R. Bras. Zootec., 49:e20190228, 2020
https://doi.org/10.37496/rbz4920190228

**Ruminants**
Full-length research article

Revista Brasileira de Zootecnia

*Brazilian Journal of Animal Science*
e-ISSN 1806-9290
www.rbz.org.br

# Use of crosses for sustainability in livestock farming in the Brazilian Meio-Norte region

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**Received:** November 6, 2019
**Accepted:** July 29, 2020

**How to cite:** Afonso, T. M.; Carvalho, G. M. C.; Hadlich, J. C.; Rodrigues, V. S.; Barros, D. A.; Vasconcelos, A. B. and Igarasi, M. S. 2020. Use of crosses for sustainability in livestock farming in the Brazilian Meio-Norte region. Revista Brasileira de Zootecnia 49:e20190228.
https://doi.org/10.37496/rbz4920190228



**ABSTRACT** - This study evaluated different crosses for sustainable beef production in the Meio-Norte, Brazil. Thirty-four cattle [seven Curraleiro Pé-duro (CPD), six Nellore (NEL), seven F1 (½ NEL + ½ CPD), seven F2A (¼ CPD + ¼ NEL + ½ Angus), and seven F2S (¼ CPD + ¼ NEL + ½ Senepol)] were evaluated on natural pastures in the states of Piauí and Maranhão. The animals were weighed at birth (BW); weaning (WW); 12 (W12), 18 (W18), and 24 months (W24); and slaughter (SW). The morphometric measurements of rump height (RH), withers height (WH), body length (BW), and heart girth (HG) were assessed. Hot carcass weight (HCW), cold carcass weight (CCW), loin-eye area (LEA), backfat thickness (BFT), carcass dressing percentage (DP), water-holding capacity (WHC), cooking loss (CL), shear force (SF), pH, meat color (L*M, a*M, and b*M), and fat color (L*F, a*F, and b*F) were also analyzed. The three-cross animals (F2A and F2S) showed heavier weights from weaning to slaughter as well as higher HCW and CCW. The three-cross cattle produced less methane per kg of meat. The lack of differences between the NEL, F1, F2A, and F2S animals indicates that crossbreeding did not increase their size, which could be detrimental to reproductive efficiency. Loin-eye area, BFT, and DP differed between the genetic groups, with the highest LEA obtained by F2A. Backfat thickness and DP were low in all animals, suggesting a need for increased carcass fatness. Water-holding capacity, CL, SF, pH, a*F, b*F, L*M, and a*M did not differ; therefore, crossbreeding did not affect qualitative or visual aspects of meat and fat. The use of crosses in meat production systems in the Meio-Norte region of Brazil is a viable option to improve sustainability. In this respect, three-cross animals have the best performance.

**Keywords:** adaptability, Angus, crossbreeding, meat quality, Nellore

## 1. Introduction

Sustainable beef production is the major challenge of livestock farming. In biomes with a low productive potential (native-pasture areas), farmers seek alternatives to reduce slaughter age and produce high-quality meat.

In Brazil, beef cattle are commonly reared in tropical pastures. The Central-West and North regions concentrate the largest herds and the largest livestock raising area in the country. The rational exploitation of non-agricultural areas can increase meat production and reduce deforestation. However, the interaction between animal genotype and rearing environment must be understood. In this context, the use of adapted local breeds (e.g., Curraleiro Pé-Duro) is an interesting practice.

Conversely, in production systems with a low nutrient uptake (e.g., native pasture), animals are slaughtered at a rather advanced age, which incurs higher methane ($CH_4$) emissions per kilogram of product (Grossi et al., 2019; Florindo et al., 2017; Frota et al. 2017; Cardoso et al., 2016; Lascano and Cardenas, 2010). Ruminants inevitably produce enteric methane, regardless of the production system. In this way, investing in the breeding of the herd will allow for increased meat production in the same area, thereby reducing methane production per unit of product in a given time period (Grossi et al., 2019).

Taurine cattle have been used by Brazilian farmers in industrial crosses with zebu breeds due to increased gain in heterosis and complementarity of desirable traits, yielding the best results in meat production (Reggiori et al., 2016). Different crosses between *Bos taurus taurus* and *Bos taurus indicus* generate positive results for the efficiency of a production system, mainly in terms of carcass weight, yield of meat cuts, and meat tenderness (Barcellos et al., 2017). Santana et al. (2013) described economic gains from the use of crosses in bioeconomic simulations with full-cycle and pre-weaning systems.

The objective of this study was to evaluate the cross between an adapted local breed (Curraleiro Pé-Duro) and zebu (Nellore), taurine (Angus), and adapted taurine (Senepol) animals on native pastures. Variables referring to the sustainability of the production system such as animal performance and meat quality were investigated. Additionally, greenhouse gas production was simulated until slaughter age between the five breed groups.

## 2. Material and Methods

This study was approved by the local ethics committee (case no. 001/2016).

The experiment was carried out in two locations in the Meio-Norte region of Brazil. The pre-weaning and growth phases took place in Campo Maior, PI, Brazil, which is a biome transition (*cerrado*-*caatinga*-forest) area, characterized by native pastures (Nascimento et al., 2002), average precipitation of 1360 mm/year, average temperature of 26.8 °C, and low-fertility soils. The cattle were finished in a native *cerrado* biome, in São Raimundo das Mangabeiras, MA, Brazil (sub-humid to semi-arid climate), characterized by annual precipitation of 1,200 to 1,300 mm and temperatures of 25 to 40 °C. The area is located at 04°49'40" S, 42°10'07", 125 m asl.

Five breed groups (treatments) were evaluated, in a total of 34 uncastrated cattle. The breed groups were composed of seven Curraleiro Pé-Duro (CPD), six Nellore (NEL), seven ½ NEL + ½ CPD (F1), seven ¼ CPD + ¼ NEL + ½ Angus (F2A), and seven ¼ CPD + ¼ NEL + ½ Senepol (F2S) animals. Supplementation consisted of mineralization with macro- and microminerals in the rainy period. During the dry period, an energy-protein supplement was used. All animals received the same supplementation.

Weight development data were collected in the period of 2014 to 2017. Birth weight (BW), weaning weight (WW), yearling weight (W12), weight at 18 months (W18), weight at two years (W24), and slaughter weight (SW) were recorded. Except for BW, all the other weight measurements were performed after a 16-h fast. The evaluated morphometric measurements were withers height (WH), rump height (RH), body length (BL), and heart girth (HG), which were performed on the day before slaughter.

The animals were slaughtered at a commercial abattoir, following the guidelines proposed by the Brazilian law. Samples of the *longissimus dorsi* muscle (sections of 2.54-cm thickness) sectioned between the 12th and 13th ribs were collected and frozen. Loin-eye area (LEA) was measured using a checkered pattern ($cm^2$). Backfat thickness (BFT) was measured using a caliper (mm). Carcass dressing percentage (DP) was calculated as the ratio between animal live weight and carcass weight. The “Index” was calculated as the ratio between DP and LEA divided by 100 kg of chilled carcass (Carvalho et al., 2017).

Meat color (L*M, a*M, and b*M), fat color (L*F, a*F, and b*F), pH, water-holding capacity (WHC), cooking loss (CL), and shear force (SF) were measured. Meat and fat color were assessed using a colorimeter

(MiniScan XE Plus-HunterLab; AMSA, 1991). The meat pH was measured after thawing for 24 h (Rodrigues Filho et al., 2014). Water-holding capacity was measured as proposed by Hamm (1960). Cooking loss was evaluated by following AMSA (1995). Lastly, SF was measured using a texture analyzer ("texturometer") (TA-XT2) coupled to a 1-mm-thick Warner-Bratzler blade (AMSA, 1995).

The simulation of the total emission of enteric methane (TEM) was performed by the product of the slaughter age (SA) in days of the different genetic groups and the estimate of daily emission of enteric methane (g of $CH_4$/day). As an estimate of the daily methane emission, we used the reference by Frota et al. (2017), who evaluated the emission of methane in animals of the Nellore and Curraleiro Pé-Duro breeds in the State of Maranhão (Brazil), conditions similar to the present study. According to Frota et al. (2017), the emission of enteric methane was 192.8 g of $CH_4$/day in the rainy season and 120.6 g of $CH_4$/day in the dry season. For the calculation, the average value between rainy and dry periods was used, being 156.7 g of $CH_4$/day.

$$\text{TEM (kg } CH_4\text{)} = \text{SA} \times \text{enteric methane emission}/1000$$

Statistical analysis was performed considering each animal an experimental unit. The experiment was set up as a completely randomized experimental design, in which the data were subjected to analysis of variance (ANOVA). The model tested fixed effect of breed group. The means were compared by Tukey's test, adopting the 5% significance level (P<0.05).

## 3. Results

The lowest BW was found in CPD (P<0.05), whereas the other groups did not differ from each other (Table 1). For WW, the F2A and F2S animals showed the highest values (P<0.05) and did not differ from each other (P>0.05), while NEL, CPD, and F1 were similar (P>0.05). The CPD and NEL groups showed the lowest W12 values (P<0.05). Results for W18, W24, and SW followed the same trend, with the highest weights (P<0.05) obtained by the F2A and F2S groups, followed by F1 and NEL, and the lowest by CPD.

No difference was detected among the F1, F2A, F2S, and CPD animals for slaughter age (P>0.05). The NEL animals were earlier (P<0.05) than the crossbred animals, although this difference has no scientific relevance. For WH, the CPD animals had the lowest values (P<0.05), whereas the NEL group had the lowest results, and the F1, F2A, and F2S animals showed intermediate values (Table 1), with no

**Table 1 -** Performance traits (mean ± standard deviation) of the evaluated breed groups[1]

| Trait | F1 | F2A | F2S | CPD | NEL | P-value |
|---|---|---|---|---|---|---|
| BW (kg) | 32.29±1.38a | 33.86±1.35a | 33.29±1.11a | 23.00±1.29b | 33.00±2.37a | <0.0001 |
| WW (kg) | 106.29±14.53b | 243.71±11.61a | 227.86±18.92a | 87.14±24.22b | 101.67±3.01b | <0.0001 |
| W12 (kg) | 203.43±22.65b | 324.29±15.51a | 300.57±19.59a | 141.14±25.20c | 174.33±21.96bc | <0.0001 |
| W18 (kg) | 377.43±39.51b | 491.29±15.03a | 478.71±40.65a | 214.14±27.60c | 345.83±75.31b | <0.0001 |
| W24 (kg) | 440.29±39.13b | 561.14±11.35a | 555.37±42.67a | 284.57±20.02c | 406.83±75.31b | <0.0001 |
| SW (kg) | 498.14±39.02b | 608.43±14.63a | 616.71±41.54a | 339.57±20.44c | 474.67±61.52b | <0.0001 |
| SA (days) | 1286.43±23.13a | 1324.14±21.35a | 1294.29±61.92a | 1259.14±68.36ab | 1205.83±37.67b | 0.0018 |
| WH (m) | 1.38±0.06b | 1.39±0.075b | 1.37±0.06b | 1.17±0.02c | 1.48±0.03a | <0.0001 |
| RH (m) | 1.43±0.05a | 1.43±0.08a | 1.43±0.07a | 1.22±0.02b | 1.50±0.03a | <0.0001 |
| BL (m) | 1.50±0.04a | 1.44±0.04a | 1.51±0.03a | 1.31±0.05b | 1.48±0.1a | <0.0001 |
| HG (m) | 1.92±0.06bc | 2.06±0.08ab | 2.28±0.32a | 1.73±0.06c | 1.94±0.15bc | 0.0001 |

CPD - Curraleiro Pé-duro; NEL - Nellore; F1 - ½ NEL + ½ CPD; F2A - ¼ CPD + ¼ NEL + ½ Angus; and F2S - ¼ CPD + ¼ NEL + ½ Senepol; BW - birth weight; WW - weaning weight; W12 - yearling weight; W18 - weight at 18 months; W24 - weight at two years; SW - slaughter weight; SA - slaughter age; WH - withers height; RH - rump height; BL - body length; HG - heart girth.
[1] Means compared by the Tukey's test at the 5% significance level (P<0.05).

differences between each other. Differences were detected (P<0.05) for RH and BL, with the CPD group exhibiting the lowest value for both morphometric traits, while the other breed groups did not differ (P<0.05). For HG, the F2A and F2S animals (P<0.05) presented the highest values, while F1, NEL, and CPD did not differ from each other.

The three-cross animals (F2A and F2S) had the heaviest carcasses. For DP, the crossbred groups (F1, F2A, and F2S) and CPD did not differ (P<0.05), while the NEL animals showed lower values than F1 and F2S. The Index differed across the breed groups (P<0.05), with the F2A, CPD, and NEL animals showing the highest values.

Loin-eye area differed (P<0.05) across the tested groups, with the F2A cattle showing the highest values (P<0.,05), whereas the other breed groups (CPD, F2S, NEL, and F1) did not differ from each other (P>0.05). Backfat thickness was significantly affected by the treatments (P<0.05). For this trait, the F2A animals were superior to the NEL group.

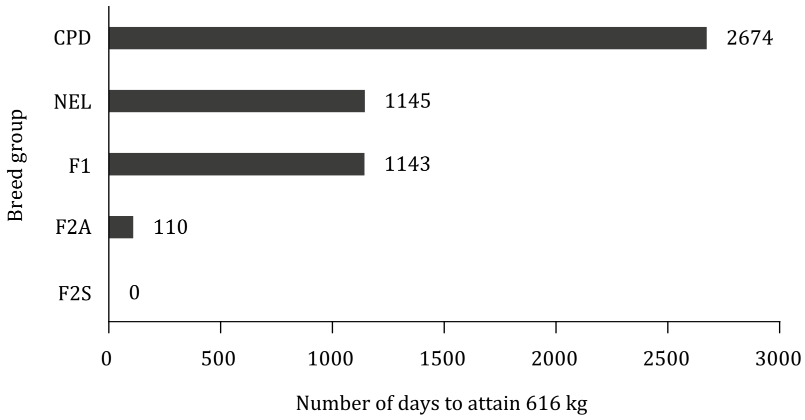
The animals of the different breed groups evaluated in this study did not differ in relation to pH, SF, WHC, CL, a*F, b*F, L*M, and a*M (P>0.05) (Table 2). Only the F2A and F2S differed for fat lightness (L*F) (P<0.05). As regards the yellow color in the meat (b*M), the purebred animals (CPD and NEL) differed from each other (P<0.05), whereas the crossbred cattle (F2A, F2S, and F1) showed similar values (P>0.05).

The increase in number of days to produce an animal weighing 616 kg was simulated for each breed group, considering weight gain between W24 and SW (Figure 1). Another simulation, for enteric methane emission (kg $CH_4$) (Figure 2), was undertaken based on the number of days presented in the previous simulation. The weight of 616 kg was adopted as a reference from the breed group that achieved the highest SW (F2S). Enteric methane emission was considered 120.6 to 192.8 g of $CH_4$/day, in accordance with the data presented by Frota et al. (2017) in a study conducted in the north region of Brazil.

**Table 2 -** Quantitative and qualitative traits of carcass and meat in different breed groups[1]

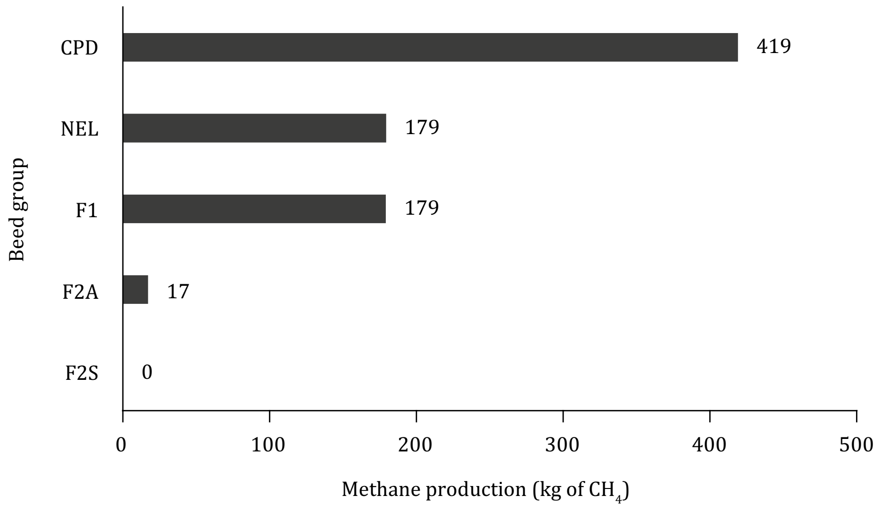
| Trait | F1 | F2A | F2S | CPD | NEL | P-value |
|---|---|---|---|---|---|---|
| HCW (kg) | 266.43±21.43b | 322.69±15.47a | 331.04±24.37a | 175.80±12.71c | 237.47±32.87b | <0.0001 |
| CCW (kg) | 260.79±20.81b | 315.57±15.22a | 324.86±24.16a | 171.31±12.41c | 232.05±32.48b | <0.0001 |
| LEA ($cm^2$) | 59.79±10.25b | 90.14±11.18a | 70.79±10.03b | 54.43±11.00b | 64.83±13.37b | 0.0001 |
| BFT (cm) | 0.19±0.09ab | 0.30 ±0.10a | 0.16 ± 0.08ab | 0.19±0.12ab | 0.15±0.05b | 0.0376 |
| DP (%) | 53.51±1.96a | 53.05±2.58ab | 53.67±1.40a | 51.76±1.98ab | 49.99±1.40b | 0.0099 |
| Index | 12.29±2.08bc | 15.17±2.01ab | 11.68±1.33c | 16.38±2.86a | 14.00±2.39abc | 0.0021 |
| pH | 5.25±0.04 | 5.24±0.09 | 5.27±0.09 | 5.21±0.09 | 5.26±0.08 | 0.7065 |
| WHC (%) | 72.67±3.38 | 73.86±2.30 | 73.26±0.91 | 74.17±2.60 | 73.17±2.90 | 0.8236 |
| CL (%) | 32.09±5.91 | 31.01±2.94 | 32.82±2.95 | 31.14±3.09 | 31.06±4.37 | 0.8914 |
| SF (kgf) | 9.02±1.77 | 9.15±1.93 | 9.46±2.24 | 7.98±1.71 | 9.93±1.60 | 0.5697 |
| L*F | 74.94±3.42ab | 75.78±1.97a | 68.61±2.78b | 69.91±5.96ab | 71.26±5.16ab | 0.0094 |
| a*F | 5.55±1.65 | 5.89±2.72 | 7.18±4.49 | 2.56±1.61 | 6.27±1.39 | 0.1088 |
| b*F | 16.69±2.91 | 16.58±3.18 | 16.26±3.20 | 13.89±2.58 | 15.81±2.25 | 0.5215 |
| L*M | 34.30±2.22 | 32.71±0.46 | 33.42±1.42 | 32.45±1.60 | 34.65±1.94 | 0.0817 |
| a*M | 16.36±0.48 | 16.09±1.05 | 15.76±0.67 | 15.71±1.12 | 15.91±0.74 | 0.6210 |
| b*M | 12.74±0.71a | 12.00±0.65ab | 11.89±0.51ab | 11.52±0.87b | 12.85±0.58a | 0.0047 |

CPD - Curraleiro Pé-duro; NEL - Nellore; F1 - ½ NEL + ½ CPD; F2A - ¼ CPD + ¼ NEL + ½ Angus; and F2S - ¼ CPD + ¼ NEL + ½ Senepol; HCW - hot carcass weight; CCW - cold carcass weight; LEA - loin-eye area; BFT - backfat thickness; DP - carcass dressing percentage; WHC - water-holding capacity; CL - cooking loss; SF - shear force; L*F - lightness of fat; a*F - red intensity of fat; b*F - yellow intensity of fat; L*M - lightness of meat; a*M - red intensity of meat; b*M - yellow intensity of meat.
[1] Means compared by the Tukey's test at the 5% significance level (P<0.05).




CPD - Curraleiro Pé-duro; NEL - Nellore; F1 - ½ NEL + ½ CPD; F2A - ¼ CPD + ¼ NEL + ½ Angus; and F2S - ¼ CPD + ¼ NEL + ½ Senepol.

**Figure 1 -** Simulation of number of days taken by the evaluated breed groups to attain the slaughter weight of 616 kg.




CPD - Curraleiro Pé-duro; NEL - Nellore; F1 - ½ NEL + ½ CPD; F2A - ¼ CPD + ¼ NEL + ½ Angus; and F2S - ¼ CPD + ¼ NEL + ½ Senepol.

**Figure 2 -** Simulation of methane production (kg of $CH_4$) by the evaluated breed groups to attain the slaughter weight of 616 kg.

## 4. Discussion

The three-cross animals (F2S and F2A) had the heaviest carcasses, demonstrating additive genetic gain with the use of a third breed (Angus and Senepol, respectively). Dillard et al. (1980) showed in a study with 22 crossed and genetic groups that additive genetic effect was positive the use of high genetic merit breeds for growth characteristics, such as daily weight gain, weaning weight and morphological-type scores. Using a third breed with greater genetic merit for weight and carcass gain generates for positive results with the use of F1 parents (Nellore × Curraleiro). Accordingly, Favero et al. (2019) showed gains in the use of three crosses, highlighting the use of F1 females, with gains in heteroses and complementarity, in addition to the additive genetic effect. The Nellore purebred (NEL) had lower performance results than the crossbred (Tables 1 and 2), showing that, despite being a zebu breed (adapted to the tropical climate), in the evaluation system, the cross with CPD (gains in hardiness) and with the Angus and Senepol breeds (gains in performance) provided consistent results in terms of adaptation and animal performance (Ferraz and Felício, 2010).

In a study in South Africa, Mokolobate et al. (2014) evaluated different crosses and genotypes and their effect on the sustainability of a beef production system. A comparison between theirs and the present experiments is interesting, since both involved adapted local European breeds; in the former case, the authors used Afrikaner animals, whereas Curraleiro Pé-Duro was the breed used in the current study. The authors observed gains of up to 21% in calf weight in cow yield (animal unit = 450 kg), using F1 animals derived from a local breed (Afrikaner) crossed to zebu (Brahman), continental (Simental and Charolais), or British (Hereford) breeds. The researchers stressed the effect of heterosis and complementarity, resulting from the crosses, on yield gains, which consequently reduced carbon dioxide emission in the meat production system.

The three-cross animals (F2A and F2S) showed the best performance (SW; Table 1), followed by the F1, Nel, and CPD. Lobato et al. (2014) argued that greenhouse gas (GG) emissions increase as weight gain decreases, which is the result of the use of pastures with low nutritional value. Considering the production system, which was characterized by native pastures (low nutritional value) in the biome of the Meio-Norte region of Brazil, the use of crosses involving three breeds provided the best productive (weight gain), environmental (lower GG emissions), and economic (higher SW) results, rendering the livestock activity more sustainable.

Florindo et al. (2017) stated that as slaughter age decreases, there is a simultaneous reduction in GG production and an increase in profitability per animal. According to Grossi et al. (2019), new breeds and crosses have a great potential to mitigate GG production. These genetic resources must be adjusted, considering the interaction between genotypes and environmental conditions of the production system. In this regard, it is important to use adapted local breeds to increase the efficiency of the production system, given their adaptation to scenarios of challenging environments. Cardoso et al. (2016) discussed the need for governmental incentives for the intensification of productive areas, which would reduce pressure in the exploitation of native areas.

Another important aspect of the system is the reproductive efficiency. The use of local breeds (CPD) confers greater adaptation for animals under restricted feeding conditions and high environmental temperatures (Carvalho et al., 2017). A small body size (rump and withers heights) with high digestive capacity (heart girth) are characteristics of an animal biotype with reduced maintenance energy requirements, but high intake and food (pasture) metabolism potential. Coupled with this, the cross between CPD and other breeds that underwent great selection for weight gain and development (Angus and Senepol) did not result in increased size in the crossbred animals, mainly when compared with the Nellore, thereby allowing the use of parents crossed in rotational crossbreeding programs. These findings demonstrate the importance of using locally adapted breeds (e.g., CPD) for production systems with low nutritional supply, given the use of crossbred females for reproduction.

The Index is used to evaluate the amount of meat in the carcass, by relating DP, LEA, and carcass weight. The crossbred animals (F1, F2A, and F2S) were not superior to the CPD or the NEL. Despite the lower SW of the CPD group, their LEA did not differ from that shown by the F1 and F2S animals. Therefore, high meat deposition in the carcass was observed, which characterizes the CPD as a breed with high potential for meat production under low nutritional uptake conditions. In this respect, Carvalho et al. (2017) found that, in the Brazilian Meio-Norte region conditions, the CPD breed and the F1 cross (CPD × NEL) produced more meat per 100 kg of carcass (Index) compared with the Nellore. The low nutritional uptake in the present experimental conditions did not allow for the expression of the genetic potential of the three-cross animals regarding muscle deposition in the carcass. Management tools such as more-intense supplementation may elevate muscle deposition gains and carcass dressing percentage at slaughter.

Carcass fatness, which is measured by BFT, is an important characteristic in determining meat quality. Backfat thickness differed significantly ($P<0.05$), although the statistical differences did not express biological relevance, since the obtained values (Table 2) are lower than the recommended 3 mm (Yokoo et al., 2010; Nassu et al., 2016). It is important to observe the sexual condition of animals (uncastrated males) in a fattening system carried out on native pasture (low nutritional quality), as it limits the increase in fat deposition in the carcass due to the low dietary energy supply. Albuquerque et al. (2006) mentioned that in management practices performed in tropical areas, where animals are finished on pasture, they reach the point of slaughter with a smaller amount of backfat than necessary, especially in the case of uncastrated males. Aranha et al. (2018) obtained better carcass traits and higher performance in uncastrated steers supplemented in systems with higher pasture availability. This illustrates the theory of improving feeding as a way to obtain a final product of better quality.

It is believed that the animals could be slaughtered at a higher degree of fatness, that is, at a higher weight and with more fat deposited in the carcass. Better utilization of the animal carcass is mandatory to achieve gains in productive efficiency provided there is economic viability, considering the existence of possible raises in costs due to nutritional plans with higher energy density. Castration may be an alternative, given the advance of fat deposition (higher BFT) and better meat physicochemical traits achieved. Kuss et al. (2009) reported superior fatness in castrated compared with uncastrated animals. Better carcass quality is the result of a thicker fat layer, which protects the carcass during chilling, resulting in more tender meat with a finer texture and a more pleasant taste (Janett et al., 2012).

In systems similar to that evaluated in the present study, energy supplementation for grazing animals would allow for improvements in meat quality due to the increased carcass fatness, as represented by BFT. In this context, the supply of concentrate in the diet will increase energy availability for the animal metabolism, in addition to reducing energy losses as methane, as observed by Pedreira et al. (2013).

The pH values were lower than the range of 5.5 to 5.9 defined as ideal for high-quality meat (Beltrán et al., 1997). This finding contradicts the expected higher pH values commonly observed in the slaughter of uncastrated males with low fatness when subjected to long periods of transport (Pearce et al., 2011). A possible hypothesis is that the step of freezing the meat for the measurement of pH might have influenced its determination.

Tenderness is the main attribute in the perception of meat quality by the consumer. In this study, the average SF was 9.11 kgf/cm$^2$, which exceeds the threshold of 4.5 to 6.0 kgf/cm$^2$ that separates tender from tough meat, as cited by Rubiano et al. (2009). Some environmental factors might have contributed to the lower meat tenderness, which was found in all breed groups. The main factor is slaughter age, considering that the animals were slaughtered at 42 months, which is near the age limit for tender meat given the higher concentrations of insoluble collagen and elastin. Frylinck et al. (2015) observed that animals with more than six definitive incisors have a reduction in meat tenderness and increased insoluble collagen concentration in their meat, especially when finished on pasture. The long transport distance of 600 km from São Raimundo das Mangabeiras to Timon, MA, travelled over 12 h on the day prior to slaughter, stressed the animals, which might have influenced final meat quality. Frylinck et al. (2015) noted that a transport time of 2 h to slaughter affects meat tenderness. Another two negative factors influencing meat tenderness are low BFT and sex category (uncastrated males).

The present discussion corroborates Nassu et al. (2016), who emphasized that carcasses with inadequate fat layers are more prone to muscle fiber shortening during chilling, which may compromise meat tenderness. Thus, castration, increased energy uptake during the fattening period, and better transport conditions (travel time) are proposed to improve meat tenderness.

No differences were observed in the crossbred animals regarding the visual aspect of meat and fat color. Muchenje et al. (2009) conducted a review on the color of beef and found that lightness values should be in the range of 33.2 to 41.0, which agrees with the results found in the current experiment (32.45 to 34.65). The red intensity values (15.71 to 16.36) were also in line with the 11.1 to 23.6 cited by the above-mentioned authors. In terms of yellow intensity in the meat, the authors cited mean values between 6.1 and 11.3, which are slightly lower than the current results (11.52 to 12.85). Carvalho et al. (2017) evaluated the meat color of CPD, Nellore, and F1 animals and found differences in the red intensity of their meat, but not in yellow intensity. The lightness, yellow intensity, and red intensity of fat agree with Fernandes et al. (2009) and Machado et al. (2015), with variations (yellow and red intensity) due to the different conditions in the aforementioned experiments. In the present results, there was a small amplitude among the evaluated groups, which indicates some statistical differences, although of low biological relevance. This may be understood by the fact that all animals were reared under the same feeding conditions (pastures), with the breed group having little influence on meat color.

## 5. Conclusions

The use of crosses in the environmental conditions of the Brazilian Meio-Norte region provides gains in beef production, possibly reducing methane production. Therefore, it meets the purpose of sustainability in local beef cattle farming, since economic, environmental, and social gains are achieved. As an improvement in the production system discussed, management alternatives such as increased supplementation, castration, and improvements in the logistics of animal transportation for slaughter can improve meat quality, especially in terms of fatness and tenderness.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

Conceptualization: T.M. Afonso and G.M.C. Carvalho. Data curation: T.M. Afonso, G.M.C. Carvalho, J.C. Hadlich and M.S. Igarasi. Formal analysis: T.M. Afonso, G.M.C. Carvalho, J.C. Hadlich and M.S. Igarasi. Funding acquisition: G.M.C. Carvalho, J.C. Hadlich and M.S. Igarasi. Investigation: T.M. Afonso, G.M.C. Carvalho, J.C. Hadlich, V.S. Rodrigues, D.A. Barros, A.B. Vasconcelos and M.S. Igarasi. Methodology: T.M. Afonso, G.M.C. Carvalho, J.C. Hadlich and M.S. Igarasi. Project administration: T.M. Afonso, G.M.C. Carvalho and M.S. Igarasi. Resources: T.M. Afonso, G.M.C. Carvalho and M.S. Igarasi. Supervision: G.M.C. Carvalho and M.S. Igarasi. Validation: T.M. Afonso, G.M.C. Carvalho, J.C. Hadlich and M.S. Igarasi. Visualization: T.M. Afonso, G.M.C. Carvalho, J.C. Hadlich and M.S. Igarasi. Writing-original draft: T.M. Afonso, G.M.C. Carvalho, J.C. Hadlich and M.S. Igarasi. Writing-review & editing: T.M. Afonso, G.M.C. Carvalho and M.S. Igarasi.

## Acknowledgments

This research was supported by Embrapa Meio-Norte, Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), and Instituto de Estudos Avançados em Veterinária “José Caetano Borges” in the Programa de Pós-graduação em Sanidade e Produção Animal nos Trópicos – Universidade de Uberaba.

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