intramuscular, enquanto CSB com 5% de gordura dietética levou a um aumento de $C_{18:2n\text{-}6}$, com 0,298 e 0,132 g / 100 g de ácido graxo intramuscular em bifes de animais alimentados com CSB e SOB, respectivamente. CSB produziu cor vermelha bovina mais intensa, aroma desagradável e maior teor de ácido linoléico; entretanto, a cor e o aroma da carne produzida em bovinos alimentados com CSB na dieta foram menos intensos e semelhantes aos observados em bovinos alimentados com SOB; estes poderiam, portanto, ser recomendados para uso como subprodutos agroindustriais na dieta de bovinos de corte.
Palavras-chave: caroço de algodão, fonte de gordura, qualidade da carne, soja

INTRODUCTION

The fatty acid (FA) composition of cattle fat has been emphasized due to the consequences on human health (Wood et al., 2008). This composition can be modified through feeding strategies, but the results are affected by several factors, including the sampled muscle, animal breed, *n*-3 FA intake, dry matter intake, fat source, protection against rumen biohydrogenation of fat source (Kronberg et al., 2006), changes in the fatty acid composition on meat lipid metabolism by rumen biohydrogenation (Cônsolo et al., 2015), liver metabolism of lipids by *de novo* lipogenesis controlled by hepatocyte intracellular non-esterified fatty acid levels and composition, and other metabolic and

hormonal factors that can alter FA composition (Nguyen et al., 2008).

According to Ludden et al. (2009), the most common method for changing the FA composition of meat is the addition of unsaturated fatty acids to the animal diets, usually in the form of soybean oil. However, these authors also state that this ingredient represents an increase in production cost. Kazama et al. (2008) emphasized that studies on ruminant nutrition involving the evaluation of agro-industrial by-product use should combine the impact of these by-products on the beef quality, considering the increasingly constant demands of consumers.

Therefore, in ruminant feeding, it is important to substitute traditional fat sources with other sources, which have the potential to modify the FA profile of beef, especially agro-industrial residues, or by-products, to reduce costs and increase the profitability of the system. From this perspective, recent studies have shown negative (Oliveira et al., 2012) or positive influence (Nute et al., 2007), and no influence (Costa et al., 2013) on the qualitative aspects of meat when alternative agro-industrial by-product fat sources are used in the animal diets. Cottonseed and Soy-bean agro-industrial by products can be used for this purpose, since those presents good composition and low costs.

Thus, the aim of this study was to evaluate the sensorial, chemical, and fatty acid compositions of intramuscular and subcutaneous fat of young Nellore bulls finished in feedlots with cottonseed and soy-bean agro-industrial by-products in the diet, to assess possible benefits for meat quality.

MATERIALS AND METHODS

The experiment was carried out in São Paulo State, Brazil, latitude°21º10 S and longitude 48º05´W. This region has a humid tropical climate, with a yearly average temperature of 24 °C and annual average rainfall of 1,300 mm. After approval by the local ethics committee (approval no. 148/2008 - CEEA).

Forty 20±2-month-old Nellore bulls were assigned to eight different plots according to their initial body weight (313.8 ± 41.2 kg) before their adaptation to diets; and slaughtered at 452.0 ± 48.4 kg of body weight.

The animals were housed in individual pens and each was considered an experimental unit. Their adaptation to diets and pens lasted 22 days, and they were evaluated during 102 days. The 10 m^2 area pens were partially covered and had a concrete floor, with an individual 1.5 m linear trough and a 100 L Australian water trough between every two pens.

The animals were individually identified by a tattoo on the left ear, treated against endoparasites and ectoparasites, and vaccinated against Clostridiosis (*Clostridium sp.;* Ourovac® Clostridium; Ourofino, Cravinhos, Brazil) and foot-and-mouth disease.

In the feedlot diets, two agro-industrial by-products were used: cottonseed by-product (CSB) and acid soybean dreg, and were formulated according to the nutritional demands estimated by CNCPS v. 6.1 – *Cornell Net Carbohydrate and Protein System* (Fox et al., 1992).

The addition of CSB was based on the ether extract (EE) content in the feedlot diet: 3, 4, or 5% EE content in the final diet. The two other reference treatments were also tested with 3 or 5% EE content and soybean by-product (SOB) as a fat source, totaling five experimental diets,

presented in Table 1, and abbreviated as: 3CSB = 3% EE in the diet with fat source from CSB; 4CSB = 4% EE in the diet with fat source from CSB; 5CSB = 5% EE in the diet with fat source from CSB; 3SOB = 3% EE in the diet with fat source from SOB; 5SOB = 5% EE in the diet with fat source from SOB.

The CSB used is the resulting by-product of the physical extraction of semi-delisted cottonseed oil, like the by-product described by Winterholler et al. (2009). In the nutrient analysis, this agro-industrial by-product had the following composition: 91.2% dry matter, 9.33% EE, 28.5% protein, 51.7% neutral detergent fiber, and 31.9% acid detergent fiber. The gossypol content was below the minimum limit of analytical quantification (<5 mg/kg).

Table 1. Composition of feedlot diets provided to animals

	Diets[1]				
Ingredients, g/Kg DM	3SOB	5SOB	3CSB	4CSB	5CSB
Brachiaria spp hay	195.00	199.00	195.00	194.00	194.00
Ground corn	312.00	319.00	312.00	311.00	311.00
Ground sorghum	352.00	147.00	330.20	193.10	552.00
Soybean meal (46% CP)	58.44	241.00	-	-	-
Acidic soybean dreg (SOB)	16.60	74.30	-	-	-
Cottonseed byproduct (CSB)	-	-	97.70	261.00	422.00
Molasses	26.30	3.40	26.30	15.50	3.30
Urea	26.50	3.20	26.70	14.70	3.10
Mineral supplement[2]	11.00	11.00	11.00	11.00	11.00
Analysis					
Total digestible nutrients	661.00	687.00	642.00	644.00	645.00
Metabolizable energy (Mcal/kg)	23.90	24.30	23.20	23.30	23.40
Crude protein	179.00	189.00	177.00	186.00	194.00
Ethereal extract	30.70	50.00	30.10	38.60	47.90
Neutral detergent fiber	406.00	401.00	458.00	452.00	491.00
Lignine	20.70	33.40	22.60	40.00	55.70
Analysis (g/ 100 g of fatty acids)					
C11:0	0.368	0.092	0.400	0.690	0.985
C12:0	0.153	0.000	1.520	1.123	0.899
C14:0	2.862	3.731	2.654	2.623	2.403
C14:1	0.533	0.155	1.509	0.789	0.500
C15:0	0.169	0.404	0.000	0.085	0.166
C16:0	14.55	14.69	14.37	16.63	18.67
C16:1	11.00	10.24	8.800	10.08	12.40
C17:0	8.344	6.106	0.806	1.928	2.997
C18:0	14.79	12.59	17.74	17.31	16.64
C18:1*n*-9	14.40	11.25	16.04	14.54	11.33
C18:2*n*-6	26.52	32.08	25.06	27.98	28.29
C18:3*n*-6	2.190	2.930	1.358	0.752	0.215
C20:0	0.778	0.386	2.749	0.471	0.404
C22:1*n*-9	0.866	1.428	0.000	0.000	0.000
Unidentified	2.470	3.918	6.994	4.999	4.101

ISSN 1519 9940

Saturated fatty acids (SFA)	42.01	37.99	40.23	40.86	43.16
Monounsaturated fatty acids (MUFA)	26.80	23.07	26.34	25.41	24.23
Polyunsaturated fatty acids (PUFA)	28.71	35.01	26.41	28.73	28.50
Unsaturated fatty acids (UFA)	55.51	58.08	52.76	54.14	52.73
MUFA/SFA	0.638	0.607	0.655	0.622	0.561
UFA/SFA	1.321	1.529	1.311	1.325	1.222

[1]3SOB and 5SOB = diets with 3 and 5 % of ethereal extract and soybean byproduct as lipid source; 3CSB, 4CSB and 5CSB = diets with 3, 4 and 5 % of ethereal extract and cottonseed byproduct as lipid source, respectively.
[2] Composition of the mineral supplement (amount per kg): 180 g Ca; 90 g P; 10 g Mg, 13 g S; 93 g Na; 145 g Cl; 17 mg Se; 1000 mg Cu; 826 mg Fe; 4000 mg Zn; 1500 mg Mn; 150 mg I; 80 mg Co; 900 mg Fl; 38.7 ppm Monensine.

In the SOB diets, acidic soybean dreg was used as a fat source, which is a residual by-product of the refining process of commercial soybean oil and presented the following nutrient composition: 56.3% dry matter and 38.4% EE.

Protein diet values were extrapolated so that they provided greater CSB inclusion, and, therefore, the diets were formulated with contents close to 18.0% protein, keeping the concentrate: roughage ratio close to 80:20, including 31.5% corn. In diets with the same EE content, similar quantities of urea and molasses were kept.

The animals were slaughtered 204 km away from the experiment location. All animals were slaughtered on a single day in the same lot. At exsanguination, the animals were identified by their tattoos and numbered in ordinal order according to their entrance. The animals were stunned by a pneumatic hammer, and immediately after exsanguination, skinning, evisceration, and carcass preparation for chilling were performed.

After the chilling period of 24 h, the pH was verified at a depth of 5 cm in the *Musculus longissimus thoracis* (LT) between the 12th and 13th ribs using a Sentron® 1001 pH meter system (Roden, Netherlands).

For quality analyses, the meat was a de-boned LT, which was packed in a plastic film and transported to the laboratory in a cooler filled with ice blocks. In the laboratory, the LT was divided into 2.54 cm thick beef samples, packed in vacuum, and sent for evaluation. The parameters analyzed included proximate composition, lipid oxidation, shear force, and sensorial aroma evaluations after 0 and 21 d of aging at 0-2 °C, and the color and FA profile of intramuscular and subcutaneous fat. The beef samples, after vacuum packaging and aging, were frozen and kept at -18 °C until analysis.

Beef chemical and physical analyses were performed after thawing in a refrigerator for 20 h, until reaching 5±2 °C. The chemical composition was evaluated in raw meat samples from LT, and was used to determine the moisture (item 39.1.02; AOAC, 2007), ash (item 39.1.09; AOAC, 2007), intramuscular fat (item 39.1.05; AOAC, 2007), and protein by the Kjeldahl-micro method (item 39.1.19; AOAC, 2007).

After removing the beef from the packages and exposing to oxygen for 30 min, muscle and subcutaneous fat color

were determined by readings at five muscle points and three subcutaneous fat points using a Minolta colorimeter (Model CR-410, Minolta Camera, Co, Ltda. Osaka, Japan), according to Honikel (1998).

Shear force was determined by the method described by Savell et al. (2013) and measured using a texture analyzer (TA XT-Plus Texture Analyzer 2i, Stable Micro System, Goldaming, Surrey, UK), equipped with a set of 3.38 mm thick Warner-Bratzler blades (capacity of 25 kg and sectioning speed of 20 cm/min).

Lipid oxidation was determined by measuring the quantity of thiobarbituric acid reactive substances (TBARS) in uncooked meat samples after 12 months of frozen storage, according to Wyncke (1970).

Sensory evaluations were performed by 10 trained panelists, according to Meilgaard et al. (1991). Since human beings were used as panelists, the procedures employed in the sensory evaluations of this experiment were approved by the Committee of Ethics in Research nº: 148/2008-CEEA.

For sensory evaluations, four beef samples/treatments were randomly chosen, thawed in a refrigerator for 20 h until reaching 5±2 °C, and diced into several small pieces free of apparent subcutaneous fat, consisting of a group of treatment sub-samples.

Part of this sub-sample group was given to the panelist as raw meat in a Petri dish with a lid, kept at 15 °C. The other part of this sub-sample group was weighed, stored in tall beakers, and distilled water, equivalent to the double of its weight, and cooked in a water bath until the internal temperature reached 71 °C (nearly 30 min). The panelists were given a beaker with a covered Petri dish on a plate heated at 50 °C.

In the evaluation of raw and cooked samples, the panelist used the 9 cm non-structured scale method for the characteristics of typical beef aroma intensity. The structured scale varies from 1 to 9, where 1 = no unpleasant aroma, and 9 = an extremely strong unpleasant aroma (Meilgaard et al., 1991).

The FA composition of intramuscular and subcutaneous fat was evaluated using gas chromatography with previous fat removal, and methyl esters were obtained through a mixture of chloroform and methanol, according to the ISO 5509 method (1978).

The fatty acid methyl esters were analyzed using a gas chromatography system (Shimadzu, Model GC-17A, Kyoto, Japan), equipped with a flame ionization detector, “split/splitless” injector, fused-silica capillary column (DB-Wax, 60 m x 0,25 mm, J&W Scientific, Folsom, CA, USA), containing polyethyleneglycol as a stationary phase, under the following chromatographic conditions: injector temperature 230 °C. The initial temperature of the column was 80 °C for 2 min at a rate of 3 °C/min, then increased to 180 °C at a rate of 30 °C/min and was maintained at this temperature for 30 min until it was finally increased to 200 °C at a rate of 3 °C/min and kept at this temperature for 108 min. The detector temperature was 240 °C, helium mobile phase with a total flow of 8.0 mL/min, and splitter ratio of 1:50. Retention times were compared to methyl ester standard times to identify fatty acids, whereas the quantification was done by area normalization; the result was expressed in the area percentage of each acid in the total FA

area according to the methodology of Hartman and Lago (1973).

Data on 24-h *post-mortem* pH, color, chemical composition, and FA profile of meat and subcutaneous fat were evaluated with animal (random), diet, and plot effects (fixed). Data on tenderness, lipid oxidation, and meat aroma evaluation were assessed with the inclusion of repeated measures (meat aging process). In the data analysis of the meat aroma evaluation, the plot effect was substituted by the inherent effect on the panelist, according to the model:

$Yijkl = \mu + Di + Bj + eijl + Matk + Di*Matk + eijk$

Yijkl is the value of the characteristic taken by animal l, diet i, block j, maturation k; μ = constant inherent to data; Di = effect of diet i, where i = diets: 3SOB, 5SOB, 3SCB, 4CSB, and 5CSB; Bj = effect of block j, where j = distribution of animals in individual pens according to live weight before 22 d of adaptation; and eijl = random error regarding the Yijl observation. Matk = effect of maturation k, with k = 0 and 21 d of maturation; Di*Matk = effect of diet i interaction and maturation k; eijk = random error regarding observation Yijkl.

The characteristics means influenced by the diet treatments were tested by four contrasts. The first two aimed to analyze if for the same dietary EE content, CSB differed from SOB: C1 = 3SOB versus 3CSB and C2 = 5SOB versus 5CSB; the other two contrasts (C3 and C4) aimed to evaluate the linear and quadratic effects of CSB inclusion.

All data were analyzed using PROC MIXED by SAS (Statistical Analysis System, Version 9.0) and the contrasts were tested by Scheffé's test, considering the difference to be significant when $P < 0.05$. Moreover, when significant at C3 and/or C4, CSB increase was evaluated by PROC REG.

RESULTS

The 24-h *post-mortem* subcutaneous fat pH and color showed no differences ($P \geq 0.05$) between the fat sources used, and no change in meat color for CSB inclusions C1 and C2 (Table 2). However, an extreme difference was found ($P = 0.03$) for b* (yellow) color index in the CSB inclusion C3, with 5.37 and 3.83 for the 3CSB and 5CSB treatments, respectively. Indeed, there was a significant difference ($P = 0.019$) in the same contrast with a higher value for the 5CSB treatment, 3.0 and 4.63, showing a significant linear relationship ($P = 0.02$) between the higher CSB content in the animal diets and a more intense red meat color (Table 2).

The use of CSB did not change ($P > 0.05$) the subcutaneous fat color, subjectively evaluated by CIEL*a*b* system and technicians. The mean chromaticity index of subcutaneous fat found in this study was 68.74 for L*, 7.21 for a*, and 7.51 for b*. Moreover, fat sources and CSB inclusion contents in the diets did not affect ($P \geq 0.05$) the chemical composition of the meat (Table 2), with average values of 74.3, 12.8, 22.9 and 1.63% for moisture, ash, protein, and intramuscular fat, respectively.

Table 2. Means of meat 24-hour *post-mortem* pH, color and chemical composition (g/100g of muscle) and subcutaneous fat color of Nellore bulls fed with agro-industrial byproducts

Component	Means	Treatments[1]					SEM[2]	*P*[3]			
		3SOB	5SOB	3CSB	4CSB	5CSB		C1	C2	C3	C4
pH 24 h *post-mortem*	5.72	5.71	5.66	5.59	5.66	5.98	0.052	0.20	0.17	0.12	0.92
Meat lightness (L*)	38.8	39.1	39.2	39.7	38.3	38.0	0.395	0.71	0.35	0.21	0.64
Meat redness (a*)	16.8	16.6	16.4	16.8	16.3	17.8	0.234	0.10	0.63	0.17	0.15
Meat yellowness (b*)	4.62	4.64	5.14	5.37	4.11	3.83	0.232	0.28	0.06	0.03[a]	0.39
Fat lightness (L*)	68.7	69.7	68.4	68.6	67.8	69.0	0.645	0.59	0.76	0.84	0.55
Fat redness (a*)	7.21	5.45	7.80	6.78	8.45	7.60	0.450	0.33	0.89	0.55	0.29
Fat yellowness (b*)	7.51	7.03	8.25	7.79	7.18	7.29	0.242	0.28	0.18	0.48	0.56
Moist	74.3	73.7	74.3	74.1	74.0	75.2	1.930	0.55	0.13	0.08	0.25
Ash	1.28	1.25	1.35	1.26	1.31	1.25	0.202	0.93	0.12	0.85	0.35
Protein	22.9	23.6	23.0	22.7	22.9	22.7	1.354	0.15	0.46	0.90	0.49
Intramuscular fat	1.63	1.58	1.60	1.53	1.72	1.71	0.980	0.88	0.77	0.62	0.75

[1]3SOB and 5SOB = diets with 3 and 5 % of ethereal extract and soybean byproduct as lipid source; 3CSB, 4CSB and 5CSB = diets with 3, 4 and 5 % of ethereal extract and cottonseed byproduct as lipid source, respectively.
[2]SEM = standard error of the mean, consider n=40.
[3]C1 = 3SOB *vs* 3CSB; C2 = 5SOB *vs* 5CSB; C3 = Linear; C4 = Quadratic.
[a]Meat b* = 7.52 – 0.77 x EE of diet with CSB (R^2 = 0.17, *P* = 0.04)
[b]Red Meat Color = 0.58 + 0.81 x EE of diet with CSB (R^2 = 0.23, *P* = 0.02)

Dietary fat source and EE content did not influence ($P > 0.05$) the shear force and meat lipid oxidation (Table 3). However, the influence of meat aging ($P < 0.05$) on shear force and meat lipid oxidation was observed, without differences ($P \geq 0.05$) among the fat sources and the CSB diet inclusion. Meat at 0-day age presented a shear force and lipid oxidation average of 5.71 kgF and 0.018 mg/kg, whereas meat aged 21 d had an average of 4.65 kgF and 0.031 mg/ kg, respectively.

For the sensory evaluation of meat aroma, with and without aging, cooked and raw (Table 3), the aging process influenced ($P < 0.05$) the aroma in raw meat, and CSB affected ($P = 0.038$) the aroma in matured cooked meat. For aged and cooked meat, a greater unpleasant aroma intensity ($P = 0.038$) was associated with an increased proportion

of CSB in the diets (1.44 for 3CSB and 3.11 for 5CSB). There was no linear relationship (P = 0.09) between unpleasant aroma in cooked meat and dietary EE fed CSB.

Table 3. Means of meat shear force, lipid oxidation and aroma sensory of Nellore cattle fed with agro-industrial byproducts

Age	Means¶	Treatments[1]					SEM[2]	P[3]			
		3SOB	5SOB	3CSB	4CSB	5CSB		C1	C2	C3	C4
Shear force (kgF)											
0 day	5.71[a]	6.03	5.93	5.62	6.03	4.92	0.197	0.49	0.09	0.24	0.14
21 days	4.65[b]	4.37	4.79	4.59	5.11	4.38	0.182	0.70	0.50	0.72	0.23
Lipid oxidation - TBARS[4] (mg/kg of muscle)											
0 day	0.018[a]	0.02	0.02	0.02	0.02	0.02	0.001	0.62	0.43	0.54	0.98
21 days	0.031[b]	0.03	0.03	0.03	0.03	0.03	0.002	0.97	0.73	0.97	0.36
Aroma intensity of raw meat (1 – 9)											
0 day	5.13[b]	5.57	4.46	5.32	4.74	5.57	0.338	0.76	0.08	0.77	0.18
21 days	6.20[a]	6.09	6.11	5.56	6.83	6.39	0.292	0.49	0.72	0.22	0.20
Bad aroma of raw meat (1 – 9)											
0 day	2.33[a]	2.00	2.78	2.22	2.11	2.56	0.264	0.69	0.94	0.49	0.52
21 days	2.22[a]	2.00	2.44	3.33	1.33	2.00	0.305	0.13	0.58	0.10	0.08
Aroma intensity of cooked meat (1 – 9)											
0 day	6.41[a]	6.22	5.71	6.76	7.03	6.34	0.213	0.28	0.31	0.31	0.26
21 days	6.66[a]	6.46	6.68	6.72	6.84	6.61	0.201	0.15	0.48	0.43	0.27
Bad aroma of cooked meat (1 – 9)											
0 day	2.16[a]	1.67	2.78	2.33	2.11	1.89	0.229	0.23	0.08	0.32	0.88
21 days	2.09[a]	2.44	1.97	1.44	1.78	3.11	0.210	0.35	0.09	0.04[a]	0.06

[1]3SOB and 5SOB = diets with 3 and 5 % of ethereal extract and soybean byproduct as lipid source; 3CSB, 4CSB and 5CSB = diets with 3, 4 and 5 % of ethereal extract and cottonseed byproduct as lipid source, respectively.
[2]SEM = standard error of the mean, consider n=40.
[3]C1 = 3SOB *vs* 3CSB; C2 = 5SOB *vs* 5CSB; C3 = Linear; C4 = Quadratic.
¶Within a column, means with a different superscript differ ($P < 0.05$)
[a]Bad aroma = - 0.55 + 0.66 x EE of diet with CSB ($R^2 = 0.14$; $P = 0.09$)
[4]TBARS - tiobarbituric acid reactive substances.

In the intramuscular fatty acid composition (Table 4) differences ($P < 0.05$) were found only for heptadecanoic acid ($C_{17:0}$) and linoleic acid ($C_{18:2n\text{-}6}$); for the other fatty acids, the tested contrasts were not significant ($P \geq 0.05$). The CSB fat source provided a lower proportion of heptadecanoic acid ($C_{17:0}$) than SOB, 1.359 and 3.238 g/100 g of intramuscular FA, respectively. The difference was observed in diets with 3% EE content (C1) (P = 0.004), but in diets with 5% EE, there was no difference between the sources (C2) for $C_{17:0}$ (P= 0.23). However, with 5% EE content, the use of CSB increased (P = 0.03) the linoleic acid ($C_{18:2n\text{-}6}$) content of the intramuscular FA (0.298 g/100 g) compared with the SOB (0.132 g/100 g).

It was observed that increasing the CSB led to a linear increase (P = 0.008) in the proportion of linoleic acid (C18:2n-6): 0.840, 0.172, and 0.298 g/100 g of intramuscular FA, with an increase of 3, 4, and 5%, respectively, in the content of EE in the diet with CBS as a fat source. However, no change was observed between these fatty acids with the increase of EE content in the diet ($P \geq$ 0.05).

Table 4. Means of meat fatty acid composition, sums and indices of fatty acids of Nellore cattle fed with agro-industrial byproducts (g/100 g of total fatty acids)

Component	Means	Treatments[1]					SEM[2]	P[3]		
		3SOB	5SOB	3CSB	4CSB	5CSB		C1	C2	C3	C4
C4:0	0.145	0.134	0.151	0.119	0.173	0.148	0.026	0.86	0.98	0.74	0.59
C6:0	0.172	0.228	0.037	0.290	0.269	0.035	0.060	0.74	0.99	0.18	0.52
C8:0	0.318	0.514	0.206	0.512	0.095	0.264	0.089	0.96	0.82	0.34	0.19
C10:0	0.321	0.525	0.201	0.528	0.143	0.206	0.100	0.99	0.99	0.26	0.37
C11:0	0.680	1.057	0.396	1.266	0.288	0.393	0.211	0.72	0.97	0.15	0.30
C12:0	0.623	1.691	0.184	0.833	0.166	0.237	0.323	0.37	0.96	0.53	0.65
C14:0	4.942	4.967	4.609	6.163	4.372	4.598	0.421	0.34	0.99	0.22	0.35
C14:1	3.997	4.702	3.520	2.189	3.979	5.593	0.474	0.12	0.20	0.06	0.95
C15:0	2.710	3.426	2.268	1.496	2.547	3.813	0.313	0.06	0.13	0.07	0.90
C15:1	1.446	1.475	1.209	0.799	1.457	2.290	0.264	0.45	0.23	0.10	0.91
C16:0	21.07	18.67	22.59	22.50	22.13	19.46	0.857	0.13	0.21	0.22	0.59
C16:1	2.861	3.531	2.329	1.304	2.839	4.300	0.387	0.09	0.13	0.07	0.97
C17:0	1.987	3.238	1.738	1.359	1.223	2.377	0.230	0.001	0.23	0.06	0.16
C17:1	0.388	0.622	0.210	0.136	0.253	0.720	0.093	0.11	0.10	0.07	0.50
C18:0	18.66	11.87	22.74	19.65	22.67	16.35	1.734	0.13	0.22	0.52	0.29
C18:1*n*-9	28.58	28.84	29.49	28.96	27.84	27.79	2.316	0.99	0.83	0.88	0.94

C18:2*n*-6	0.163	0.132	0.132	0.084	0.172	0.298	0.024	0.53	0.03	0.00[a]	0.26
C18:3*n*-3	0.559	1.177	0.222	0.311	0.395	0.692	0.143	0.07	0.26	0.36	0.77
C18:3*n*-6	0.616	0.826	0.515	0.570	0.498	0.670	0.070	0.20	0.43	0.61	0.47
C20:0	0.381	0.485	0.165	0.305	0.416	0.533	0.074	0.48	0.15	0.37	0.99
C20:1	1.112	1.300	0.793	1.015	1.012	1.443	0.137	0.54	0.17	0.36	0.59
C20:2	1.662	1.488	1.820	1.536	1.531	1.937	0.117	0.90	0.77	0.31	0.55
C20:3*n*-3	0.373	0.709	0.139	0.160	0.251	0.606	0.078	0.11	0.23	0.24	0.47
C20:3*n*-6	0.280	0.366	0.256	0.180	0.294	0.304	0.033	0.11	0.68	0.28	0.60
C20:4*n*-6	0.053	0.051	0.015	0.075	0.023	0.101	0.016	0.60	0.08	0.59	0.12
C20:5*n*-3	0.058	0.122	0.010	0.030	0.089	0.039	0.020	0.16	0.65	0.90	0.33
C21:0	0.028	0.079	0.002	0.000	0.025	0.034	0.012	0.05	0.42	0.39	0.81
C22:0	0.051	0.050	0.053	0.012	0.082	0.058	0.015	0.45	0.92	0.36	0.28
C22:1*n*-9	0.482	0.952	0.105	0.950	0.190	0.212	0.224	0.96	0.86	0.24	0.47
C22:2	0.198	0.144	0.154	0.241	0.240	0.210	0.019	0.12	0.36	0.60	0.78
C22:6*n*-3	0.055	0.063	0.073	0.036	0.049	0.054	0.016	0.63	0.72	0.75	0.94
C23:0	0.003	0.004	0.000	0.000	0.003	0.009	0.002	0.45	0.09	0.09	0.75
C24:0	0.495	0.383	0.680	0.536	0.451	0.428	0.041	0.15	0.12	0.30	0.73
C24:1	0.004	0.003	0.000	0.000	0.011	0.004	0.002	0.64	0.61	0.61	0.21
Unidentified	2.995	4.663	1.896	4.273	2.538	1.604	0.746	0.86	0.89	0.22	0.83
Sums and indices of fatty acids											
SFA	52.6	47.3	56.0	55.6	55.1	49.0	1.561	0.10	0.16	0.18	0.51
MUFA	40.2	42.7	38.7	36.9	38.8	44.1	1.795	0.34	0.37	0.24	0.74
PUFA	4.17	5.28	3.41	3.24	3.63	5.33	0.398	0.08	0.10	0.07	0.50

UFA	44.4	48.0	42.1	40.1	42.4	49.4	1.760	0.18	0.21	0.12	0.64
MUFA/SFA	0.82	0.93	0.74	0.74	0.77	0.90	0.048	0.25	0.31	0.31	0.72
PUFA/SFA	0.08	0.11	0.06	0.06	0.07	0.11	0.009	0.15	0.16	0.15	0.49
UFA/SFA	0.90	1.04	0.80	0.80	0.84	1.02	0.050	0.15	0.20	0.20	0.65
HYPER	26.0	23.6	27.2	28.7	26.5	24.1	0.702	0.09	0.14	0.13	0.94
HYPO	29.6	30.6	30.0	29.5	28.6	29.4	2.217	0.89	0.94	0.99	0.90
HYPO/HYPER	1.11	1.26	1.09	1.00	1.07	1.17	0.072	0.29	0.74	0.49	0.95
n-3	1.05	2.07	0.45	0.54	0.79	1.39	0.228	0.12	0.14	0.18	0.74
n-6	1.27	1.57	0.99	0.92	1.07	1.79	0.135	0.12	0.06	0.24	0.42
n-9	30.4	31.1	30.6	31.5	29.2	29.8	2.171	0.96	0.91	0.82	0.83
n-6:*n*-3	1.98	1.56	2.89	2.15	1.50	1.79	0.184	0.31	0.06	0.53	0.34

[1]3SOB and 5SOB = diets with 3 and 5 % of ethereal extract and soybean byproduct as lipid source; 3CSB, 4CSB and 5CSB = diets with 3, 4 and 5 % of ethereal extract and cottonseed byproduct as lipid source, respectively.
[2]SEM = standard error of the mean, consider n=40.
[3]C1 = 3SOB *vs* 3CSB; C2 = 5SOB *vs* 5CSB; C3 = Linear; C4 = Quadratic.
[a]$C_{18:2n-6}$ = -0.24 + 0.11 x EE diet with CSB (R^2 = 0.27; *P* = 0.008)
SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; UFA = unsaturated fatty acids; HYPO = $C_{18:1cis9}$ + $C_{18:2n-6}$ + $C_{18:3n-3}$ + $C_{20:4n-6}$ + $C_{20:5n-3}$ + $C_{22:6n-3}$; HYPER = $C_{14:0}$ + $C_{16:0}$

There was no difference ($P \geq 0.05$) in the intramuscular FA sums and qualitative indices of the dietary fat source studied (Table 4). In general, intramuscular FA had 44.4 g/100 g of unsaturated fatty acids (UFA), 52.6 g/100 g of saturated fat (SFA), and a ratio of 0.90 between them when the provided diets maintained this ratio closer to 1.17 (Table 1).

The highest proportion of FA in meat was Cis-oleic acid (C18:1,9c). The quantity of hyper- and hypo-cholesterolemic acids were not modified ($P \geq 0.05$) by diets with different fat sources or by the increase of CSB in the diet. Moreover, the average ratio of n-6:n-3 found in intramuscular FA was 1.98, a value that was not significantly changed ($P \geq 0.05$) by different fat sources and increasing CSB contents (Table 4).

No differences ($P \geq 0.05$) were observed in the composition of fatty acids in subcutaneous fat (Table 5). In addition, there was no difference ($P \geq 0.05$) in the sums and FA qualitative indices of subcutaneous fat fatty acids with respect

to the dietary fat sources studied (Table 5).

Table 5. Means of subcutaneous fat fatty acid composition, sums and indices of fatty acids of Nellore cattle fed with agro-industrial byproducts (g/100 g of total fatty acids)

Component	Means	Treatments[1]					SEM[2]	*P*[3]			
		3SOB	5SOB	3CSB	4CSB	5CSB		C1	C2	C3	C4
C4:0	0.002	0.004	0.000	0.007	0.000	0.000	0.001	0.55	0.94	0.19	0.48
C6:0	0.002	0.000	0.002	0.002	0.002	0.001	0.001	0.46	0.55	0.78	0.58
C8:0	0.006	0.000	0.004	0.000	0.022	0.001	0.005	0.96	0.85	0.94	0.10
C10:0	0.022	0.005	0.010	0.004	0.074	0.012	0.015	0.98	0.97	0.87	0.13
C11:0	0.139	0.135	0.127	0.116	0.176	0.139	0.013	0.64	0.77	0.59	0.19
C12:0	0.045	0.052	0.041	0.025	0.065	0.039	0.009	0.33	0.94	0.62	0.17
C14:0	6.932	6.582	7.260	6.878	6.818	7.200	0.127	0.48	0.89	0.46	0.55
C14:1	0.187	0.185	0.147	0.248	0.165	0.192	0.014	0.14	0.30	0.20	0.14
C15:0	1.245	1.316	1.369	1.077	1.280	1.163	0.030	0.24	0.36	0.28	0.42
C15:1	0.140	0.115	0.135	0.122	0.150	0.177	0.014	0.89	0.41	0.28	0.98
C16:0	26.83	25.96	27.14	27.38	26.34	27.57	0.334	0.21	0.71	0.87	0.25
C16:1	5.839	5.541	5.748	6.646	5.683	5.619	0.221	0.15	0.87	0.20	0.50
C17:0	5.046	5.149	5.279	4.456	5.136	5.236	0.171	0.25	0.94	0.21	0.58
C17:1	1.269	1.307	1.388	1.051	1.272	1.332	0.067	0.27	0.81	0.24	0.69
C18:0	0.002	0.004	0.000	0.007	0.000	0.000	0.001	0.40	0.78	0.93	0.37
C18:1*n*-9c	0.002	0.000	0.002	0.002	0.002	0.001	0.001	0.61	0.84	0.38	0.22
C18:1*n*-9t	0.006	0.000	0.004	0.000	0.022	0.001	0.005	0.12	0.80	0.50	0.98
C18:2*n*-6c	0.022	0.005	0.010	0.004	0.074	0.012	0.015	0.32	0.63	0.46	0.40

C18:2*n*-6t	0.139	0.135	0.127	0.116	0.176	0.139	0.013	0.14	0.67	0.22	0.79
C18:3*n*-3	0.045	0.052	0.041	0.025	0.065	0.039	0.009	0.17	0.92	0.24	0.60
C18:3*n*-6	6.932	6.582	7.260	6.878	6.818	7.200	0.127	0.13	0.61	0.35	0.60
C20:0	0.187	0.185	0.147	0.248	0.165	0.192	0.014	0.25	0.87	0.31	0.40
C20:1	1.245	1.316	1.369	1.077	1.280	1.163	0.030	0.69	0.97	0.56	0.70
C20:2	0.140	0.115	0.135	0.122	0.150	0.177	0.014	0.82	0.83	0.26	0.82
C20:3*n*-3	26.83	25.96	27.14	27.38	26.34	27.57	0.334	0.91	0.69	0.32	0.79
C20:3*n*-6	5.839	5.541	5.748	6.646	5.683	5.619	0.221	0.95	0.07	0.12	0.33
C20:5*n*-3	5.046	5.149	5.279	4.456	5.136	5.236	0.171	0.98	0.14	0.14	0.48
C22:0	1.269	1.307	1.388	1.051	1.272	1.332	0.067	0.24	0.88	0.22	0.16
C22:1*n*-9	0.002	0.004	0.000	0.007	0.000	0.000	0.001	0.60	0.79	0.95	0.99
C22:2	0.002	0.000	0.002	0.002	0.002	0.001	0.001	0.43	0.82	0.21	0.45
C24:0	0.006	0.000	0.004	0.000	0.022	0.001	0.005	0.93	0.75	0.88	0.10
Unidentified	0.022	0.005	0.010	0.004	0.074	0.012	0.015	0.44	0.58	0.20	0.88
Sums and indices of fatty acids											
SFA	48.4	48.5	49.8	47.7	46.7	49.4	0.622	0.69	0.86	0.40	0.26
MUFA	49.7	49.4	48.1	50.8	51.4	48.5	0.617	0.47	0.84	0.25	0.29
PUFA	1.79	1.92	1.93	1.39	1.83	1.89	0.116	0.19	0.91	0.24	0.58
UFA	51.5	51.4	50.1	52.2	53.2	50.4	0.623	0.68	0.87	0.38	0.26
MUFA/SFA	1.04	1.03	0.97	1.07	1.12	1.00	0.027	0.63	0.75	0.41	0.23
PUFA/SFA	0.04	0.04	0.04	0.03	0.04	0.04	0.003	0.22	0.93	0.31	0.39
UFA/SFA	1.08	1.07	1.01	1.10	1.16	1.04	0.028	0.73	0.77	0.49	0.21
HYPER	33.8	32.5	34.4	34.3	33.2	34.8	0.419	0.22	0.80	0.72	0.27
HYPO	40.5	40.2	39.0	40.9	42.4	39.4	0.638	0.73	0.84	0.44	0.18

HYPO/HYPER	1.21	1.25	1.14	1.20	1.29	1.14	0.027	0.47	0.92	0.51	0.09
n-3	0.45	0.49	0.51	0.32	0.46	0.49	0.037	0.21	0.91	0.21	0.64
n-6	1.31	1.42	1.39	1.06	1.34	1.36	0.073	0.16	0.89	0.26	0.54
n-9	42.1	42.2	40.5	42.6	43.9	41.0	0.606	0.80	0.79	0.39	0.18
n-6:*n*-3	3.18	3.02	2.92	3.31	2.87	2.95	0.152	0.22	0.96	0.20	0.11

[1]3SOB and 5SOB = diets with 3 and 5 % of ethereal extract and soybean byproduct as lipid source; 3CSB, 4CSB and 5CSB = diets with 3, 4 and 5 % of ethereal extract and cottonseed byproduct as lipid source, respectively.
[2]SEM = standard error of the mean, consider n=40.
[3]C1 = 3SOB *vs* 3CSB; C2 = 5SOB *vs* 5CSB; C3 = Linear; C4 = Quadratic.
SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; UFA = unsaturated fatty acids; HYPO = $C_{18:1cis9}$ + $C_{18:2n-6}$ + $C_{18:3n-3}$ + $C_{20:4n-6}$ + $C_{20:5n-3}$ +

DISCUSSION

The final pH of the meat is influenced by glucose and lactate metabolism to lactic acid, and the resulting pH reduction is one of the most important requirements for turning muscle into high quality meat (Poso & Puolanne, 2005). The final average pH across treatments was 5.72, within the interval of 5.40 and 5.80 considered adequate for a meat quality by Mach et al. (2008) for maintenance of meat shelf life. In addition, the same was observed by Cônsolo et al. (2015), who fed Nellore bulls with 0 to 24% whole raw soybean.

Although 5CSB treatment was not different from the others, it showed an average final pH over the 5.8 threshold. This greater average value was a consequence of the individual characteristics of three animals (37%) from the group of animals that underwent this treatment, possibly because the *ante-mortem* stress produced high pH meat (> 6.0), thus increasing the average of the group. The exact cause of pre-slaughter stress has not been identified because several factors may induce it, and consequently reduce the reserves of muscle glycogen, resulting in meat with relatively high pH values (Jeleníková et al., 2008).

Both the fat sources and the quantity of EE in the diets did not change the meat color, which concur with previous observations by Nelson et al. (2004), who did not find any differences in meat color using residual oil from restaurants and animal tallow in the feeding of cross-breed feedlot cattle, and by Oliveira et al. (2012) in a study of 35 Nellore cattle fed with rumen protected and unprotected oil.

In contrast, the highest color index b * (yellow) in the inclusion of CSB (C3) indicated that the diet with greater EE content with CSB as a fat source resulted in less yellow meat, which helps explain the difference in the subjective evaluation of red meat color. As for luminosity, according to the review by Muchenjea et al. (2009) on cattle, the L* ranges from 33.2 to 41.0, the a* from 11.1 to 23.6, and b* from 6.1 to 11.3. The values of L * and a * in this study are

within the average, except for b *, whose values are below the average.

The use of CSB did not change the subcutaneous fat color; similar results were reported by Oliveira et al. (2012), in a study using a Minolta CR 300 colorimeter, in which no differences were observed in subcutaneous fat color in Nellore fed with rumen protected and unprotected oil. The mean chromaticity index of subcutaneous fat found in this study was 68.74 for L*, 7.21 for a*, and 7.51 for b*. These values are close to those noted by Nelson et al. (2004) and Andrade et al. (2014), who evaluated the subcutaneous fat color of Angus × Nellore cross-breed animals with a colorimeter model identical to the one used in this study.

Moreover, fat sources and CSB inclusion contents in the diets did not influence the chemical composition of the meat. These findings differ from those of a study by Oliveira et al. (2012), in which differences in intramuscular fat content were found between animals fed with rumen protected and unprotected linseed oil, and this study found lower fat in relation to the average velour of 2.11% observed by Cônsolo et al. (2015) with Nellore bulls fed different levels of whole raw soybean in the diet.

The source of fat in the diet and the EE content did not influence the shear strength and the lipid oxidation of the meat, discordant with Cônsolo et al. (2015), who observed a quadratic effect on the shear force when Nellore bulls were fed with crescent levels of whole ram soybean. The mean shear force at 0-day age (5.71 kgF) was close to the average value noted by Oliveira et al. (2012) (5.95 kgF) in Nellore cattle of similar age, using rumen-protected and unprotected oil in the finishing diet system and a similar analytical equipment; however, it was lower than the 6.39 kgF observed by Cônsolo et al. (2015).

The influence of meat aging on shear force and meat lipid oxidation shows the benefits of the aging process in reducing the shear force; however, aging increases lipid oxidation. Wicklund et al. (2005) also reported this benefit when studying the influence of aging on meat tenderness and sensorial characteristics. In relation to lipid oxidation, more changes in meat fatty profile and differences in lipid oxidation were expected since the FA profile makes the meat more susceptible to lipid oxidation, which has been associated with an unpleasant taste (Mottran, 1998).

Moreover, the aging process increased aroma intensity only in raw meat, with no difference in cooked meat. Classical studies attribute the more intense aroma to an increase in free fatty acids, hydrocarbons, and benzene compounds (Coppock & Macleod, 1977). In studies by Nute et al. (2007), a difference in aroma was found when flaxseed oil, fish oil, and protected fat were provided to feedlot sheep. However, they observed a decrease in meat taste, and the unpleasant meat taste of animals fed fish oil and protected fat increased. These authors stated that the reduction of typical taste might be related to an increase in linoleic acid ($C_{18:2n-6}$). The findings reported in this study are consistent with this conclusion since there was an increase in unpleasant taste when linoleic acid increased with CSB feeding.

Costa et al. (2013) evaluated the increasing inclusion of cottonseed in the diet of feedlot Nellore cattle and found that 27.5% of cottonseed inclusion caused an unpleasant meat taste. In contrast, the studies from Gibb et al.

(2004) assessed the inclusion effect of sunflower seed in cattle diet and did not find changes in meat off-flavor. In addition, Gill et al. (2008) did not find a sensory difference in the meat from feedlot cattle fed with corn and distillery residue, and Cônsolo et al. (2015) did not find any alteration in the meat sensory from Nellore bulls fed different levels of whole raw soybean in the diet.

Oliveira et al. (2012) studied Nellore cattle in feedlots fed soybean and linseed oil, and Gill et al. (2008) studied cattle fed flaked corn and moist distillery residue, but did not observe a difference in the proportion of heptadecanoic acid ($C_{17:0}$), and reported that the increase of this FA would not be very important because it does not alter the plasma cholesterol in humans, but as odd-chain fatty acids come from the membrane of ruminal bacteria, the diet probably provided greater evasion of bacteria adhering to food particles.

By increasing the addition of CSB, the proportion of linoleic acid ($C_{18:2n\text{-}6}$) in the EE content in the diet increased. This result is similar to that reported by Nute et al. (2007), who found an increase in these fatty acids and sensory differences in lamb, as discussed before, and is corroborated by the study of Oliveira et al. (2012), who also observed modification of UFA with 18 carbons ($C_{18:1n\text{-}7}$;$C_{18:2n\text{-}6}$;$C_{18:3n\text{-}3}$;$C_{18:3n\text{-}6}$) of Nellore meat in the sensory panel. Therefore, this study confirms the findings of Larick & Turner (1990) that the FA composition may affect the sensory characteristics of meat, influenced mainly by linoleic acid ($C_{18:2n\text{-}6}$) and linolenic acid ($C_{18:3n\text{-}3}$).

Felton & Kerley (2004) analyzed the FA profile in the meat of cattle fed with high fat content diets, such as soybean and corn bran, and verified that the meat of animals receiving greater fat content presented lower concentrations of myristic acid ($C_{14:0}$) and lower contents of palmitic acid ($C_{16:0}$). Palmitic and myristic acids are particularly important as they are considered hyper-cholesterolemic (Cônsolo et al., 2015). Oliveira et al. (2012) did not find differences in myristic acid and observed lower contents of palmitic acid when EE was increased in the diet. Here, differences between these fatty acids were not observed with the increase in EE content in the diet, which agrees with the report by Costa et al. (2013), who did not find alterations of these fatty acids in Nellore young bulls in feedlots that received diets with increasing addition of cottonseed.

The changes were not noticed in the intramuscular sums of FA and the qualitative indices of the fat source of the studied diet, which is in agreement with Felton & Kerley (2004), who did not find any alteration in the concentration of saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acid (PUFA) in intramuscular fat of cattle fed high-fat diets, and with Cônsolo et al. (2015), who concluded that Nellore supplementation with soybean grains did not increase the percentage of UFA in meat. Ruminants have the capacity to reduce the quantity of UFA and increase the quantity of SFA mainly through biohydrogenation by the microbial flora in the rumen, if the liver lipid metabolism in ruminants is modest (Nguyen et al., 2008).

Cis-oleic acid ($C_{18:1,9c}$) was the FA with the highest proportion in the meat, a finding also reported by Oliveira et al. (2012) in Nellore cattle under similar conditions. According to Wood et al. (2008), this FA has the greatest concentration in meat and is mainly

formed by stearic acid ($C_{18:0}$) due to the action of stearoyl-CoA desaturase endogenous enzymes.

The ratio of PUFA/SFA is widely used to evaluate the nutritional value for human consumption, according to the Department of Health and Social Security (1984), the PUFA/SFA ratio must be presented and discussed due to its potential to increase plasma cholesterol in humans and the recommended food with a ratio over or close to 0.45. In this study, the PUFA/SFA ratio was 0.08. However, Williams (2000) claimed that this ratio must be used with restriction because it does not take into consideration the quantity of MUFA, which may undergo desaturation, as in the ruminants, and may be utilized as PUFA in the human organism.

The quantification of hyper acids (HYPER) and hypo-cholesterolemic acids (HYPO) is important in the search for healthier foods for human consumption, and a greater ratio between HYPO:HYPER is beneficial because it shows that the food has a greater proportion of hypo-cholesterolemic acids. Likewise, Andrade et al. (2014) did not find differences in the content of hyper- and hypo-cholesterolemic FA among the treatments with rumen protected fat fed to Angus × Nellore crossbreed animals. Huerta-Leidenz et al. (1991) also did not find differences between the treatments with and without cottonseed, and observed that the HYPO:HYPER ratio varied from 1.58 to 2.82. In this study, varying dietary fat sources and increasing CSB did not change the quantity of hyper- and hypo-cholesterolemic acids. However, the variation ranged from 1.00 to 1.26.

Moreover, both the increase in CSB content and the different fat sources did not influence the mean ratio between *n*-6:*n*-3, with the value found in intramuscular AF being 1.98, similar to the average of 1.82 reported in a study by Pestana et al. (2012), in which no differences were observed between spring and autumn in organic beef cattle. The average value found is considered ideal because the Department of Health and Social Security (1984) recommends food with *n*-6:*n*-3 lower than 4.0 as desirable to prevent cardiovascular diseases. In addition, 1.98 is close to 2.1, the value suggested for meat in the review by Wood et al. (2008), and for the same of *n*-6:*n*-3 ratio, Talpur et al. (2007) found a range of 1.43 to 1.86 with Kundi steers beef fed on pasture with cottonseed cake supplement.

The FA composition of subcutaneous fat did not change, showing that there was no influence of the fat source and CSB inclusion on the composition of FA of deposited subcutaneous fat. Some SFAs of subcutaneous fat are particularly relevant, such as myristic acid ($C_{14:0}$), palmitic acid ($C_{16:0}$), and stearic acid ($C_{18:0}$) because they are associated with an increase in LDL plasma cholesterol and, therefore, a risk for cardiopathies. In this study, mean values of subcutaneous fat of 6.93, 26.7, and 7.76 g/100 g of fat FA were found for myristic acid ($C_{14:0}$), palmitic acid ($C_{16:0}$), and stearic acid ($C_{18:0}$), respectively. According to a review by Wood et al. (2008), the composition of subcutaneous fat FA is 3.7, 26.1, and 12.2 g/100 g of fat FA for $C_{14:0}$, $C_{16:0}$, and $C_{18:0}$, respectively.

Ludden et al. (2009) observed the influence of providing soybean oil to cattle on the deposit of palmitic acid ($C_{16:0}$), and Pavan & Duckett (2007) reported a decrease in palmitic acid with an increase in oil supplementation for grazing cattle. However, like this

experiment, Beaulieu et al. (2002) did not find differences in palmitic acid of subcutaneous fat of feedlot cattle with and without soybean oil.

Our results are similar to those reported in studies by Pavan & Duckett (2007), who also did not find alterations in the concentration of stearic acid ($C_{18:0}$) of cattle fed a corn oil supplemented diet, and by Huerta-Leidenz et al. (1991), who observed a similar proportion of stearic acid and the other fatty acids in the subcutaneous fat of cattle fed with 0, 15, and 30 % of cottonseed. In contrast, Preston *et al.*[43] reported an increase in the stearic acid ($C_{18:0}$) content in the subcutaneous fat with the addition of cottonseed for cattle.

The dietary fat source used did not influence the sums and qualitative indices of FA, which is like that reported by Ludden et al. (2009), who did not observe differences in the SFA and PUFA when studying the FA composition of subcutaneous fat in cattle fed with a control diet and a diet supplemented with soybean oil.

In subcutaneous fat, the average SFA and UFA values were 48.4 and 51.5 g/100 g, respectively, and the ratio between SFA and PUFA was 0.04. Wood et al. (2008) reported a PUFA and SFA ratio of 0.05 for cattle subcutaneous fat. Subcutaneous fat, as part of the food used by humans, should also contain hyper fatty acids (HYPER) and hypo-cholesterolemic fatty acids (HYPO), Omega 6 (*n*-6), and Omega 3 (*n*-3). The fat sources and the increasing CSB did not change the concentrations of these indices in the subcutaneous fat. In this study, the HYPO:HYPER ratio varied from 1.14 to 1.29, and the average ratio of *n*-6:*n*-3 was 3.18; however, Huerta-Leidenz et al. (1991) reported that the variation in the HYPO:HYPER ratio was 2.56, 2.36, and 2.40 with the addition of cottonseed 0, 15, and 30% in the cattle feedlot, respectively. Wood et al. (2008) reported an average *n*-6:*n*-3 ratio of 2.10 in bovine subcutaneous fat.

CONCLUSIONS

The use of cottonseed cake as a fat source in the diet of Nellore cattle in feedlot, caused a more intense beef red color, and a greater proportion of linoleic fatty acids in the meat. However, increased unpleasant aroma. But, since these effects were lower and like those observed in cattle fed with higher soybean content, the use of these by-products could be recommended, to increase the meat composition.

REFERENCES

Andrade, E.N; Polizel Neto, A; Roça, R.O.; Faria, M.H.; Resende, F.D.; Siqueira, G.R. and Pinheiro. 2014. Beef quality of young Angus × Nellore cattle supplemented with rumen-protected lipids during rearing and fatting periods. **Meat Science** 98: 591-598. http://dx.doi.org/10.1016/j.meatsci.2014.05.028

AOAC – Association of Official Analytical Chemistry. 2007. Official methods of Analysis: current through revision 2. 18th ed. **AOAC International**, Gaithersburg, MD.

Beaulieu, A.D.; Drackley, J.K. and Merchen, N.R. 2002. Concentrations of conjugated linoleic acid (*cis*-9, *trans*-11-octadecadienoic acid) are not increased in tissue lipids of cattle fed a high-concentrate diet supplemented with soybean oil. **Journal of Animal Science** 80: 847-861. https://doi.org/10.2527/2002.803847x

Cônsolo, N.R.B.; Gardinal, R.; Gandra, J.R.; Freitas Junior, J.E.; Renno, F.P.; Santana, M.H.; Pflanzer Junior, S.B. and Pereira, A.S.C. 2015. High levels of whole raw soybean in diets for Nellore bulls in feedlot: effect on growth performance, carcass traits and meat quality. **Journal of Animal Physiology and Animal Nutrition** 99: 201-209. https://doi.org/10.1111/jpn.12237

Coppock, B.M. & Macleod, G. 1977. The effect of ageing on the sensory and chemical properties of boiled beef aroma. **Journal of Science Food Agriculture** 28: 206-214. https://doi.org/10.1002/jsfa.2740280216

Costa, D.P.B.; Roça, R.O.; Costa, Q.P.B.; Lanna, D.P.D.; Lima, E.S. and Barros, W.M. 2013. Meat characteristics of Nellore steers fed whole cottonseed. **Brazilian Journal of Animal Science** 42: 138-192. https://doi.org/10.1590/S1516-35982013000300006

Department of Health and Social Security. 1984. Diet and cardiovascular disease. London: **Report on Health and Social Subjects**, 28.

Felton, E.E.D. & Kerley, M. S. 2004. Performance and carcass quality of steers fed different sources of dietary fat. **Journal of Animal Science** 82**:** 1794-1805. https://doi.org/10.2527/2004.8261794x

Fox, D.G.; Sniffen, C.J.; O'Connor, J.D.; Russell, J.B. and Van Soest, P.J. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. **Journal of Animal Science** 70: 3578–3596. https://doi.org/10.2527/1992.70113578x

Gibb, D.J.; Owens, F.N.; Mir, P.S.; Mir, Z.; Ivan, M. and McAllister, T.A. 2004. Value of sunflower seed in finishing diets of feedlot cattle. **Journal of Animal Science** 82: 2679-2692. https://doi.org/10.2527/2004.8292679x

Gill, R.K.; VanOverbeke, D.L.; Depenbusch, B.; Drouillard, J.S. and DiCostanzo, A. 2008. **Impact of beef cattle diets containing corn or sorghum distillers' grains on beef color, fatty acid profiles, and sensory attributes. Journal of Animal Science** 86: 923-935**.** https://doi.org/10.2527/jas.2007-0244

Hartman, L. and Lago, B. C. A. 1973. Rapid preparation of fatty methyl esters from lipids. London, DC.

Honikel, K. O. 1998. Reference methods for the assessment of physical characteristics of meat. **Meat Science** 49: 447-457. https://doi.org/10.1016/S0309-1740(98)00034-5

Huerta-Leidenz, N.O.; Cross, H.R.; Lunt, D.K.; Pelton, L.S.; Savell, J.W. and Smith, S.B. 1991. Growth, carcass traits, and fatty acid profiles of adipose tissues from steers fed whole cottonseed. **Journal of Animal Science** 69: 3665-3672. https://doi.org/10.2527/1991.6993665x

ISO - International Standard Organization. 1978. Animal and vegetable fats and oils - Preparation of methyl esters of fatty acids. **Method ISO 5509**, Int. Org. Stand., Geneve.

Jeleníková, J.; Pipek, P. and Staruch L. 2008. The influence of ante-mortem treatment on relationship between pH and tenderness of beef. **Meat Science** 80: 870-874. https://doi.org/10.1016/j.meatsci.2008.04.004

Kazama, R.; Zeoula, L.M; Prado, I.N.; Silva, D.C.; Ducatti, T. and Matsushita, M. 2008. Quantitative and qualitative carcass characteristics of heifers fed different energy sources on a cottonseed hulls and soybean hulls based diet. **Brazilian Journal of Animal Science** 37: 350-357.

Kronberg, S.L.; Barcelo-Coblijn, G.; Shin, J.; Lee, K. and Murphy, E.J. 2006. Bovine muscle n-3 fatty acid is increased with flaxseed feeding. **Lipids** 41: 1059-1068. https://doi.org/10.1007/s11745-006-5056-z

Larick, D.K. & Turner, B.E. 1990. Flavor characteristics of forage on grain-fed beef as influenced by phospholipid and fatty acid composition differences. **Journal of Animal Science** 55: 312-317. https://doi.org/10.1111/j.1365-2621.1990.tb06751.x

Ludden, P.A.; Kucuk, O.; Rule, D.C. and Hess, B.W. 2009. Growth and carcass fatty acid composition of beef steers fed soybean oil for increasing duration before slaughter. **Meat Science** 82: 85-192. https://doi.org/10.1016/j.meatsci.2009.01.009

Mach, N.; Bach, A.; Velarde, A. and Devant, M. 2008. Association between animal, transportation, slaughterhouse practices, and meat pH in beef. **Meat Science** 78: 232-238. https://doi.org/10.1016/j.meatsci.2007.06.021

Meilgaard, D.; Civille, G.V. and Can, B. T. 1991. **Sensory evaluation techniques**. Boca Raton, Florida.

Mottran, D.S. 1998. Flavor formation in meat and meat products: a review. **Food Chemistry** 62: 415-424. Available at: <https://fs.ntou.edu.tw/ezfiles/21/1021/attach/67/pta_20429_3061576_06666.pdf>. Accessed on: June 17, 2013.

Muchenjea, V.; Dzamac, K.; Chimonyoa, M.; Strydomd, P.E.; Hugoe, A. and Raats, J.G. 2009. Some biochemical aspects pertaining to beef eating quality and consumer health: a review. **Food Chemistry** 112: 279-289. https://doi.org/10.1016/j.foodchem.2008.05.103

Nelson, M.L.; Marks, D.J.; Busboom, J.R.; Cronrath, J.D. and Falen, L. 2004. Effects of supplemental fat on growth performance and quality of beef from steers fed barley-potato product finishing diets I: feedlot performance, carcass traits, appearance, water binding, retail storage, and palatability attributes**.** **Journal of Animal Science** 82: 3600-3610. https://doi.org/10.2527/2004.82123600x

Nguyen, P.; Leray, V.; Diez, M.; Serisier, S.; Le Bloc'h, J.; Siliart, B. and Dumon, H. 2008. Liver lipid metabolism. **Journal of Animal Physiology and Animal Nutrition** 92: 272-283. https://doi.org/10.1111/j.1439-0396.2007.00752.x

Nute, G.R.; Richardson, R.I.; Wood, J.D.; Hughes, S.I.; Wilkinson, R.G.; Cooper, S.L. and Sinclair, L.A. 2007.

Effect of dietary oil source on the flavor and the color and lipid stability of lamb meat. **Meat Science** 77: 547-555. https://doi.org/10.1016/j.meatsci.2007.05.003

Oliveira, E.A.; Sampaio, A.A.M.; Henrique, W.; Pivaro, T.M.; Rosa, B.L.; Fernandes, A.R.M. and Andrade, A.T. 2012. Quality traits and lipid composition of meat from Nellore young bulls fed with different oils either protected or unprotected from rumen degradation. **Meat Science** 90: 28-35. https://doi.org/10.1016/j.meatsci.2011.05.024

Pavan, E. & Duckett, S. K. 2007. Corn oil supplementation to steers grazing endophyte-free tall fescue II: effects on longissimus muscle and subcutaneous adipose fatty acid composition and stearoyl-CoA desaturase activity and expression. **Journal of Animal Science** 85: 1731-1740. https://doi.org/10.2527/jas.2006-732

Pestana, J.M.; Costa, A.S.H.; Martins, S.V.; Alfaia, C.M.; Alves, S.P.; Lopes, P.A.; Bessa, R.J.B. and Prates, J.A.M. 2012. Effect of slaughter season and muscle type on the fatty acid composition, including conjugated linoleic acid isomers, and nutritional value of intramuscular fat in organic beef. **Journal of the Science of Food and Agriculture** 92: 2428-2435. https://doi.org/10.1002/jsfa.5648

Poso, A.R. & Puolanne, E. 2005. Carbohydrate metabolism in meat animals: review. **Meat Science** 70: 423-434. https://doi.org/10.1016/j.meatsci.2004.12.017

Savell, J.; Miller, R.; Wheeler, T.; Koohmaraie, M.; Shackelford, S.; Morgan, B.; Calkins, C.; Miller, M.; Dikeman, M.; McKeith, F.; Dolezal, G.; Henning, B.; Busboom, J.; West, R. and Parrish, F. 2013. **Standardized Warner-Bratzler shear force procedures for genetic evaluation**. Available at: <https://meat.tamu.edu/research/shear-force-standards/>. Accessed on: June 17, 2013.

Talpur, F.N.; Bhanger, M.I. and Khuhawar, M.Y. 2007. Intramuscular fatty acid profile of longissimus dorsi and semitendinosus muscle from Kundi steers fed on pasture with cottonseed cake supplement. **International Journal of Food Science and Technology** 42: 1007-1011. https://doi.org/10.1111/j.1365-2621.2006.01451.x

Wicklund, S.E.; Homco-Ryan, C.; Ryan, K.J.; McKeith, F.K.; McFarland, B.J. and Brewer, M.S. 2005. Aging and enhancement effects on quality characteristics of beef strip steaks. **Journal of Food Science** 70: S242-S248. https://doi.org/10.1111/j.1365-2621.2005.tb07164.x

Williams, C.M. 2000. Dietary fatty acids and human health. **Annales de Zootechnie** 49: 165-180. https://doi.org/10.1051/animres:2000116

Winterholler, S.J; Lalman, D.L.; Hudson, M.D. and Goad, C.L. 2009. Supplemental energy and extruded-expelled cottonseed meal as a supplemental protein source for beef cows consuming low-quality forage. **Journal of Animal Science** 87: 3003-

3012. https://doi.org/10.2527/jas.2008-1605

Wood, J.D.; Enser, M.; Fisher, A.V.; Nute, G.R.; Sheard, P.R.; Richardson, R.I.; Hughes, S.I. and Whittington, F.M. 2008. Fat deposition, fatty acid composition and meat quality: a review. **Meat Science** 78: 343-358. https://doi.org/10.1016/j.meatsci.2007.07.019

Wyncke, W. 1970. Direct determination of the thiobarbituric acid value in trichloroacetic acid extracts of fish as a measure of oxidative rancidity**. Fette-Scifen Anstrichmittel** 72: 1084-1087. https://doi.org/10.1002/lipi.19700721218