Effects of quantitative feed restriction and sex on carcass traits, meat quality and meat lipid profile of Morada Nova lambs

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Abstract

Background: An experiment was conducted to evaluate the effects of feed restriction (FR) and sex on the quantitative and qualitative carcass traits of Morada Nova lambs. Thirty-five animals with an initial body weight of 14.5 ± 0.89 kg and age of 120 d were used in a completely randomized study with a 3 × 3 factorial scheme consisting of three sexes (11 entire males, 12 castrated males and 12 females) and three levels of feeding (ad libitum – AL and 30% and 60% FR).

Results: Entire males presented greater hot and cold carcass weights (P < 0.05), followed by castrated males and females. However, the hot carcass yield was higher for females and castrated males than for entire males. Luminosity values were influenced (P < 0.05) by sex, with entire males presenting higher values than castrated males and females. Females showed higher (P < 0.05) concentrations of linoleic acid and arachidonic acid in the meat of the longissimus thoracis muscle. The meat of animals submitted to AL intake and 30% FR showed similar (P > 0.05) concentrations, and the concentrations of palmitic acid, palmitoleic acid, stearic acid, oleic acid and conjugated linoleic acid were higher (P < 0.05) than those of animals with 60% FR. The meat of females had a higher ω6/ω3 ratio and lower h/H ratio, and females had greater levels of feeding. The meat of animals on the 60% FR diet had a greater ω6/ω3 ratio, lower h/H ratio and lower concentration of desirable fatty acids in addition to a greater atherogenicity index (AI) and thrombogenicity index (TI).

Conclusion: Lambs of different sexes had carcasses with different quantitative traits without total influence on the chemical and physical meat characteristics. The lipid profile of the meat was less favorable to consumer health when the animals were female or submitted to 60% feed restriction.

Keywords: Dietary restriction, Fatty acid, Hair sheep, Lean meat, Semi-arid condition
The improvement of animal yield by enhancing sustainable biodiversity may be a pathway toward greater food supplies. Such sustainable increases may be especially important for the 2 billion people reliant on small farms, many of which are undernourished, yet we know little about the efficacy of this approach.

Some productive strategies affect animal performance as well as the chemical and physical quality of the meat produced. The farmer can, for example, opt to obtain production rates and carcasses with different characteristics depending on the sex of the animals [5–7]. In tropical semi-arid regions, animals can be submitted naturally to periods of feed restriction (FR) due to feed supply variations or due to feed management planning, which is commonly used to save resources and reduce costs [8, 9].

Under these conditions, it may be assumed that in addition to lower performance, meat products may have different chemical and physical characteristics if the animals are sold [10, 11].

In the face of global concerns about the safety and nutritional quality of foods, it is necessary to understand the effects of commonly used production strategies not only on productivity but also on aspects related to human health, as is the case with lipid quality parameters. Thus, we simulate the impact of feed restriction in hair sheep of different sexes in semi-arid regions. We then evaluate their effects on carcass characteristics, meat quality and fatty acid profiles in the meat of Morada Nova lambs.

Methods
Animal care and location
This study was conducted at the Department of Animal Science, Federal University of Ceará, located in Fortaleza, CE, Brazil. Protocols (n° 98/2015) were in accordance with the standards established by the Committee of Ethics in Animal Research of the Federal University of Ceará.

Animals, experimental design and management
Experimental lambs were obtained from the Morada Nova sheep breeding facility. The mating season was established with the objective of enabling a selection of animals with little variation in BW. Thirty-five lambs of the Morada Nova breed, including 23 males and 12 females, were selected. Twelve entire males were randomly assigned to the sexual class of castrated males, and the males were castrated using the burdizzo castrating method. Initially, the lambs had $14.5 \pm 0.89$ kg of BW and $120$ days of age. The lambs were distributed in a completely randomized design in a $3 \times 3$ factorial scheme. Experimental treatments consisted of three sexes (11 entire males, 12 castrated males and 12 females) and three quantitative feeding levels (ad libitum (AL), $30\%$ and $60\%$ FR). The ration was formulated to supply the nutritional requirements of late maturity lambs with a gain of $150$ g/d as recommended by the National Research Council (NRC) [12]. Before beginning data collection, the animals were randomly assigned to individual boxes provided with feed and water troughs, where they underwent an adaptive period of $15$ days. Total mixed rations were provided twice a day ($0730$ and $1600$ h), allowing for up to $10\%$ orts only for animals fed AL. Before each morning feeding, the orts of each animal fed AL were removed and weighed to calculate the intake and feeding level of the lambs submitted to $30\%$ and $60\%$ FR ($300$ and $600$ g/kg of FR). Thus, the restrictions were proportionally based on the intake of animals fed AL of each sex.

The ingredients used in the total ration and their proportions and composition are described in Table 1.

Samples of the roughage, concentrated and feed orts were taken to determine their chemical compositions and dry matter intake (DMI) of the lambs. The lambs were weighed every fifteen days to calculate BW gain (BWG). The trial period lasted $120$ days. At the end of the trial period, the animals were weighed to determine total weight gain (TWG) and average daily gain (ADG).

Slaughter, carcass data and meat samples
After $18$ h of fasting, the animals were weighed to determine their BW at slaughter (BWS). The animals were then skinned and eviscerated according to the rules established in the Regulation of Brazilian Industrial and Sanitary Inspection of Animal Products. Subsequently, the lambs were stunned with the proper equipment, bled, skinned, and eviscerated. The viscera were weighed when filled, emptied, washed, drained, and weighed when empty to determine the contents of the gastrointestinal tract and subsequently the empty BW (EBW) of the animals. The carcasses were identified and weighed to obtain the hot carcass weight (HCW) and yield (HCY) calculated in relation to BWS. After $24$ h of cooling at $4^\circ$C, the carcasses were weighed to obtain the cold carcass weight (CCW). Twenty-four hours post mortem, the pH was measured using a pH meter (HI-99163, Hanna® instruments, São Paulo, Brazil) by inserting the meter between the $4^{\text{th}}$ and $5^{\text{th}}$ lumbar vertebrae in the longissimus lumborum muscle.

The carcasses were sectioned with an electric saw (Ki Junta®, São Paulo, Brazil) along the spine, and the left halves of the carcasses were divided into six commercial cuts (leg, loin, ribs, lower ribs, neck and shoulder), which were individually weighed. A cross-sectional cut was made between the $12^{\text{th}}$ and $13^{\text{th}}$ ribs to expose the longissimus thoracis (LT) muscle, which measured the maximum distances between the ends of the muscle in the mediolateral direction (A) and dorsal-ventral (B) to subsequently calculate the rib eye area (REA) according
to Eq. REA = (A / 2 × B / 2) × π. Subcutaneous fat thickness (SFT) was verified above measure B using a digital caliper. Samples were taken from the LT and longissimus lumborum (LL) muscles, vacuum packed and stored at −20 °C.

Physicochemical meat analyses

The meat color was evaluated using a transverse cut on the back section, which was exposed to atmospheric air for 30 min before reading the oxygen myoglobin, which is the primary element that defines meat color [13]. As described by Miltenburg et al. [14], the coordinates L*, a* and b* were measured at three different points on the muscle, and the triplicates were averaged for each coordinate per animal. These measurements were performed using a Minolta CR-10 colorimeter (Konica® Minolta, Osaka, Japan) that was previously calibrated with the CIELAB system using a blank tile, illuminant D65 and 10° as the standard observation points. L* is related to lightness (L* = 0 black, 100 white); a* (redness) ranges from green (−) to red (+); and b* (yellowness) ranges from blue (−) to yellow (+). Measurements were made from a 2° viewing angle using illuminant C. The color saturation (chroma, C*) was calculated as (a*² + b*²)½ [15].

Meat samples of LL muscle were processed in a crusher to determine the water holding capacity (WHC), and cooking weight loss (CWL) was determined according to the American Meat Science Association (AMSA) [16] using LL meat samples (triplicate) without visible connective tissue that were previously thawed at 10 °C for 12 h. CWL indicated the difference in the weight of the meat before and after cooking on a preheated grill (George Foreman Jumbo Grill GBZ6BW, Rio de Janeiro, Brazil) at 170 °C. A digital skewer thermometer (Salcasterm 200®, São Paulo, Brazil) was used to monitor the internal temperature of the steak until the center reached 71 °C. Then, each steak was brought to room temperature, removed from the oven after temperature stabilization, and weighed again. The difference between the initial and final weights of a sample was used to determine the CWL, with the value expressed as a percentage.

After cooling at room temperature, the samples were again wrapped in foil and placed in a refrigerator (Consul CHB53C®, Salvador, Brazil) for 12 h at 4 °C. Fillets (5 ± 1) approximately 2 cm long, 1 cm wide and 1 cm high were cut from the meat to be evaluated for Warner-Bratzler shear force (WBSF). The instrumental texture analysis was performed on a TAXT2 texturometer (Stable Micro Systems Ltd., Vienna Court, UK) at 200 mm/min using standard shear blades (1.016 mm thick with a 3.05-mm blade). The instrumental texture analysis was performed according to the Research Center for Meat (US Meat Animal Research Center) and Shackelford et al. [17].

To evaluate lipid oxidation, meat samples of LL muscle stored under fast freezing at −20 °C for three months were thawed and crushed. Using the aqueous acid extraction method described by Cherian et al. [18], the 2-thiobarbituric acid reactive substances (TBARS) were measured in mg of malondialdehyde (MDA)/g of tissue.

Meat samples of LT muscle were evaluated for moisture, ash and protein contents, following method numbers 930.15, 920.153 and 928.08, respectively [19]. LT muscle samples were used to extract and quantify intramuscular fat (IMF). The fat of meat samples was isolated and purified using polar solvents (chloroform and

### Table 1 Ingredient proportion and chemical composition of experimental rations

| Ingredient                      | Proportion, % of DM | Total ration | Tifton 85 grass hay | Ground corn grain | Soybean meal |
|---------------------------------|---------------------|--------------|---------------------|-------------------|--------------|
| Tifton 85 grass hay             | 60.0                | 913.40       | 892.40              | 910.00            |
| Ground corn grain               | 32.72               |              | 172.50              | 102.80            |
| Soybean meal                    | 6.30                |              | 25.57               | 43.18             |
| Dicalcium phosphate             | 0.06                |              | 6.193              | 13.30             |
| Mineral premix a                | 0.92                |              | 438.65              | 112.54            |
| Chemical composition, g/kg of DM|                     |              | 418.32              | 97.89             |
| Total ration                    |                     |              | 201.93              | 26.31             |
| Tifton 85 grass hay             |                     |              | 319.67              | 728.19            |
| Ground corn grain               |                     |              | 58.30               | 273.30            |
| Soybean meal                    |                     |              | 102.05              | 102.05            |
| Dry matter                      | 907.72              | 913.40       | 892.40              | 910.00            |
| Crude protein                   | 169.32              | 172.50       | 102.80              | 508.80            |
| Ether extract                   | 30.77               | 25.57        | 43.18               | 19.32             |
| Ash                             | 61.93               | 73.40        | 13.30               | 65.90             |
| Neutral detergent fiber         | 438.65              | 668.20       | 112.54              | 134.63            |
| NDap b                          | 418.32              | 644.85       | 97.89               | 110.41            |
| Acid detergent fiber            | 201.93              | 317.54       | 26.31               | 102.05            |
| Non-fiber carbohydrate          | 319.67              | 58.30        | 728.19              | 273.30            |

*Composition, 1 kg of premix: Calcium 225 g to 215 g; Phosphor 40 g; Sulfur 15 g; Sodium 50 g; Magnesium 10 g; Cobalt 11 mg; Iodine 34 mg; Manganese 1,800 mg; Selenium 10 mg; Zinc 2,000 mg; Iron 1,250 mg; Copper 120 mg; Fluor 400 mg; Vitamin A 37.5 mg; Vitamin D₃ 0.5 mg and Vitamin E 800 mg

*Neutral detergent fiber corrected for ash and protein
methanol) according to the procedure of Folch et al. [20]. Aliquots of the fat extract were reserved and stored at −20 °C for subsequent use in determining the fatty acid profile.

**Fatty acid profile**

To determine the fatty acid profile, the fat samples previously extracted from LT muscle were converted to fatty acid methyl esters (FAMEs). The FAMEs were prepared using a solution of methanol, ammonium chloride and sulfuric acid, following the procedure described by Hartman and Lago [21]. Samples were analyzed using a chromatograph (GC2010, Shimadzu®, São Paulo, Brazil) equipped with a flame-ionization detector and a biscyanopropyl polydimethylsiloxane capillary column of stationary phase (SP2560, 100 m × 0.25 mm, d f 0.20 μm; Supelco®, Bellefonte, PA, USA). The column oven temperature was as follows: the initial temperature was held for 80 °C, increased at 11 °C/min to 180 °C and at 5 °C/min to 220 °C and then maintained for 19 min. Hydrogen was used as a carrier gas at a flow rate of 1.5 mL/min, the split ratio was 1:30, and the injector and detector temperatures were 220 °C. The FAMEs were identified by a comparison of the FAME retention times with those of authentic standards (FAME mix components, Supelco®, Bellefonte, PA, USA) following the same injection method. The results were quantified by normalizing the areas of the methyl esters and converted to mg/100 g of meat using a conversion factor of 0.92 for the contribution of fatty acids in lipids [22].

The concentrations of saturated fatty acids (SFAs), unsaturated fatty acids (UFAs), monounsaturated fatty acids (MUUFAs), polyunsaturated fatty acids (PUFAs), ω6 and ω3 were calculated based on the fatty acid profile of the meat. Lipid quality indexes were determined using the sum of the desirable fatty acids [23], the thrombogenicity index (TI), the atherogenicity index (AI) [24], and the ratio between fatty acids hypocholesterolemic acid and hypercholesterolemic acid (h/H) [25]. The activity of enzymes involved in lipid metabolism, such as Δ9 desaturase in C16, Δ9 desaturase in C18 and elongase, were calculated according to the methods of Malau-Aduli et al. [26].

**Feed chemical analysis**

To determine the chemical composition of the feed, triplicate samples were dried at 55 °C for 72 h in a forced-air oven, ground with a Willey mill (Tecnal®, São Paulo, Brazil) with a 1-mm sieve, and stored in airtight plastic containers (ASS®, São Paulo, Brazil). The samples were then stored in plastic jars with lids (ASS®, São Paulo, Brazil), labeled, and subjected to further laboratory analysis to determine the contents of dry matter (DM method 967.03), ash (method 942.05), crude protein (CP method 981.10), and ether extract (EE method 920.29) according to the Association of Official Analytical Chemists (AOAC) [27].

The neutral detergent fiber (NDF) content was determined as described by Van Soest et al. [28]. The acid detergent fiber (ADF) contents were determined as described by Robertson and Van Soest [29]. The NDF residue was incinerated in an oven at 600 °C for 4 h to determine the ash content, and the protein concentration was calculated by subtracting the neutral detergent insoluble protein (NDIP). NDF was corrected for the ash and protein contents. The Non-fiber carbohydrate (NFC) content was measured according to Mertens [30] and calculated based on the differences in the equation NFC = 100 − NDF − CP − EE − ash.

**Statistical analyses**

Variables were subjected to analysis of variance using the GLM procedure of Statistical Analysis System - SAS® software [31] and the following equation: $Y_{ijk} = \mu + S_i + R_j + S_i \times R_j + \varepsilon_{ijk}$, where $Y_{ijk}$ is the dependent or response variable measured in the animal or experimental unit "k" of sexual class "i" at FR "j"; $\mu$ is the population mean or global constant; $S_i$ is the effect of sexual class "i"; $R_j$ is the effect of FR "j"; $S_i \times R_j$ is the interaction between effects of sexual class "i" and FR "j"; and $\varepsilon_{ijk}$ is unobserved random error. Tukey-Kramer’s test was used to compare the means with a significance level of 5% probability ($P < 0.05$), and the same criterion was adopted for interactions between the effects of sex and FR.

**Results**

**Performance and carcass traits**

There was an interaction ($P < 0.05$) between sex and FR for ADG, BWS and EBW (Table 2). In sum, females subjected to AL intake presented similar ADG, BWS and EBW ($P > 0.05$) to those of entire males and castrated males fed 30% FR (Table 3). Entire males fed AL presented higher ($P < 0.05$) ADG, BWS and EBW due to their higher growth (Table 3, Fig. 1).

Except for SFT, the carcass traits that were analyzed (HCW, HCY, CCW, CCY and REA) were influenced ($P < 0.05$) by sex (Table 4). Entire males showed higher means of HCW and CCW followed by castrated males and females. However, females and castrated males had a higher HCY than did entire males. After cooling and considering the losses caused by this process, only females had the highest yield (CCY), whereas castrated males did not differ from the other sexes. The level of FR did not influence ($P > 0.05$) the HCY and CCY, which indicated that the lower weights due to lower feed intake occurred proportionately throughout the bodies of the animals. HCW, CCW and SFT decreased with increasing FR (60%).
There was an interaction ($P < 0.05$) between sex and FR in neck weight (Table 4). However, no clear result was evidenced (Table 5). The weights of all commercial cuts were influenced ($P < 0.05$) by sex and by FR (Table 4). Entire males had heavier cuts, followed by castrated males and females, which reflected the effects observed with the CCW. The weights of the commercial cuts decreased due to the reduction in feeding supply.

**Physicochemical meat quality**

L* was influenced ($P < 0.05$) by sex (Table 6). The color parameters a*, b* and C* were not affected by sex or FR. Castrated males and females did not differ ($P > 0.05$), and they had lower values ($P < 0.05$) than did entire males. Animals subjected to 60% FR showed a higher 24 h post-mortal pH in their meat compared to that of animals subjected to AL intake.

There was no effect ($P > 0.05$) of FR and sex on the protein content in meat from LT muscle (Table 6). However, an interaction ($P < 0.05$) between sex and FR for this variable was observed. Females fed AL had a higher ($P < 0.05$) protein content than did females submitted to 30% FR (Table 7). The moisture content in the LT muscle of animals with AL intake was lower ($P < 0.05$) compared to that of animals subjected to 30 and 60% FR (Table 6). Animals submitted to AL intake and 30% FR provided similar ($P > 0.05$) amounts of IMF, whereas animals subjected to 60% FR had a reduced ($P < 0.05$) concentration of IMF. Ash percentage was higher ($P < 0.05$) in the meat from animals subjected to 60% FR.

**Fatty acid profile**

It was not possible to separate the peaks of conjugated linoleic acid (CLA) isomers normally identified in meats from ruminants. Thus, the nomenclature used covered all isomers (CLA). There was an interaction ($P < 0.05$) between sex and FR for elaidic acid (C18:1 t9) and behenic acid (C22:0) in the meat of the LT muscle (Table 8). However, after adjusting for multiple comparisons, a clear interaction response was only detected for elaidic acid (Table 9). Probably data set characteristics contributed to the absence of significance after the Tukey-Kramer test, contradicting the initial result of the ANOVA for the behenic acid. Females submitted to 60% FR had higher amounts of elaidic acid than did entire males and castrated males submitted to 60% FR (Table 9).

There was an effect ($P < 0.05$) of sex only on the concentrations of linoleic acid (C18:2 c9c12) and arachidonic acid (C20:4 c5c8c11c14) (Table 8) Females showed higher ($P < 0.05$) concentrations of these fatty acids than did entire males and castrated males, which showed no difference ($P > 0.05$) compared to the other categories. Meat of animals submitted to AL intake and 30% FR showed similar ($P > 0.05$) and higher ($P < 0.05$) values compared to those of animals subjected to 60%

### Table 2

| Variables | Sexes | Feed restrictions | SEM | P-value |
|-----------|-------|-------------------|-----|---------|
| IBW, kg   | Ent   | AL, 30%, 60%      | 0.158 | 0.711 |
| DMI, kg   | Cas   | 0.60<sup>a</sup>, 0.62<sup>b</sup> | 0.909 | <0.001 |
| BWS, kg   | Fem   | 0.52<sup>c</sup> | 0.009 | <0.001 |
| EBW, kg   | AL    | 21.0<sup>a</sup>, 18.1<sup>b</sup> | 0.308 | <0.001 |
| ADG, g    | Cas   | 106<sup>c</sup> | 0.214 | <0.001 |
| ADG, g    | Fem   | 71.7<sup>b</sup> | 0.217 | <0.001 |
| ADG, g    | AL    | 164<sup>a</sup> | 0.156 | <0.001 |

Ent Entire males, Cas Castrated males, Fem Females. AL ad libitum intake, 30% 30% feed restriction, 60% 60% feed restriction. SEM standard error of the mean. Sexes and Res = feed restriction, IBW initial body weight, DMI dry matter intake, BWS body weight at slaughter, EBW empty body weight, TWG total weight gain, ADG average daily gain.

<sup>a</sup> Means followed by different letters differ between sexes according to a Tukey-Kramer test ($P < 0.05$).

<sup>b</sup> Means followed by different letters differ between sexes according to a Tukey-Kramer test ($P < 0.05$).

### Table 3

| Variables | Entire male | Castrated male | Female |
|-----------|-------------|----------------|--------|
| BWS       | 35<sup>ABC</sup> | 27<sup>c</sup> | 20<sup>ABC</sup> |
| EBW       | 27<sup>ABC</sup> | 21<sup>c</sup> | 15<sup>DEF</sup> |
| ADG       | 164<sup>AABC</sup> | 110<sup>c</sup> | 47<sup>DE</sup> |

AL ad libitum intake, 30% 30% feeding restriction, 60% 60% feeding restriction. BWS body weight at slaughter (kg), EBW empty body weight (kg), ADG average daily gain (g).

<sup>ABC</sup> Means followed by different letters in same sexes differ by Tukey-Kramer test ($P < 0.05$).

<sup>c</sup> Means followed by different letters in same feeding restriction level differ by Tukey-Kramer test ($P < 0.05$).

<sup>DE</sup> Means followed by different capital letters in same line differ by Tukey-Kramer test ($P < 0.05$).
FR for concentrations of palmitic acid (C16:0), palmitoleic acid (C16:1c9), stearic acid (C18:0), oleic acid (C18:1c9) and CLA. The concentration of myristic acid (C14:0) was higher (\(P < 0.05\)) in meat from animals subjected to 30% FR than in meat from animals subjected to 60% FR. Meat from animals subjected to 60% FR showed greater (\(P < 0.05\)) concentrations of arachidonic acid and eicosapentaenoic acid (C20:5c5c8c11c14c17 - EPA) than did meat from animals subjected to AL intake and 30% FR.

The concentration of PUFAs was greater in the meat of females and lower in the meat of entire males (Table 10). However, the meat of females provided a higher \(\omega 6/\omega 3\) ratio and AI in addition to presenting a lower h/H ratio. The activity of the elongase enzyme was higher in the LT muscle of castrated males. The sum of SFA, UFA and PUFAs was similar (\(P > 0.05\)) in the meat of animals subjected to AL intake and 30% FR and was higher (\(P < 0.05\)) compared to that in animals subjected to 60% FR. The meat of animals subjected to 60% FR provided a greater \(\omega 6/\omega 3\) ratio, lower h/H ratio and lower concentration of desirable fatty acids, in addition to a greater AI and TI.

**Discussion**

Performance, carcass traits and physicochemical meat quality

Productions systems in semi-arid regions are based on the use of genetic resources with high adaptability and heat tolerance, which are heavily influenced by qualitative and quantitative seasonality of food [32, 33]. An example is the Morada Nova, an important indigenous breed of hair sheep in northeastern Brazil that is used for meat and skin production and is highly valued on the international market [34]. Weight loss has a strong impact on animal productivity [35], compromising the animal welfare and income of farmers worldwide [33]. In our study, we observed an absence of growth in females with 60% FR and a low ADG in lambs with 30% FR. This effect is a response to a lower amount of nutrients [36] because lambs have higher energy and protein requirements for growth [32, 37], which demand higher intakes.

**Table 4** Carcass characteristics and commercial cuts weight of Morada Nova lambs of different sexes subjected to feed restriction

| Variables            | Sexes | Feed restrictions | SEM | \(P\)-value |
|----------------------|-------|-------------------|-----|-------------|
|                      | Ent   | Cas               | Fem | AL  | 30%  | 60%  | Sex | Res | Sex × Res |
| HCW, kg              | 11.5ₜ | 10.3ᵇ           | 8.9ₙ² | 12.7ₜ | 10.6ᵇ | 7.5₁ᶜ | 0.139 | <.0001 | <.0001 | 0.110 |
| HCY, %               | 42.1₉ˢ | 44.1ᵃᵇ         | 45.2ᵃ | 44.4 | 43.6 | 43.4 | 0.325 | 0.002 | 0.474 | 0.967 |
| CCW, kg              | 11.ₙᵇ | 10.1ₙᵇ         | 8.8ₙᵇ | 12.5ₙᵇ | 10.5₁ᵇ | 7.ₙᵇ | 0.138 | <.0001 | <.0001 | 0.106 |
| CCY, %               | 41.ₙᵇ | 43.ₙᵇᵃᵇ       | 44.ₙᵇᵃ | 43.ₙᵇ | 43.₂ᵇ | 42.ₙᵇ | 0.ₙᵇ | 0.002 | 0.ₙᵇ | 0.ₙᵇ |
| SFT, mm              | 1.ₙᵇ   | 1.ₙᵇᵃᵇ         | 1.ₙᵇᵃ | 1.ₙᵇᵃ | 1.₂ₙᵇᵃᵇ | 0.ₙᵇ | 0.₀ₙᵇ | <.0001 | <.0001 | 0.₀ₙᵇ |
| REA, cm²             | 1.ₙᵇ   | 1.ₙᵇᵃᵇ         | 9.ₙᵇᵃᵇ | 11.ₙᵇ | 10.₁ᵇ | 8.ₙᵇᵇ | 0.2₀ₙᵇ | <.0001 | <.0001 | 0.ₙᵇ |
| Leg, kg              | 1.ₙᵇ   | 1.ₙᵇᵃᵇ         | 1.ₙᵇᵃᵇ | 2.₀ₙᵇ | 1.ₙᵇᵇ | 1.ₙᵇᵇ | 0.₀ₙᵇ | <.0001 | <.0001 | 0.ₙᵇ |
| Loin, kg             | 0.ₙᵇ   | 0.ₙᵇᵃᵇ         | 0.ₙᵇᵃᵇ | 0.ₙᵇᵃᵇ | 0.ₙᵇᵇ | 0.ₙᵇᵇ | 0.₀ₙᵇ | <.0001 | <.0001 | 0.ₙᵇ |
| Neck, kg             | 0.ₙᵇ   | 0.ₙᵇᵃᵇ         | 0.ₙᵇᵃᵇ | 0.ₙᵇᵃᵇ | 0.ₙᵇᵇ | 0.ₙᵇᵇ | 0.₀ₙᵇ | <.0001 | <.0001 | 0.ₙᵇ |
| Shoulder, kg         | 1.ₙᵇ   | 0.ₙᵇᵃᵇ         | 0.ₙᵇᵇ | 1.₂ₙᵇ | 0.ₙᵇᵇ | 0.ₙᵇᵇ | 0.₀ₙᵇ | <.0001 | <.0001 | 0.ₙᵇ |
| Rib, kg              | 0.ₙᵇ   | 0.ₙᵇᵃᵇ         | 0.ₙᵇᵃᵇ | 1.ₙᵇᵃᵇ | 0.ₙᵇᵇ | 0.ₙᵇᵇ | 0.₀ₙᵇ | <.0001 | <.0001 | 0.ₙᵇ |
| Lower rib, kg        | 0.ₙᵇ   | 0.ₙᵇᵃᵇ         | 0.ₙᵇᵃᵇ | 0.ₙᵇᵃᵇ | 0.ₙᵇᵇ | 0.ₙᵇᵇ | 0.₀ₙᵇ | <.0001 | <.0001 | 0.ₙᵇ |

Ent Enitre males, Cas Castrated males, Fem Females, AL ad libitum intake, 30% 30% feed restriction, 60% 60% feed restriction, SEM standard error of the mean, Sex sexes and Res = feed restriction, HCW hot carcass weight, HCY hot carcass yield, CCW cold carcass weight, CCY cold carcass yield, SFT subcutaneous fat thickness, REA Rib eye area

*Means followed by different letters differ between sexes according to a Tukey-Kramer test (\(P < 0.05\))

*Means followed by different letters differ between feed restrictions according to a Tukey-Kramer test (\(P < 0.05\))

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**Fig. 1** Evolution of animal weights during the experimental period. Average animal weight (kg) of each treatment in relation to approximate age in days from the beginning (120 d) to the end of the experiment (240 d); Ent AL = Entire males subjected to ad libitum intake; Cas AL = Castrated males subjected to ad libitum intake; Fem AL = Females subjected to ad libitum intake; Ent 30 = Entire males subjected to 30% feed restriction; Cas 30 = Castrated males subjected to 30% feed restriction; Fem 30 = Females subjected to 30% feed restriction; Ent 60 = Entire males subjected to 60% feed restriction; Cas 60 = Castrated males subjected to 60% feed restriction; Fem 60 = Females subjected to 60% feed restriction.
Cooking weight losses, TBARS yellowness, ranges from blue (b*) to red (+), lightness, 0 black and 100 white, chroma; C* = (a*2 + b*2)1/2 (MacDougall and Taylor, 1975), dietary restrictions have reduced the accumulation of the body stores of fat and protein, which resulted in lighter carcasses and commercial cuts. Nutritional limitations reduce cell proliferation and differentiation in tissues in response to reduced local production of insulin-like growth factor-1 (IGF-1), as signaled by the state of relative resistance of growth hormone (GH) [45]. In addition, in the post-absorptive state, non-esterified fatty acids, glycerol, alanine and glycine are oxidized, which supplies part of the energy demand [46]. Thus, in situations of lower nutritional intake, some of the body energy reserves are consumed. This situation was observed in animals submitted to the levels of FR used in this research.

The 24 h post-mortem pH was higher in the meat from animals subjected to 60% FR, which may be related to the lower content of muscle glycogen caused by lower feed intake and intense mobilization of reserves during the development of these animals. However, the pH remained between 5.5 and 5.8, which is desirable for meat [47]. An increase in the pH of meat can increase

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### Table 5: Interactions between sexes and feed restriction on the weight of commercial cuts of Morada Nova lambs

| Variables | Entire male | Castrated male | Female |
|-----------|-------------|----------------|--------|
| AL        | 30%         | 60%            |        |
| Neck      | 0.51<sup>abc</sup> | 0.36<sup>bcd</sup> | 0.33<sup>abc</sup> |
| Fat, %    | 3.99        | 4.32           | 4.18   |
| Protein, %| 18.6        | 18.9           | 19.0   |
| pH        | 5.61        | 5.60           | 5.66   |
| WHC, %    | 35.9        | 34.5           | 35.0   |
| CWL, %    | 38.6        | 38.5           | 37.4   |
| Moisture, %| 76.5        | 75.9           | 75.8   |
| Protein, %| 18.6        | 18.9           | 19.0   |
| Fat, %    | 3.99        | 4.32           | 4.18   |
| Ash, %    | 0.92        | 0.90           | 0.93   |

### Table 6: Physicochemical quality of Morada Nova lamb meat of different sexes subjected to feed restriction

| Variables | Sexes | Feed restrictions | SEM | p-value |
|-----------|-------|-------------------|-----|---------|
|           | AL    | 30%               | 60% | Sex     | Res | Sex X Res |
| L*        | Ent   | 39.7<sup>b</sup> | 38.2<sup>b</sup> | 37.5<sup>b</sup> | 38.2 | 38.4 | 38.8 | 0.244 | 0.003 | 0.657 | 0.659 |
| a*        | Cas   | 22.2              | 21.8 | 21.9 | 21.9 | 22.3 | 21.7 | 0.233 | 0.767 | 0.541 | 0.689 |
| b*        | Fem   | 9.83              | 9.43 | 8.80 | 9.36 | 9.93 | 8.77 | 0.220 | 0.197 | 0.126 | 0.866 |
| C*        | AL 30%| 24.3              | 23.8 | 23.6 | 23.8 | 24.4 | 23.4 | 0.320 | 0.386 | 0.252 | 0.771 |
| WHC, %    | 35.9  | 34.5              | 35.0 | 34.7 | 32.8 | 37.9 | 1.045 | 0.859 | 0.154 | 0.511 |
| CWL, %    | 38.6  | 38.5              | 37.4 | 37.4 | 38.5 | 38.6 | 0.403 | 0.443 | 0.408 | 0.937 |
| pH        | 5.61  | 5.60              | 5.66 | 5.57<sup>b</sup> | 5.62<sup>ab</sup> | 5.69<sup>a</sup> | 0.019 | 0.354 | 0.044 | 0.667 |
| Shear force, N | 42.9 | 46.1              | 39.2 | 44.0 | 41.4 | 42.8 | 1.623 | 0.236 | 0.808 | 0.702 |
| TBARS     | 0.72  | 0.75              | 0.85 | 0.82 | 0.64 | 0.86 | 0.041 | 0.395 | 0.073 | 0.534 |
| Moisture, %| 76.5 | 75.9              | 75.8 | 75.4<sup>b</sup> | 75.9<sup>a</sup> | 76.9<sup>a</sup> | 0.146 | 0.167 | 0.001 | 0.064 |
| Protein, %| 18.6  | 18.9              | 19.0 | 18.9 | 18.5 | 19.1 | 0.117 | 0.332 | 0.139 | 0.018 |
| Fat, %    | 3.99  | 4.32              | 4.18 | 4.74<sup>a</sup> | 4.70<sup>a</sup> | 3.05<sup>b</sup> | 0.107 | 0.468 | <0.001 | 0.680 |
| Ash, %    | 0.92  | 0.90              | 0.93 | 0.92<sup>b</sup> | 0.87<sup>b</sup> | 0.98<sup>a</sup> | 0.009 | 0.327 | <0.001 | 0.155 |

Ent: Entire males, Cas: Castrated males, Fem: Females, AL ad libitum intake, 30% 30% feed restriction, 60% 60% feed restriction, SEM standard error of the mean, Sex and Res = feed restriction, Color parameter L* lightness, 0 black and 100 white, Color parameter a* redness, ranges from green (−) to red (+), Color parameter b* yellowness, ranges from blue (−) to yellow (+), Color parameter C* chroma; C* = (a*2 + b*2)1/2 (MacDougall and Taylor, 1975), WHC water holding capacity, CWL cooking weight losses, TBARS 2-thiobarbituric acid reactive substance, MDA malondialdehyde

* a: Means followed by different letters differ between sexes according to a Tukey-Kramer test (P < 0.05)
* b: Means followed by different letters differ between feed restrictions according to a Tukey-Kramer test (P < 0.05)
the activity of cytochrome oxidase by reducing the uptake of oxygen by myoglobin, which results in a purplish red color [48]. However, the higher pH in meat from animals subjected to 60% FR was not enough to influence the color and other quality parameters analyzed in this study.

L* was greatly influenced by the pigment contents, especially those of hematin, myoglobin and their forms [49]. Chromophores, such as myoglobin and hemoglobin, absorb visible light by increasing light penetration and consequently decreasing reflectance [50]. Sañudo et al. [51] observed more myoglobin in females (2.90 mg/g of meat) than in entire males (2.56 mg/g of meat) and reported a similar effect of sex on L*, recording 39.80% for females and 41.26% for entire males. More myoglobin may explain the color variation in the meat of female animals observed in the present study.

Testosterone, besides providing an anabolic effect [41], acts on plasma glucose levels in males but does not alter the phosphorylation of AMP-activated protein kinase in muscle [40], which influences the concentration of IMF in males to a small degree. A similar result was observed in this study because the percentage of meat fat was similar between the sexes and did not reflect the effects of higher HCW in entire males.

| Table 7 | Interactions between sexes and feed restriction on Meat composition of Morada Nova lambs |
|---------|-----------------------------------------------------------------|
| Variables | Entire male | Castrated male | Female |
|          | AL 30% 60% | 30% 60% | AL 30% 60% |
| Protein  | 18.24AB | 18.70AB | 18.99AB |
|          | 18.57AB | 18.66AB | 19.46AB |

AL ad libitum intake, 30% 30% feeding restriction, 60% 60% feeding restriction

Means followed by different letters in same sex differ by a Tukey-Kramer test (P < 0.05)

Means followed by different letters in same feeding restriction level differ by a Tukey-Kramer test (P < 0.05)

Means followed by different capital letters in same line differ by a Tukey-Kramer test (P < 0.05)

| Table 8 | Fatty acids profile in the meat of the longissimus thoracis muscle of Morada Nova lambs of different sexes subjected to feed restriction |
|---------|-----------------------------------------------------------------|
| Fatty acids, mg/100 g of meat | Sexes | Feed restrictions | SEM | P-value |
|          | Ent  | Cas  | Fem  | AL  | 30% | 60% | Sex | Res | Sex × Res |
| C10:0    | 4.70 | 6.56 | 6.05 | 7.18 | 5.24 | 4.89 | 0.700 | 0.540 | 0.392 | 0.913 |
| C12:0    | 32.8 | 59.7 | 43.6 | 44.9 | 35.1 | 56.1 | 6.476 | 0.254 | 0.432 | 0.648 |
| C14:0    | 87.3 | 89.8 | 108  | 109.0| 110.0| 78.5 | 4.568 | 0.156 | 0.027 | 0.937 |
| C14:1c9  | 8.51 | 10.3 | 9.95 | 10.9 | 9.64 | 8.26 | 0.610 | 0.447 | 0.255 | 0.436 |
| C15:0    | 22.6 | 29.3 | 33.0 | 23.6 | 26.2 | 34.6 | 1.984 | 0.122 | 0.084 | 0.572 |
| C16:0    | 912  | 914  | 966  | 1069 | 1080 | 642  | 0.711 | <.0001 | 0.816 |
| C16:1c9  | 41.2 | 40.3 | 43.8 | 49.0 | 48.0 | 18.3 | 1.660 | 0.685 | <.001 | 0.551 |
| C17:0    | 44.4 | 47.2 | 48.6 | 48.9 | 46.9 | 44.4 | 1.047 | 0.277 | 0.245 | 0.314 |
| C17:1c10 | 18.9 | 16.8 | 17.3 | 18.9 | 17.3 | 16.8 | 0.901 | 0.635 | 0.606 | 0.300 |
| C18:0    | 620  | 687  | 649  | 695  | 701  | 561  | 19.03 | 0.377 | 0.008 | 0.770 |
| C18:1c9  | 1474 | 1639 | 1474 | 186  | 1814 | 911  | 41.65 | <.0001 | 0.604 |
| C18:1t9  | 36.0 | 36.1 | 44.5 | 41.1 | 38.4 | 37.1 | 1.819 | 0.106 | 0.666 | 0.032 |
| C18:2c9c12| 70.1b| 83.1ab| 91.4b| 82.8 | 79.1 | 82.8 | 2.388 | 0.005 | 0.768 | 0.582 |
| CLA      | 3.96 | 4.92 | 4.54 | 5.29 | 4.99 | 3.14 | 0.289 | 0.410 | 0.016 | 0.397 |
| C18:3c9c12c15| 18.5 | 21.6 | 21.0 | 22.2 | 20.5 | 18.4 | 0.701 | 0.201 | 0.109 | 0.510 |
| C20:4c5c8c11c14| 31.2b| 37.3ab| 39.2b| 33.0 | 33.2b| 41.6b| 1.236 | 0.045 | 0.010 | 0.862 |
| C20:5c5c8c11c14c17| 7.57 | 8.73 | 8.75 | 7.74b| 7.39b| 9.92b| 0.216 | 0.061 | <.0001 | 0.171 |
| C22:0    | 8.08 | 9.13 | 9.02 | 8.24 | 8.51 | 9.48 | 0.253 | 0.201 | 0.143 | 0.042 |
| Unidentified | 550  | 583  | 565  | 618  | 617  | 474  | -         | -     | -     | -     |

Ent Entire males, Cas Castrated males, Fem Females, AL ad libitum intake, 30% 30% feed restriction, 60% 60% feed restriction, SEM standard error of the mean, Sex sexes and Res = feed restriction, C10:0 Capric acid, C12:0 Lauric acid, C14:0 Myristic acid, C14:1c9 Myristoleic acid, C15:0 Pentadecylic acid, C16:0 Palmitic acid, C16:1c9 Palmitoleic acid, C17:0 Margaric acid, C17:1c9 Heptadecenoic acid, C18:0 Stearic acid, C18:1c9 Oleic acid, C18:1t9 Elaidic acid, C18:2c9c12 Linoleic acid, C18:3c9c12c15 α-Linolenic acid, C20:4c5c8c11c14 Arachidonic acid, C20:5c5c8c11c14c17 Eicosapentaenoic acid, C22:0 Behenic acid, CLA Conjugated linoleic acids: rumenic acid and their isomers

Means followed by different letters differ between feed restrictions according to a Tukey-Kramer test (P < 0.05)
Variations in meat fat concentration occur mainly due to changes in balance between dietary energy and nutrient requirements [52]; thus, the least amount of energy consumed by animals subjected to 60% FR decreased the deposition of IMF. FR of 60% meets the net energy requirements [52]; thus, the least amount of energy to changes in balance between dietary energy and nutrients for the deposition of adipose tissue. However, 30% FR did not cause significant changes to this balance or to the concentration of IMF in LT muscle.

**Fatty acid profiles**

Studies on cattle have indicated increased incorporation of long chain fatty acids into the phospholipids of heifer muscle in response to concentrations of plasmalogens [53]. The effects observed on the concentration of linoleic and arachidonic acids in meat of females indicate that this incorporation can also occur in lamb meat but was not observed due to the need for a more detailed analysis. The effect of the interaction between sex and FR on elaidic acid concentration shows that under 60% FR, females accumulate a greater amount of this acid. It becomes important to know the unique physiological functions of specific isomers as well as their origin. A portion of the trans-11 C18:1 isomer produced by ruminal microbes is converted into cis-9, trans-11 C18:2 by tissue desaturase [54]; however, this cannot occur with

**Table 9** Interactions between sexes and feed restriction on fatty acids profile in the meat of the *longissimus thoracis* muscle of Morada Nova lambs

| Fatty acids, mg/100 g of meat | Entire male | Castrated male | Female |
|-----------------------------|-------------|----------------|--------|
|                             | AL 30% 60% | AL 30% 60%     | AL 30% 60% |
| C18:1 t9                    | 38.6<sup>a</sup> 41.8<sup>b</sup> 28.6<sup>a</sup> | 45.8<sup>a</sup> 34.6<sup>b</sup> 28.1<sup>a</sup> | 39.2<sup>a</sup> 39.9<sup>b</sup> 54.5<sup>a</sup> |
| C22:0                       | 8.2         | 8.6            | 7.4    |

<sup>AL</sup> ad libitum intake, 30% 30% feeding restriction, 60% 60% feeding restriction

<sup>a</sup>, <sup>b</sup> Means followed by different capital letters in same line differ by Tukey-Kramer test (<i>P</i> < 0.05)

<sup>ab</sup> Means followed by different letters in same line differ by Tukey-Kramer test (<i>P</i> < 0.05)

**Table 10** Fatty acid classes, ratios, indexes and enzyme activity in meat of *longissimus thoracis* muscle of Morada Nova lambs of different sexes subjected to feed restriction

| Index, mg/100 g of meat | Sexes | Feed restrictions | SEM | <i>P</i>-value |
|------------------------|-------|-------------------|-----|--------------|
|                        | Ent   | Cas               | Fem | Sex | Res | Sex × Res |
| ΣFA                    | 1731  | 1837              | 1853| 1988<sup>a</sup> 2007<sup>b</sup> | 1425<sup>b</sup> 50.12 0.579 <0.001 | 0.770 |
| ΣUFA                   | 1707  | 1896              | 1748| 2131<sup>a</sup> 2069<sup>b</sup> | 1151<sup>b</sup> 44.52 0.210 <0.001 | 0.602 |
| ΣMUFA                  | 1578  | 1741              | 1758| 1981<sup>a</sup> 1926<sup>a</sup> | 997<sup>b</sup> 44.10 0.248 <0.001 | 0.569 |
| ΣPUFA                  | 129<sup>b</sup> 155<sup>a</sup> 163<sup>a</sup> | 150 | 142 | 154 | 4.222 0.008 | 0.504 | 0.716 |
| Σω6                    | 990<sup>b</sup> 120<sup>a</sup> 131<sup>a</sup> | 116 | 110 | 124 | 3.338 0.003 | 0.212 | 0.777 |
| Σω3                    | 2610  | 30.3              | 28.9 | 29.9 | 27.9 | 27.4 | 0.099 | 0.188 | 0.515 | 0.628 |
| ω6/ω3                  | 3.84<sup>b</sup> 3.99<sup>b</sup> 4.53<sup>a</sup> | 3.90<sup>b</sup> 3.96<sup>b</sup> | 4.50<sup>a</sup> | 0.076 | 0.003 | 0.009 | 0.784 |
| h/H                    | 1.60<sup>ab</sup> 1.77<sup>a</sup> 1.54<sup>b</sup> | 1.74<sup>a</sup> 1.65<sup>ab</sup> | 1.55<sup>b</sup> | 0.027 | 0.008 | 0.015 | 0.661 |
| DFA                    | 2328  | 2583              | 2397| 2826<sup>a</sup> 2769<sup>a</sup> | 1713<sup>b</sup> 56.65 0.185 <0.001 | 0.661 |
| T1                     | 1.78  | 1.70              | 1.81 | 1.64<sup>b</sup> 1.72<sup>ab</sup> | 1.93<sup>a</sup> | 0.031 | 0.351 | 0.003 | 0.741 |
| Δ<sup>6</sup> desaturase C16 | 4.26 | 4.17              | 4.28 | 4.36 | 4.28 | 4.07 | 0.124 | 0.925 | 0.631 | 0.872 |
| Δ<sup>Δ</sup> desaturase C18 | 69.8 | 69.0              | 67.9 | 72.6<sup>a</sup> 72.1<sup>a</sup> | 61.9<sup>b</sup> | 0.556 | 0.428 | <0.001 | 0.431 |
| Elongase               | 68.9<sup>b</sup> 70.9<sup>a</sup> | 67.4<sup>b</sup> | 69.6 | 69.3 | 68.4 | 0.273 | <0.001 | 0.240 | 0.179 |

<sup>Ent</sup> Entire males, <sup>Cas</sup> Castrated males, <sup>Fem</sup> Females, <sup>AL</sup> ad libitum intake, 30% 30% feed restriction, 60% 60% feed restriction, SEM standard error of the mean, Sex sexes and Res = feed restriction

<sup>a</sup> Means followed by different letters differ between sexes according to a Tukey-Kramer test (<i>P</i> < 0.05)

<sup>a</sup> Means followed by different letters differ between feed restrictions according to a Tukey-Kramer test (<i>P</i> < 0.05)
elaidic acid (C18:1 (9). The quality lipid indexes showed that the meat of female animals had a lipid profile with less desirable characteristics compared to that of meat from other sexes due to a higher AI and a lower h/H ratio. The higher ω6/ω3 ratio would also indicate lower quality meat fat in females [55]; however, the latest recommendations suggest no rational limit for this ratio if the intake of ω6 and ω3 is within the proper range for human diets [56].

More feeding can explain the higher concentration of palmitic acid, palmitoleic acid, stearic acid and oleic acid in the meat of animals subjected to AL intake and 30% FR. These effects reflect the results observed with the IMF content. As 30% FR did not significantly influence the deposition of IMF, there was no effect on the composition of fatty acids. The kinetics of the feed in the rumen may also have influenced the exposure time of the fatty acids to biohydrogenation [57]. The more severe restriction may have resulted in a lower passage rate, higher biohydrogenation, and higher deposition of SFA. Furthermore, the incorporation of fatty acids synthesized in muscle tissue may have been more effective in animals subjected to AL intake and 30% FR. This is related to a more lipogenic substrate for de novo synthesis in muscle adipocytes [58, 59], especially glucose from the propionate originating from the fermentation of carbohydrates in the rumen [60].

In our study, the lowest IMF deposit was in the meat of animals subjected to 60% FR, which justified the lower concentration of CLA in meat, as CLA is preferentially deposited in triglycerides [61, 62]. Similarly, the lowest IMF deposits in the meat of animals subjected to 60% FR may explain the higher concentration of long chain PUFAs (EPA and AA) in meat, which are deposited primarily in phospholipids [63, 64]. The IMF consists of triglycerides deposited in adipocytes and myofibril cytoplasm droplets, structural phospholipids and cholesterol present in membranes [58]. Triglycerides are more mobile, and phospholipids are more stable in muscle [65].

Based on the results of this study, lambs subjected to 60% FR can be expected to produce meat with fatty acid concentrations that are less favorable to consumer health and with a lower amount of desirable fatty acids, a lower h/H ratio, a higher AI and T1 and a higher proportion of SFA (55.3%) compared to those of animals submitted to AL intake (48.3%) and 30% FR (49.2%). A lipid profile favorable to the thrombogenicity and atherogenicity in the meat of animals subjected to 60% FR is related to myristic acid, palmitic acid and stearic acid concentrations [24]. Values from 0.9 to 1.94 for T1 and 0.59 to 1.15 for AI have been reported in the literature [66–69]; the maximum values of T1 (1.93) and AI (0.87) found in this study were within this range.

The activity of the elongase enzyme is related to concentrations of palmitic, palmitoleic and oleic acids [11, 70]. Combined concentrations of these fatty acids resulted in increased activity of elongase in the muscle of castrated male animals. The lower activity of the Δ9 desaturase enzyme C18 in animals subjected to 60% FR could be attributed to lower amounts of oleic acid present in the muscle of these animals [71].

Conclusions

Lambs in different sexes produced carcasses with different characteristics, and except for lightness, sex did not influence meat quality or chemical composition. However, females had a fatty acid profile in their meat that was less favorable to consumer health. FR affected carcass traits without influencing the quality of the meat. IMF content decreased when animals were subjected to 60% FR, but the lipid profile was less favorable to consumer health.

Abbreviations

a*: Redness; ADF: Acid detergent fiber; ADG: Average daily gain; AI: Atherogenicity index; AL: Ad libitum; b*: Yellowness; BW: Body weight; BWS: Body weight at slaughter; C*: Chroma; CCW: Cold carcass weight; CCY: Cold carcass yield; CP: Crude protein; CWL: Cooking weight losses; DFA: Desirable fatty acids; DM: Dry matter; DMI: Dry matter intake; EBW: Empty body weight; EE: Ether extract; FR: Feed restriction; HCW: Hot carcass weight; HCY: Hot carcass yield; IBW: Initial body weight; L*: Lightness; LT: longissimus lumborum; LT: longissimus thoracis; MDA: Malondialdehyde; MUFA: Monounsaturated fatty acid; NDF: Neutral detergent fiber; NFC: Non-fiber carbohydrate; NRC: National research council; PUFA: Polyunsaturated fatty acid; REA: Rib eye area; SAS: Statistical analysis software; SFA: Saturated fatty acid; SFT: Subcutaneous fat thickness; TBARS: 2-thiobarbituric acid reactive substances; TI: Thrombogenicity index; TWG: Total weight gain; UFA: Unsaturated fatty acid; WHC: Water holding capacity; ω3: Omega 3; ω6: Omega 6

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Availability of data and materials

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Authors’ contributions

TA and ES conceived the study and conducted statistical analysis. TA, ES, AC and MP conducted the laboratory analyses and prepared the manuscript. ES, AC and BH managed the animal model and assisted with manuscript preparation. IM and EH assisted with diet formulation, statistical analysis and manuscript preparation. HM contributed to fatty acid analysis. LB and RO critically revised the manuscript and edited the language. LP contributed to conception and statistical analyses. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.
Ethics approval
The experimental protocol used in this study, including animal management, housing, and slaughter procedures, was approved by the Animal Care and Use Committee of Federal University of Ceará, Brazil (Protocol n°98/2015).

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