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Meat quality and fatty acid profile of Brazilian goats subjected to different nutritional treatments

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ABSTRACT

This study evaluated the effect of feed restriction and goat genotype on meat quality. Three genotypes (Brazilian native breed Canindé; Brazilian native breed Moxotó; and F1 Boer crossbred animals obtained by crossing Boer bucks with local breed does) and three different feeding regimens (ad libitum fed, AL; restricted fed at 75% of the ad libitum, R.75; or restricted fed at 50% of the average ad libitum intake, R.50) were used. There was no difference ($P > 0.05$) in chemical composition, total and soluble collagen, and shear force of the *Longissimus lumborum* muscle among genotypes. However, AL had greater amounts of soluble collagen and crude protein in the muscle ($P < 0.05$) than R.75. No difference ($P > 0.05$) was observed for the myofibrillar fragmentation index. The goat genotype presented few differences in their fatty acid profiles. However, goats fed ad libitum had a more favorable fatty acid profile for human health with greater concentrations of oleic acid, unsaturated fatty acids, and conjugated linoleic acid.

1. Introduction

Goat's meat is an important food source in developing countries. The browsing habits and adaptation to harsh climates of goats makes them useful in semi-arid and harsh environmental conditions. Goat meat constitutes one of the main sources of animal protein in the human diet in the semi-arid region of developing countries (Upton, 2004). In Brazil, the northeast herd represents 91% of the national goat population (IBGE, 2012), and is primarily composed of native, non-descript and crossbred goats (resulting from mating between native, non-descript and also exotic breeds). The dry season in northeast Brazil is long and frequently animals are subjected to feed restriction that could alter their meat characteristics. Moxotó and Canindé are Brazilian native goat breeds that are classified as suitable for meat and hide (Canindé) or meat, hide and milk (Moxotó) production. They are small sized animals (on average 30 to 40 kg body weight and 55 cm average height), that are well adapted to semi-arid conditions and feeding restrictions, but are not specialized for meat or milk production, so exotic breeds, notably Boer, have been used in crossbreeding schemes to improve productivity and meat quality.

Meat sensory attributes such as color, texture, taste and tenderness can be affected by animal age, gender, breed and diet, due to differences in biological characteristics (collagen, fibers, lipids, enzymes, and others) of the muscular tissue (Renand, Picard, Touraille, Berge, & Lepetit, 2001).

Yáñes et al. (2006, 2007) studied the effect of feed restriction (0%, 30% and 60%) on Saanen goats, and observed that feed restriction reduced carcass weight, while decreasing muscle tissue and fat proportions. Nonetheless, Madruga et al. (2008) reported that feed restriction had no effect on the chemical, physical, and sensory quality of Moxotó and Canindé meat.

The hypothesis for the current study was that different genotypes and restricted feeding levels would lead to a different metabolic status which might impact meat characteristics. Therefore, the objectives were to determine if different feed restriction levels in different goat genotypes affects chemical composition, total collagen content, collagen solubility, tenderness, loss of exudate, color and fatty acid profile of goat meat.

2. Materials and methods

2.1. Animals, diets and experimental design

The experiment was performed on the Campus of Agricultural Sciences of the Federal University of San Francisco Valley, in Petrolina

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(PE), Brazil. Before the beginning of the trial, animals were allowed to adapt to feed and pens for 30 days, during which all goats were fed the same diet, ad libitum, to decrease the effect of previous nutrition on their performance and body composition.

Three different genotypes, Brazilian native breed Canindé, Brazilian native breed Moxotó, and F_1 Boer crossbred animals obtained by crossing Boer bucks with local breed does were used. The animals were subjected to three feeding regimens : ad libitum fed, AL; restricted fed at 75% of the average ad libitum intake, R.75; or restricted fed at 50% of the average ad libitum intake, R.50. The amount of feed offered to the restricted fed animals was adjusted every 15 days in order to offer 75 or 50% of the average feed intake (in g of DM/kg of body weight) of the ad libitum fed animals of the same genotype. Forty-five intact male goats (15 Canindé, 15 Moxotó, and 15 F1 Boer × local breed), with an average age of 4 months and an initial body weight (BW) of 15 ± 0.85 kg were used. Five animals of each genotype (Canindé, Moxotó, or F1 Boer) were randomly assigned to one of three feeding regimens (AL, R.75 or R.50) in a 3 × 3 factorial design.

The diet was formulated according to recommendations of National Research Council — NRC (2007) for native goats with daily weight gain of 100 g (Table 1) with a forage:concentrate ratio of 40:60 in the form of a total mixed diet. Clean water was available all the time in plastic buckets. The goats were confined for 100 days and then slaughtered at the Instituto Federal do Sertão Pernambucano (Petrolina, PE, Brazil).

2.2. Slaughter and sampling procedures

Before slaughter, final BW was measured as the BW after fasting (12 h for liquids and 24 h for solids). The goats were slaughtered using captive bolt stunning followed by cutting carotid arteries and jugular veins. The carcasses were chilled at 4 °C for 24 h, and the cold carcass weight was measured. Each carcass was split into 2 longitudinal halves. The *Longissimus lumborum* muscle, between the 10th and 13th ribs of the right half-carcass was removed and dissected into muscle, fat, and bone components. Cross-cuts were performed from the cranial portion and five 2.54 cm thick steaks were obtained (one for the determination of color, shear force and losses; one for fatty acid profile; one for chemical composition, one for total collagen and collagen solubility; and one for myofibrillar fragmentation index), vacuum-packed and stored at −20 °C.

2.3. Chemical and physical analyses

To determine chemical composition, the steak was placed in a multiprocessor to obtain a homogenous mass, which was subsequently lyophilized and grounded. Crude protein (CP) was quantified according to the Kjeldahl method and ether extract (EE) was obtained according to the Soxhlet method, the moisture was removed in a dry oven at 105 °C for 24 h, and the mineral matter (MM) was determined in oven at 550 °C for 6 h.

Table 1
Ingredients and chemical composition of the experimental diet.

	Composition (% DM)
Ingredients	
Napier grass	40.0
Ground whole corn	33.0
Soybean meal	25.2
Common salt	0.6
Mineral mix	1.2
Nutrients	
Dry matter[1]	63.1
Crude protein[2]	19.2
Ether extract[2]	2.2
Ash[2]	7.0
Neutral detergent fiber[2]	26.6
Non-fibrous carbohydrates[2]	43.5
Indigestible neutral detergent fiber[2]	4.7

[1] Base of organic matter.
[2] Base of dry matter.

To determine the color, the steak was exposed to air for approximately 30 min and the values of L^* (luminosity), a^* (intensity of red), and b^* (intensity of yellow) were read using a Minolta CR-10 colorimeter, calibrated for a white standard, using illuminant D65 and 10° observer. Five readings were performed for each sample, and the average values of L^*, a^*, and b^* recorded.

For the analysis of the shear force (SF) and loss of exudates during preparation, only the *Longissimus lumborum* muscle from the goats fed ad libitum was used because the other groups did not have sufficient muscle area for this analysis. The SF was determined using 2.54-cm steak, which had been previously thawed and baked in an electric oven pre-heated to 150 °C until the internal temperature of the meat reached 71 °C. The monitoring of the internal temperature was performed using a K-type thermometer, whose probes were inserted into the geometric center of each steak. The samples were then cooled overnight in a refrigerator until an internal temperature of 1 to 5 °C was reached. Five cylinders from each meat sample were removed, in the direction of the muscular fibers, using a sharp, stainless steel 1.27 cm diameter borer according to Wheeler, Koohmaraie, and Shackelford (1995). The cylinders were sheared perpendicularly using a V-shaped cutting blade attached to a MECMESIN BFG 500 N model texturometer equipped with a Warner Bratzler style blade to determine the SF in kgf/cm^2.

The quantification of the water loss due to thawing and cooking was performed on the steak used to determine the SF. The loss of water was quantified by weighing the sample before and after thawing. The cooking losses (drip + evaporation) were obtained by weighing the baking pans with and without the samples (AMASA, 1978).

The total collagen (mg/g) and soluble collagen (% of the total) were quantified through their hydroxyproline content based on the methodology proposed by Woessner Jr. (1961) and modified by Hadlich, Morales, Silveira, Oliveira, and Chardulo (2006). From a homogenized steak, five grams were removed and placed in plastic tubes with 20 mL of distilled placed in a water bath for two hours at 80 °C. After cooking, the samples were homogenized for 1 min in a turrax mixer and centrifuged at 1000 *g* for 15 min at room temperature. The supernatant and sediment fractions were separated into glass tubes and 30 and 50 mL of 6 M HCl were added, respectively. The samples were placed in a dry oven at 100 °C for 16 h for hydrolysis. The samples were then filtered and diluted 1:10 and 1:25, and the pH adjusted to 6.0 with 2 M NaOH. After this procedure, 2.0 mL of the supernatant and sediment fractions and 1 mL of the oxidizing solution (10 mL of Chloramine solution T 7%; 40 mL of Citrate Buffer) were transferred to the test tubes. After 20 min at room temperature, 1.0 mL of color reagent (5 g of 4-dimethylaminobenzaldehyde, 20 mL of propanol, and 9 mL of 60% perchloric acid) was added. The samples were maintained in a water bath for 15 min at 60 °C. After cooling, their absorbance at 560 nm was measured (Penfield & Meyer, 1975).

To determine the myofibrillar fragmentation index (MFI), the steak without fat and connective tissue was homogenized and a 4 g sample taken. The samples were homogenized in a turrax homogenizer in 40 mL of MFI buffer (MFIB) at 2 °C for 30 s. After homogenization, the samples were centrifuged at 1000 *g* for 15 min at 2 °C, and the supernatant was discarded. The pellet was suspended in 40 mL of MFIB at 2 °C and homogenized with a glass rod (Culler, Parrish Júnior, Smith, & Cross, 1978). Then further centrifugation was performed at 1000 *g* for 15 min at 2 °C, and the supernatant again discarded. The pellet was then suspended in 10 mL of MFIB at 2 °C and homogenized in a vortex and filtered in a polyethylene sieve with approximately 1.0-mm mesh. Ten milliliters of MFIB were added at 2 °C to wash the centrifuge tube and assist in the filtration, in which the material retained in the sieve was discarded and the extracted material was used for MFI.

Table 2
Means and standard errors of the means of performance of Moxotó, Canindé, and F1 Boer goats subjected to different nutritional levels (NL).

	F1 Boer			Canindé			Moxotó			SEM	P value		
	AL	R.75	R.50	AL	R.75	R.50	AL	R.75	R.50		B	NL	B * NL
IBW	15.8	15.2	13.9	13.1	15.4	14.3	14.5	16.1	15.8	–	–	–	–
DMI	907^{A}	306^{D}	193^{D}	707^{B}	304^{D}	200^{D}	549^{C}	301^{D}	216^{D}	33.5	0.001	<.0001	<.0001
FBW	33.5^{A}	16.1^{CD}	13.9^{D}	26.5^{AB}	16.4^{CD}	14.4^{D}	23.5^{BC}	15.3^{CD}	13.8^{D}	1.84	0.063	<.0001	0.050
ADG	176^{ad}	10^{bd}	15^{bd}	156^{ade}	32^{bde}	0^{bde}	95^{ae}	-9^{be}	-18^{be}	0.02	0.003	<.0001	0.570
HCW	16.0^{a}	6.9^{b}	5.9^{b}	13.2^{a}	7.0^{b}	6.0^{b}	11.8^{a}	7.0^{b}	5.8^{b}	0.88	0.163	<.0001	0.096
CCW	15.6^{a}	6.5^{b}	5.6^{b}	12.8^{a}	6.6^{b}	5.7^{b}	11.4^{a}	6.6^{b}	5.4^{b}	0.86	0.13	<.0001	0.084

IBW = final body weight, kg; DMI = dry matter intake, g; FBW = final body weight, kg; ADG = average daily gain, g; HCW = hot carcass weight, kg; CCW = cold carcass weight, kg.
AL = ad libitum fed; R.75 = restricted fed at 0.75 of ad libitum intake; and R.50 = restricted fed at 0.5 of ad libitum intake.
^{a,b,c} Distinct lowercase letters in the same row, within breed, differ by Tukey's test.
^{d,e,f} Distinct lowercase letters in the same row, within breed, differ by Tukey's test.
^{A,B,C,D}Distinct capital letters in the same row, differ by Tukey's test.

Subsequently, a 0.25-mL aliquot of the suspended material was removed and deposited in a 100-mL glass tube. After this procedure, 0.75 mL of MFIB were added with 4 mL of biuret reagent to determine the protein content. Simultaneous with the preparation of the samples, standards were prepared with bovine albumin. To determine the MFI, the samples were prepared with MFIB to a final volume of 8 mL and protein concentration of 0.5 mg/mL. The samples were homogenized and the absorbance read (540 nm), and the MFI value was obtained as follows: MFI = absorbance × 200 (Culler et al., 1978).

2.4. Fatty acid profile

For the analysis of the fatty acid profile, the steak was thawed at 5 °C for 12 h followed by lipid extraction (Folch, Lees, & Sloane-Stanley, 1957). The fatty acid profile was determined according to Hartman and Lago (1973). A 5-mL sample of lipid extract was concentrated in a water bath at 45 °C with a gentle nitrogen stream followed by saponification with a solution of NaOH in 0.5 M methanol and methylation with NH_4Cl, methanol, and H_2SO_4. After methylation, 5 mL of hexane were added, and the solution agitated for 10 s to separate the esterified fatty acids. Three milliliters of the supernatant fraction (hexane and methylated fatty acids) were then removed and again concentrated in a water bath at 45 °C with a gentle nitrogen stream. This extract was diluted with 1 mL of hexane, and 1 μL of this solution was injected into a Focus CG-Finnigan model gas chromatograph with a flame ionization detector and a 100-m long, 0.25-mm internal diameter, and 0.20-μm thick (Supelco, Bellefonte, PA) CP-Sil 88 capillary column (Varian). Hydrogen at 1.8 mL/min was used as the carrier gas. The oven was maintained at 70 °C for 4 min and then the temperature was increased, at 13 °C/min to 175 °C, which was maintained for 27 min and then increased at 4 °C/min to 215 °C, which was maintained for 9 min, and then increased at 7 °C/min to 230 °C, which was maintained for 5 min. The injector temperature was 250 °C, and the detector temperature 300 °C.

Identification of the fatty acids was performed by a comparison of their retention times with standard fatty acids in butter, and the percentage of the fatty acids was obtained through Chromquest 4.1 software (Thermo Electron, Italy).

2.5. Statistical analysis

The goats performance and chemical composition, color, total and soluble collagen, myofibrillar fragmentation index and fatty acid profile of the meat were statistically analyzed using the proc GLM of SAS software (1999), in a 3 × 3 factorial scheme with three genotypes and three nutritional levels, according to the following model:

$$Y_{ijk} = \mu + G_i + N_j + H \times G_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} is the response variable measured in the experimental unit k of the i genotype in the nutritional level j; μ is the overall constant; G_i is the effect of the i genotype; N_j is the effect j nutritional level; $G \times N_{ij}$ is the interaction between the principal effects; ε_{ijk} is the non-observable random error, presupposed with normal distribution.

The shear force and water losses of the meat of the ad libitum nutritional level were analyzed using the proc GLM of SAS software (1999), according to the following model:

$$Y_{ik} = \mu + G_i + \varepsilon_{ik}$$

where Y_{ik} is the response variable measured in the experimental unit k of the i genotype; μ is the overall constant; G_i is the effect of the i genotype; and ε_{ik} is the random error.

When significant effects were detected at $P < 0.05$, multiple comparisons of the means were performed, using Tukey's test.

3. Results and discussion

3.1. Chemical and physical analyses

Dry matter intake and performance are depicted in Table 2. There was no difference ($P > 0.05$) in the chemical composition of the *Longissimus lumborum* muscle between the different genotypes (Table 3). Regarding the different nutritional levels, the AL presented greater amounts of CP in the muscle ($P < 0.05$) compared to the goats of the R.50 treatment, which could be partially explained by the higher protein synthesis and rib eye areas in AL.

According to Geay, Bauchart, Hocquette, and Culioli (2001), the main variation in fat content is due to the balance between the energy of the diet and nutritional demands of the goats. However, the greater consumption of energy in AL was not sufficient to increase the percentage intramuscular fat in the *Longissimus lumborum* muscle.

Table 3
Means and standard errors of the means of the chemical composition of the *Longissimus lumborum* muscle of Moxotó, Canindé, and Boer goats subjected to different nutritional levels (NL).

	Genetic group			Nutritional level			SEM	P value		
(%)	C	M	B	AL	R.75	R.50		Breed	NL	Breed*NL
CP	17.1	17.8	16.7	18.1^{a}	16.9^{ab}	16.3^{b}	1.29	0.46	0.01	0.27
MM	4.7	4.8	5.0	4.8	4.6	5.0	0.55	0.23	0.23	0.99
MOIS	75.6	75.2	76.7	74.9	75.9	76.7	1.08	0.07	0.06	0.40
EE	2.6	2.2	1.6	2.2	2.6	2.0	0.24	0.22	0.12	0.45

$^{a, b, c}$ Different uppercase letters within nutritional level differ by Tukey's test.
CP = crude protein; MM = mineral matter; MOIS = moisture; and EE = ether extract.
C = Canindé; M = Moxotó; and B = F1 Boer.
AL = ad libitum fed; R.75 = restricted fed at 0.75 of ad libitum intake; and R.50 = restricted fed at 0.5 of ad libitum intake.

Table 4
Means and standard errors of the means of the *Longissimus lumborum* color characteristics of Moxotó, Canindé, and F1 Boer goats subjected to different nutritional levels.

	Genetic group			Nutritional level			SEM	P value		
	C	M	B	AL	R.75	R.50		Breed	NL	Breed * NL
a^*	9.36	10.50	9.34	10.65a	9.57ab	8.98b	0.49	0.16	0.06	0.52
b^*	8.28ab	8.89a	7.21b	9.30b	7.82a	7.25a	0.45	0.02	0.01	0.91
L^*	24.54	24.71	24.85	22.82	25.85	25.44	0.80	0.75	0.03	<0.001

[a, b, c] Different uppercase letters within breed or nutritional level, in the same row, differ by Tukey's test.
C = Canindé; M = Moxotó; and B = F1 Boer.
AL = ad libitum fed; R.75 = restricted fed at 0.75 of ad libitum intake; and R.50 = restricted fed at 0.5 of ad libitum intake.

There was no difference in the redness (a^*) of the meat between breeds ($P > 0.05$). The meat of the AL treatment displayed greater values of a^* when compared to that of goats of the R.50 ($P < 0.05$); however, the meat of R.75 displayed a^* values similar to those of the other nutritional levels ($P > 0.05$).

The yellowness (b^*) did not differ among nutritional levels ($P > 0.05$). The meat of F_1 Boer goats had smaller values of b^* in relation to Moxotó goats ($P < 0.05$), and Canindé goats displayed b^* values similar to those of the other genotypes ($P > 0.05$) (Table 3).

There was an interaction between the genotype and nutritional level ($P < 0.05$) for L^*. The meat of F_1 Boer goats fed ad libitum displayed lower values of L^*. Monte, Selaive-Villarroel, Garruti, Zapata, and Borges (2007) also reported lower L^* values for F_1 Boer crossbreeds than for Anglo-Nubian crossbred goats. The greater the values of L^*, the paler the meat, and this is related to the final pH, the muscular fiber structure, and the onset of rigor mortis (Albertí et al., 2005).

According to Dhanda, Taylor, and Murray (2003), genetics may influence the color of meat due to differences in pigment deposition in the muscular and adipose tissues and different proportions of muscle fiber types, which would explain the differences in the values of L^* between the genotypes in this study. However, Oman, Waldron, Griffin, and Savell (2000) observed, through sensory analysis that the breed did not influence the color of lamb meat during storage.

There was no difference between the breeds for total and soluble collagen ($P > 0.05$). However, a greater amount of soluble collagen was observed in AL than the other nutritional levels. Similar to the total collagen, no difference was observed in the myofibrillar fragmentation index (MFI) ($P > 0.05$) (Table 4).

According to Hadlich et al. (2006), connective tissue is a fundamental element of organisms and exerts a structural function as an aggregator and support for cells. This function occurs because collagen, which is a fibrous protein endowed with great tensile strength is distributed among nearly all organs. The effect of collagen on the texture of meat is influenced by the cross-links, which make the collagen molecule less soluble and compromise the tenderness of the meat in older animals.

The greater amounts of soluble collagen in the meat of goats fed ad libitum was consistent with Harper (1999), who stated that the weight gain rate influences the meat's tenderness; greater weight gains in less time promote meat with a greater amount of soluble, less stable collagen with fewer covalent cross-links between the collagen fibers.

There was no difference ($P > 0.05$) for the SF and thawing, drip, evaporation, and cooking water losses among the different genotypes (Table 5). The SF values were below the limit of 4.5 kgf for meat to be characterized as tender (Shackelford, Wheeler, & Koohmaraie, 1997), which confirms the tenderness observed through the evaluation of the MFI for goats fed ad libitum.

In addition to the color, the released juice is one of the greatest determining factors for consumers purchasing meat and is a factor mainly associated with succulence. The water-holding capacity is the power of the meat to retain water during the application of external forces, mainly with the loss of water, fat, and ions during cooking. The water-holding capacity may be determined by several factors, including post-mortem glycolysis, pH, and cooling of the carcass. In addition, the intramuscular fat content may interfere in the water retention, loosening the muscular microstructure and consequently retaining a greater amount of water. The amount of intramuscular and subcutaneous fats that provide protection against dehydration could explain the low water loss values in the animals.

3.2. Fatty acid profile

There was a difference among the breeds in relation to the fatty acid profile in the *Longissimus lumborum* muscle ($P < 0.05$). The muscles of F_1 Boer goats presented greater ($P < 0.05$) amounts of capric, arachidonic, and docosahexaenoic fatty acids when compared to Canindé goats but no difference compared to Moxotó goats ($P > 0.05$). Myristoleic fatty acids were present in greater concentrations ($P < 0.05$) in the meat of F1 Boer goats compared to Moxotó goats. The meat of Canindé and Moxotó goats displayed greater concentrations of heptadecanoic fatty acid compared to F_1 Boer goats (Table 6).

The fatty acids observed in the greatest concentrations in the goat meat, regardless of the genotype, were stearic and oleic acids. A high concentration of oleic acid in the intramuscular fat of goats has been reported (Banskalieva, Sahlu, & Goetsch, 2000). Oleic acid in its *cis* form is hypocholesterolemic and represents approximately 88% of the mono-unsaturated fatty acids (MUFA). It acts to reduce LDL and maintain HDL, and is related to the prevention of cardiac diseases (Melton, Amiri, Davis, & Backus, 1982). In addition, F1 Boer goats had greater amounts of arachidonic and docosahexaenoic fatty acids in their meat.

The meat of Canindé and Moxotó goats displayed greater concentrations of margaric acid (C17:0) compared to F_1 Boer goats ($P < 0.05$).

Table 5
The means and standard errors of the means of the total collagen (mg/g), soluble collagen (%), and myofibrillar fragmentation index (MFI) of the *Longissimus lumborum* muscle in Moxotó, Canindé, and F_1 Boer goats subjected to different nutritional levels (NL).

	Genetic group			Nutritional level			SEM	P value		
	C	M	B	AL	R.75	R.50		Breed	NL	Breed * NL
Total collagen	1.85	2.08	2.02	1.77	2.02	2.16	0.42	0.31	0.66	0.61
Soluble collagen	10.81	13.15	13.32	15.21[a]	11.65[b]	10.41[b]	2.42	0.37	0.03	0.12
MFI	83.50	84.01	74.98	81.88	80.40	80.21	8.94	0.46	0.99	0.92

[a, b, c] Different uppercase letters differ by Tukey's test.
C = Canindé; M = Moxotó; and B = F1 Boer.
AL = ad libitum fed; R.75 = restricted fed at 0.75 of ad libitum intake; and R.50 = restricted fed at 0.5 of ad libitum intake.

Table 6
Means and standard errors of the means of shear force (SF) and water losses in the *Longissimus lumborum* muscle of Moxotó, Canindé, and F_1 Boer goats.

Variable	Genetic group			P value	SEM
	C	M	B		
Shear force (kgf/cm^2)	2.61	2.77	2.54	0.893	0.33
Water losses (%)					
Thawing	2.93	1.30	2.32	0.434	0.74
Dripping	2.02	1.15	2.04	0.667	0.64
Evaporation	16.24	17.03	17.91	0.697	1.36
Cooking	18.26	18.18	19.95	0.694	1.55

C = Canindé; M = Moxotó; and B = F1 Boer.

There was no difference ($P > 0.05$) between genotypes in relation to the total of odd- and branched-chain fatty acids (C13:0; C15:0; C15:0 iso; C15:0 anteiso; C17:0; C17:0 iso, and C17:1) in the meat (4.6%, 4.8%, and 4.3 for the Canindé, Moxotó, and F_1 Boer, respectively).

Regardless of the breed used, goat meat displayed a fatty acid profile that is beneficial to health due to the high concentrations of oleic acid, the presence of essential fatty acids, and low concentrations of lauric, myristic, and palmitic acids when compared to the meats of other species.

When the effect of different nutritional levels on the fatty acid profile was analyzed, a larger change was observed in relation to the different genotypes. With the exception of tridecylic and margaric acids (C13:0 and C17:0, respectively), the AL treatment displayed greater concentrations for all odd- and branched-chain fatty acids (C15:0, C15: iso, C15:0 anteiso; C17:0 iso, and C17:1) in the meat ($P < 0.05$) compared to R.50 and R.75 goats (Table 7). The summations of odd- and branched-chain fatty acids for the AL, R.75 and R.50 were 5.81%, 4.28%, and 3.67%, respectively. The experimental diet consisted only of fresh forage and concentrate, and according to Wu, Ohajuruka, and Palmiquist (1991), insignificant odd-numbered fatty acids occur in products of plant origin. Therefore, the odd-numbered fatty acids present in the meat originated from rumen microorganisms. The greater concentrations of odd- and branched-chain fatty acids observed in the AL may be due to the greater consumption of TDN by this group (0.61, 0.34, and 0.24 kg of TDN/day for the AL, R.75 and R.50, respectively).

The meat of goats from R.50 had greater ($P < 0.05$) concentrations of myristoleic acid (C14:1 *cis*9) in relation to the other groups. When the C14:0, C16:0, C18:0, C14:1 *cis*-9, C16:1 *cis*-9, and C18:1 *cis*-9 acids were analyzed as a group, the result suggested that the activity of delta-9 desaturase was more effective in the AL. The meat of the goats fed ad libitum displayed greater amounts of oleic acid and both isomers of conjugated linoleic acid (CLA, *cis*-9 *trans*-11 and *trans*-11 *cis*-15) ($P < 0.05$). The greater values of oleic acid (C18:1) may be attributed to the greater animal biosynthesis from stearic acid (C18:0) (Rule, Macneil, & Short, 1997). Therefore, nutritional strategies that increase the conversion of stearic acid into oleic acid contribute to an improvement in meat quality.

As it was not possible to separate the isomers C18:1 *trans*-9, *trans*-10, and *trans*-11, there was no way of attributing the formation of CLA in the meat to the presence of vaccenic acid. Therefore, a hypothesis for the greater CLA values observed in AL would be that the higher intake, which would allow a greater rate of passage of food through the rumen and less exposure of the fatty acids to rumen bacteria allows intermediate compounds of biohydrogenation to escape and be absorbed in the small intestine.

According to Jenkins, Wallace, Moate, and Mosley (2008), the greater amount of starch consumed by goats fed ad libitum favors the development of protozoa, which are an important source of polyunsaturated fatty acids (PUFA) and CLA to be incorporated into the meat, since the values observed for CLA in the protozoa were 3 to 8 times greater than observed in the bacteria.

There was a decrease in the concentrations of lauric acid (C12:0) ($P < 0.05$) in the meat as the nutritional levels increased in the diet. There is evidence that this fatty acid, in addition to myristic (14:0) and palmitic (16:0) fatty acids, are fats associated with an increase in blood cholesterol and increase the concentration of LDL due to interference in the LDL hepatic receptors (Woollett, Spady, & Dietschy, 1992).

Table 7
Means and standard errors of the means of the c of Moxotó, Canindé, and F1 Boer goat meat subjected to different nutritional levels (NL).

	Breed			Nutritional level			SEM	P value		
Fatty acid	C	M	B	AL	R.75	R.50		Breed	NL	Breed * NL
C10:0	0.10	0.11	0.13	0.10	0.13	0.12	0.001	0.16	0.06	0.85
C12:0	0.14	0.14	0.17	0.12b	0.14ab	0.19a	0.021	0.58	0.08	0.48
C13:0	0.10	0.10	0.08	0.07	0.06	0.15	0.035	0.89	0.18	0.75
C14:0	2.48	2.50	2.73	2.50	2.52	2.69	0.202	0.47	0.80	0.06
C14:1 c9	0.17	0.12	0.19	0.05c	0.08b	0.11a	0.018	0.06	0.01	0.11
C15:0	0.80	0.87	0.81	1.06a	0.72b	0.70a	0.034	0.34	<0.001	0.13
C15:0 iso	0.32	0.33	0.35	0.42a	0.31b	0.27b	0.022	0.63	<0.001	0.06
C15:0 anteiso	0.63	0.75	0.73	1.11a	0.60b	0.41b	0.10	0.71	<0.001	0.44
C16:0	22.05	22.14	21.30	21.08	22.28	22.12	0.491	0.58	0.17	0.05
C16:1 c9	1.17	1.02	1.18	1.53a	1.03b	0.81c	0.075	0.71	<0.001	0.82
C17:0	1.70a	1.74a	1.30b	1.66	1.65	1.43	0.081	<0.001	0.10	0.66
C17:0 iso	0.07	0.06	0.04	0.09a	0.04b	0.04b	0.008	0.09	0.001	0.45
C17:1	1.040	0.950	1.004	1.400a	0.907b	0.687c	0.070	0.78	<0.001	0.51
C18:0	22.91	24.70	22.94	19.90b	25.90a	24.76a	1.004	0.63	<0.001	0.94
C18:1 *c*9	33.03	30.81	31.76	40.48a	30.78b	24.35c	1.147	0.88	<0.001	0.97
C18:1 *t*10, *t*11e *t*12	0.96	1.20	1.19	0.78b	1.25a	1.31a	0.102	0.24	0.001	0.51
C18:2 *c*9 *t*11	0.26	0.21	0.26	0.30a	0.23b	0.22b	0.025	0.40	0.05	0.28
C18:2 *c*9 *c*12	2.06	2.68	2.13	1.80b	2.05b	3.021a	0.219	0.09	0.003	0.97
C18:2 *t*11 *c*15	0.06	0.05	0.07	0.07a	0.05b	0.05b	0.004	0.07	0.002	0.06
C18:3 *c*9 *c*12 *c*15	0.16	0.17	0.18	0.13b	0.15b	0.24a	0.011	0.51	<0.001	0.91
C18:3 *c*6 *c*9 *c*12	0.02	0.02	0.02	0.01b	0.02b	0.03a	0.003	0.79	0.003	0.09
C20:4	0.47b	0.85ab	1.15a	0.43b	0.74ab	1.31a	0.173	0.04	0.01	0.89
C20:5	0.11	0.15	0.16	0.04b	0.11b	0.27a	0.036	0.50	<0.001	0.33
C22:5	0.36	0.46	0.58	0.13b	0.34b	0.92a	0.99	0.40	<0.001	0.07
C22:6	0.05	0.08	0.09	0.02b	0.04b	0.16a	0.017	0.25	<0.001	0.26

[a, b, c] Different uppercase letters within breed or nutritional level, in the same row, differ by Tukey's test.
C = Canindé; M = Moxotó; and B = F1 Boer.
AL = ad libitum fed; R.75 = restricted fed at 0.75 of ad libitum intake; and R.50 = restricted fed at 0.5 of ad libitum intake.

Table 8
Means and standard errors of the means of the fatty acid proportions and indices of the enzymes involved in the metabolism of fatty acids in the meat of Moxotó, Canindé, and F1 Boer goats subjected to different nutritional levels (NL).

	Breed			Nutritional level			SEM	P value		
	C	M	B	AL	R.75	R.50		Breed	NL	Breed * NL
Saturated	52.3	54.2	51.5	47.5b	54.8a	55.6a	1.25	0.48	<0.001	0.56
Unsaturated	42.1	40.6	40.4	48.6a	39.9b	34.5c	0.99	0.55	<0.001	0.38
Monounsaturated	38.9	36.0	37.2	45.6a	36.4b	30.2c	1.08	0.38	<0.001	0.77
Polyunsaturated	2.99b	4.69a	3.33b	3.03b	3.61ab	4.39a	0.42	0.03	0.01	0.71
ω-6	2.62	3.38	2.59	2.13b	3.06a	3.41a	0.27	0.27	0.03	0.32
ω-3	0.92b	1.88a	1.40ab	0.75b	1.24b	2.20a	0.21	0.02	<0.001	0.48
ω-6/ω-3	3.26	2.79	2.62	3.94a	3.04b	1.70c	0.28	0.27	<0.001	0.48

[a, b, c] Different uppercase letters within breed or nutritional level, in the same row differ by Tukey's test.
C = Canindé; M = Moxotó; and B = F1 Boer.
AL = ad libitum fed; R.75 = restricted fed at 0.75 of ad libitum intake; and R.50 = restricted fed at 0.5 of ad libitum intake.

However, greater concentrations ($P < 0.05$) for all MUFA, with the exception of arachidonic acid (C20:4), was observed in R.50 compared to AL and R.75. The greater MUFA concentrations observed in R.50 is in accordance with Rule et al. (1997). According to these authors, as the de novo synthesis of fatty acids increases, the MUFA present in the muscle is diluted.

The meat of Moxotó goats displayed a greater concentration of MUFA when compared to the other breeds ($P < 0.05$) and a greater concentration of ω-3 series fatty acids ($P < 0.05$) compared to the meat of Canindé goats but no difference compared to F_1 Boer goats ($P > 0.05$) (Table 8).

The meat of goats fed ad libitum displayed a concentration of fatty acids that is better for human health in relation to the other nutritional levels. The AL treatment displayed lower concentrations of SFA ($P < 0.05$) and greater concentrations of UFA ($P < 0.05$). Similarly, AL treatment displayed greater concentrations of MUFA ($P < 0.05$) compared to other feeding levels and lower concentrations of PUFA ($P < 0.05$) compared to R.50 (Table 8).

A likely explanation for the aforementioned values would be the lower biohydrogenation of fatty acids in the rumen, which allows for increased escape of fatty acids and, consequently, a greater absorption of unsaturated fatty acids in the small intestine. In addition, AL goats produced more fatty acids through de novo synthesis (mainly oleic acid), which diluted the concentrations of MUFA.

A lower concentrations of ω-3 and ω-6 series fatty acids was found in AL when compared R.50, because of the dilution of fatty acids. However, according to Enser et al. (1990), three factors should be taken into account when the nutritional value of food fat is assessed: the total lipid content, the unsaturated:saturated fatty acid ratio, which should be greater than 0.4, and the ω6:ω3 ratio, which should be less than 4. Therefore, the meat from the three nutritional levels fit within the values proposed by these authors.

Another possible explanation for the lower concentration of ω-3 and ω-6 series fatty acids displayed by the goats fed ad libitum, in addition to the effect caused by dilution, would be the greater activity of the desaturase enzymes that convert linoleic and linolenic acids into fatty acids with more than 20 carbons and the action of the elongase enzyme, which promotes the addition of 2 carbons in the fatty acid structure (Malau-Aduli, Siebert, Bottema, & Pitchford, 1997).

Approximately 70% of the fat was in the form of stearic acid, MUFA, and PUFA and is therefore not a fat source that potentially causes cardiovascular diseases in humans. In addition, oleic acid was the fatty acid observed in the greatest amount and this fatty acid can increase HDL blood levels.

4. Conclusion

The different goat genotypes displayed small differences in the quality of their meat and fatty acid profiles. However, the goats fed ad libitum displayed better quality meat due to the lower amounts of soluble collagen and a more favorable fatty acid profile for human health with greater concentrations of oleic acids, unsaturated fatty acids, and CLAs.

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