Correlation between body biometric measurements and productive and reproductive performance characteristics of zebu males

Correlação entre medidas de biometria corporal e características de desempenho produtivo e reprodutivo de machos Zebu

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Highlights

Nellore presented better evaluations in the weight and most body biometrics.
Nellore and Tabapuã showed similar thoracic perimeters and scrotal circumferences.
All evaluated breeds showed a high correlation between weight and thoracic perimeter.
All breeds reached slaughter weight by 12 months, showing super-precocity.

Abstract

Brazil is the largest beef exporter and has the largest commercial herd in the world, making it necessary to evaluate zebu breeds to promote their genetic improvement, as they make up a large part of the Brazilian beef herd. The sire plays a major role in the formation of elite and commercial herds. The aim of this study was to evaluate males of the Nellore, Nellore Mocho and Tabapuã breeds, allocated to categories 1 (8–9 months) to 17 (33–36 months), which were present in Expozebu between 2000 and 2019 in the city of Uberaba. Based on the animals' body biometry data, the following traits were measured in Nellore, Nellore Mocho and Tabapuã males: weight (WE), forelimb height (FH), hindlimb height (HH), length (LE), thoracic perimeter (TP), scrotal circumference (SC), loin eye area (LEA), subcutaneous fat

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thickness (SFT), and subcutaneous fat thickness of the croup (SFC). Data were statistically analysed between breeds, and their correlations were determined. The Nellore males were superior to the Nellore Mocho and Tabapuã in terms of WE, FH, HH, and LE. As for TP and SC, the Nellore males were similar to the Tabapuã in most categories. In terms of carcass traits, Nellore males also had a higher LEA, STF, and STC in certain categories. There was a high correlation between WE and biometric traits, such as FH, HH, LE and TP, with TP having the highest correlation. The carcass traits showed the highest correlations with WE and TP, moderate to high correlations with biometric traits, and moderate values between them, except for LEA, which obtained high values with STF (0.80 for Nellore, 0.79 for Nellore Mocho and 0.76 for Tabapuã). The data presented on the performance of Nellore, Nellore Mocho and Tabapuã males at different ages can be used as a reference for assessing cattle development in preparation for shows and/or intensive meat production systems.

Key words: Carcass traits. Nellore. Nellore Mocho. Scrotal circumference. Tabapuã.

Resumo

O Brasil é o maior exportador de carne bovina e possui o maior rebanho comercial do mundo. Isso torna necessária a avaliação das raças Zebuínas para promover o seu melhoramento genético, que constituem grande parte do rebanho bovino brasileiro. Sabe-se que o touro desempenha um papel importante na formação de rebanhos de elite e comerciais. O objetivo deste estudo foi avaliar machos das raças Nelore, Nelore Mocho e Tabapuã, alocados nas categorias 1 (8 a 9 meses) a 17 (33 a 36 meses), que participaram da Expozebu entre 2000 e 2019 na cidade de Uberaba, MG. Com base nos dados de biometria corporal dos animais, como características de produção, peso (PESO), características de biometria corporal: altura de anterior (AA), altura posterior (AP), comprimento (COMP) e perímetro torácico (PT); características reprodutivas como circunferência escrotal (CE) e características de carcaça como área de olho de lombo (AOL), espessura de gordura subcutânea (EGS) e espessura de gordura subcutânea da garupa (EGG) de machos Nelore, Nelore Mocho e Tabapuã foram tabulados e comparados em diferentes categorias, respectivamente. Os machos Nelore foram superiores aos Nelore Mocho e Tabapuã nas características de PESO, AA, AP e COMP. Quanto ao PT e CE, os machos Nelore foram semelhantes aos Tabapuã na maioria das categorias. As características de carcaça, os machos Nelore também apresentaram maiores AOL, EGS e EGG em determinadas categorias. Houve alta correlação entre PESO e características biométricas como AA, AP, COMP e PT, sendo que PT apresentou a maior correlação. As características de carcaça apresentaram as maiores correlações com PESO e PT, correlações médias a altas com as características biométricas e valores médios entre elas, com exceção do EGS que obteve valores elevados com EGG, 0,80 para machos Nelore, 0,79 para Nelore Mocho e 0,76 para machos Tabapuã. Os dados apresentados dos desempenho de machos Nelore, Nelore Mocho e Tabapuã em diferentes idades podem ser utilizados como referência para avaliação do desenvolvimento de bovinos em preparação para exposições e/ou sistemas intensivos de produção de carne.

Palavras-chave: Características da carcaça. Circunferência escrotal. Nellore. Nelore Mocho. Tabapuã.

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Introduction

In 2024, Brazil produced 11.812 million tons of beef in carcass equivalent (ton/equi carcass), corresponding to 15% of the world's production. This high production guaranteed Brazil's leadership in beef exports, shipping 3.78 thousand (ton/eq carcass), far ahead of second-placed Australia, with 2.01 thousand (ton/eq carcass) (Associação Brasileira das Indústrias Exportadoras de Carne [ABIEC], 2025). In 2024, the Brazilian herd was estimated at 194 million head, which was comprised of approximately 70% zebu cattle. They play an important role in meat production, as they have beneficial traits, such as greater resistance to ectoparasites and endoparasites, tolerate ambient temperatures that exceed 35°C in long summer periods, and are suited to beef cattle production systems in tropical countries (Anuário CiCarne, 2023; ABIEC, 2025).

According to Abreu (2022), Brazil has approximately 63 million breeding females, of which 16 million undergo artificial insemination and 47 million are naturally mated by 1.56 million bulls. Assuming that each bull services 30 females over an average lifespan of 6 years, about 300,000 bulls must enter the market annually. This highlights the crucial need to select sires with superior performance to sustain and improve elite and commercial herds.

The Brazilian Association of Zebu Breeders (ABCZ) is focused on the genetic improvement of zebu breeds, promoting the development and improvement of beef cattle in Brazil. Registering animals with a breed association enables identification, traceability, genealogy studies and information on animal performance, especially when submitted for evaluation. This is essential for improving the genetic quality of the herd and to meet market demands, which requires animals with known pedigree and evaluated in a genetic improvement program, a fact that adds value to breeding stock (Associação Brasileira dos Criadores de Zebu [ABCZ], 2025).

The ABCZ organises regional and national exhibitions to evaluate zebu cattle across different ages and categories. During these events, animals undergo detailed biometric assessments, and zootechnical and productive data, including key growth traits, such as weight gain, are collected. These data are essential for judges to accurately evaluate and classify individual animals, reinforcing the genetic improvement process. Beef production efficiency heavily relies on growth-related traits, which are influenced by complex biological mechanisms spanning biochemistry, physiology, endocrinology, nutrition, genetics and animal management (Owens et al., 1993; ABCZ, 2025).

Body biometrics are related to animal performance and thus can be used as predictors of specific aspects of body composition. Cyrillo et al. (2012) studied the relationships between body measurements and performance traits and found high genetic correlations between chest circumference, croup width and live weight when data were collected at the same age. Similarly, positive correlations between growth and carcass traits were identified by Nardon et al. (2001) and Bonilha et al. (2008). When evaluating zebu animals of the Brahman breed, Mota et al. (2010) found a greater correlation

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between live weight and thoracic perimeter (TP), with a value of 0.96, suggesting that TP measurements should be used to predict live weight, especially in genetic improvement programs. Current affairs uses body biometrics data in advanced algorithmic models, such as XGBoost and LightGBM, achieving high efficiency in estimating the live weight of cattle (Herrera-Camacho et al., 2025). Firdaus et al. (2023) predicted beef cattle body weight using meta-analysis by evaluating body measurement data with breed, sex and age categories and found that TP had an average correlation of r = 0.88 with live weight.

Obtaining values for animal performance traits provides parameters for evaluating individuals and groups of animals for use in selection and breeding systems. The correlation between these traits reveals the gains or losses of the related trait. Therefore, this study aimed to determine the productive and reproductive performance as well as the body biometrics of zebu males and their correlations.

Materials and Methods

This study was approved by the Ethics Committee for the Use of Animals at the Federal University of the Fronteira Sul (UFFS) – Protocol CEUA: n° 1202180321. The ABCZ keeps genealogical records of eight zebu breeds. To carry out a comparative study between breeds, we followed the methodology proposed by Brasil et al. (2013), who determined the closest degree of kinship among the Nellore, Nellore Mocho and Tabapuã breeds. A total of 7900 male animals aged between 8 and 36 months, comprising the Nellore (5350), Nellore Mocho (1188) and Tabapuã (1362) breeds, were evaluated. All animals were registered based on their age and category in the aforementioned year of EXPOZEBU, between 2000 and 2019, and placed in 17 predetermined categories according to the ABCZ zebu animal judging regulations, based on age in months: C1 (8–9); C2 (9–10); C3 (10–11); C4 (11–12); C5 (12–13); C6 (13–14); C7 (14–15); C8 (15–16); C9 (16–18); C10 (18–20); C11 (20–22); C12 (22–24); C13 (24–26); C14 (26–28); C15 (28–30); C16 (30–33); C17 (33–36). Animals were registered at specialised breed shows in Uberaba, Minas Gerais, Brazil, held between 2000 and 2019. Most of these registered animals were obtained using the main reproductive biotechnologies, such as artificial insemination, embryo transfer and *in vitro* fertilisation. The animals were reared in intensive breeding systems under nutritional management for high weight gain and growth performance. This management typically began in the first few months of the calf's life.

The parameters evaluated were live weight, body biometrics, carcass quality and scrotal circumference. The animals were weighed individually using electronic scales attached to containment trunks located in the animal reception area inside the fairgrounds. The individual body biometrics of the animals at different ages were carried out using a stick, calliper and measuring tape attached to the inside of the containment trunk. To determine the individual biometrics, the traits reported and defined by Lôbo et al. (2002) were measured as follows: forelimb height (FH): vertical lowered from the withers to the ground; hindlimb height (HH): vertical lowered from the hip portion of the sacrum to the ground; thoracic perimeter (TP): taken

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by the contour of the thorax passing through the eyebrow and returning perpendicular to the line of the back; body length (LE): taken laterally between the lower tip of the shoulder blade and the tip of the ischium; loin eye area (LEA), subcutaneous fat thickness (SFT) and subcutaneous fat of the croup (SFC) were measured from ultrasound images obtained using an Aloka SSD 500V (Electro Medicina Berger, Ltda) main unit and echo camera equipped with a UST 5049 linear transducer with a frequency of 3.5 MHz and a length of 17.2 cm. Ultrasound measurements of the LEA and SFT were taken between the 12th and 13th ribs using an acoustic guide. After this procedure, the images were stored on the hard disk of a laptop computer and interpreted using the Animal Ultrasound Service software AUS (AUSKey 4W) (Tarouco et al., 2007).

Scrotal circumference (SC) was measured horizontally in the median portion, equivalent to the maximum perimeter of the scrotum taken with an appropriate metal measuring tape, as described by Valvassori et al. (1985). Once the information had been collected, correlations between the productive, reproductive and biometric traits were estimated using the following model:

$$Y_{ijk} = \mu + R_i + C_j + R_i \times C_j + E_{ijk}$$

where Y_{ijk} is the dependent variable (WE, FH, HH, LE, TP, SC, LEA, SFT, SFC); μ is the general average; R_i is the ith breed (Nellore, Nellore Mocha and Tababapuã); C_j is the ith of age (j = 1 ,..., 17); $R_i \times C_j$ is the interaction between the ith breed and the jth category; E_{ijk} is a component of the random error associated with the ith breed of the jth age. Statistical analysis was performed using R (R Core Team [R], 2024). Data were considered significant at a maximum significance level of 5% using the Tukey test (LSMEANS).

Results and Discussion

Productive traits: live weight of males

The adjusted average weights of Nellore males were higher than those of Nellore Mocho and Tabapuã breeds, practically in all categories (Table 1). The weights of Tabapuã males were higher than those of Nellore Mocho males in categories 6, 7, 11, 12 and 13; therefore, they were ready for slaughter earlier than the ideal slaughter age of 24 months.

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Table 1
Adjusted average weight of Nellore, Nellore Mocho and Tabapuã males in different age categories during Expozebu from 2000 to 2019 in Uberaba, MG, BR

Category (age in months)	Weight, kg		
	Nellore	Nellore Mocho	Tabapuã
1 (8–9)	407.1a ± 43.4	370.3b ± 38.8	354.0c ± 41.5
2 (9–10)	444.9a ± 39.5	409.0ab ± 36.0	387.5b ± 59.6
3 (10–11)	484.5a ± 44.2	431.7b ± 44.0	418.6b ± 62.1
4 (11–12)	520.6a ± 46.8	478.2ab ± 43.9	477.6b ± 55.0
5 (12–13)	555.7a ± 50.3	502.6b ± 45.1	508.2b ± 65.8
6 (13–14)	590.2a ± 49.3	535.4b ± 52.3	578.7a ± 68.3
7 (14–15)	633.2a ± 55.0	555.7b ± 50.8	605.9a ± 71.1
8 (15–16)	657.8a ± 59.4	602.5b ± 60.8	631.2ab ± 82.9
9 (16–18)	707.0a ± 64.0	656.4bc ± 61.1	652.5c ± 85.5
10 (18–20)	771.5a ± 70.8	691.3bc ± 57.6	714.9b ± 82.5
11 (20–22)	828.8a ± 71.5	744.4b ± 65.9	799.2a ± 98.8
12 (22–24)	891.4a ± 76.9	829.2b ± 63.2	848.0a ± 91.8
13 (24–26)	941.5a ± 78.3	875.3b ± 69.1	894.7a ± 86.8
14 (26–28)	995.0a ± 74.0	903.0b ± 74.1	936.4ab ± 84.5
15 (28–30)	1038.6a ± 77.1	982.7b ± 84.0	976.5b ± 88.7
16 (30–33)	1094.8a ± 81.4	1010.9b ± 76.7	1023.5ab ±73.9
17 (33–36)	1134.5a ± 91.7	1073.0ab ± 75.35	1066.8b ± 62.9

[a, b] Averages followed by different letters in the row differ significantly (p < 0.05).

The weight of the males in the first category (8–9 months) was 417.11 kg for Nellore, 370.32 kg for Nellore Mocho and 354.04 kg for Tabapuã, showing a difference (p < 0.05) between breeds. In category 17 (33–36 months), the weights were 1134.5, 1073.02 and 1066.80 kg, respectively (p < 0.05). The weight of Nellore males was higher (p < 0.05) than that of Nellore Mocho and Tabapuã males. All males aged over 12 months (category 5) had slaughter weights, emphasising that these breeds, with their current genetics, are super-precocious animals. Some animals that have with better performance in exhibitions are used as sires.

When evaluating the evolution of the weight growth curve (Table 1) among the evaluated breeds, a similar slope was observed, with a slight increase in this slope between categories 8 and 13, which is when puberty occurs and hormones, such as testosterone, increase. This weight evolution in the Nellore, Nellore Mocho and Tabapuã breeds was similar to that of Brahman males, with a steeper slope up to the age of 24–26 months in the Brahman (Mota et al., 2010).

Body biometrics traits: forelimb height (FH) and hindlimb height (HH) of the males

In addition to body weight, limb height has also been shown to be a relevant characteristic among breeds (Table 2). Nellore showed a greater evolution in the growth curve of stature in the hip and withers heights, the animals showed parallel growth in both limbs, but the withers height was higher. In category 1 (8–9 months) the Nellore recorded an average of 131.89 cm in FH, followed by 130.58 and 127.28 cm for Nellore Mocho and Tabapuã, respectively, and the Nellore males were superior to Tabapuã ($p < 0.05$), (Table 2). In category 17 (33–36 months), HH was 160.90, 156.59 and 157.60 cm for Nellore, Nellore Mocho and Tabapuã, respectively, with the Nellore males being highest ($p < 0.05$).

Table 2

Adjusted average forelimb height and adjusted hindlimb height of Nellore, Nellore Mocho and Tabapuã males in different age categories during Expozebu from 2000 to 2019 in Uberaba, MG, Brazil

Category (age in months)	Height, cm		Height, cm		Height, cm	
	Forelimb	Hindlimb	Forelimb	Hindlimb	Forelimb	Hindlimb
	Nellore	Nellore	Nellore Mocho	Nellore Mocho	Tabapuã	Tabapuã
1 (8–9)	131.9a±3.9	140.5a±4.4	130.4ab±3.4	138.4a±4.3	127.3b±4.7	135.0b±5.0
2 (9–10)	134.9a±3.4	143.5a±3.7	133.2ab±4.0	141.9a±3.6	129.9b±4.6	137.3b±5.1
3 (10–11)	137.0a±3.6	146.2a±4.0	133.3b±3.7	142.3b±3.9	132.4b±3.8	139.8b±4.8
4 (11–12)	138.9a±3.8	148.3a±4.0	137.4a±3.9	145.7a±3.7	134.3b±4.2	144.1b±4.5
5 (12–13)	140.9a±3.8	150.5a±3.8	139.1a±4.3	148.2a±3.7	136.5b±4.3	145.89b±5.3
6 (13–14)	142.7a±3.9	152.4a±3.8	140.3a±3.9	149.3b±4.4	138.8b±5.0	149.7b±4.9
7 (14–15)	144.4a±4.1	154.6a±3.8	140.8a±4.47	150.8b±4.25	139.8b±5.8	150.4b±5.0
8 (15–16)	145.6a±3.7	156.1±3.9	143.8a±3.8	154.3±4.3	141.8b±5.0	152.0±4.6
9 (16–18)	147.5a±3.9	158.5a±4.0	145.6a±4.6	156.1ab±4.5	143.0b±4.1	153.2b±5.1
10 (18–20)	150.6a±3.9	161.1a±4.2	147.8a±3.9	157.6a±4.8	144.2b±4.2	155.8b±4.2
11 (20–22)	152.3a±4.2	163.5a±4.2	148.5b±4.1	159.6b±3.5	148.1b±5.4	158.9b±5.2
12 (22–24)	154.5a±4.2	165.7a±4.2	151.3a±4.1	162.56b±3.9	149.5b±4.8	159.5b±4.4
13 (24–26)	156.0a±3.7	167.2a±4.3	153.8a±3.9	164.7a±3.9	151.4b±5.1	160.7b±5.3
14 (26–28)	157.7a±4.5	168.4a±4.3	154.0a±4.2	165.3ab±4.5	151.5b±4.4	162.5b±5.1
15 (28–30)	157.6a±3.8	169.4a±4.1	155.2a±4.1	166.8ab±4.5	153.4b±6.16	163.2b±5.2
16 (30–33)	159.7a±4.7	170.9a±4.2	156.3a±3.7	167.6ab±4.5	154.0b±5.4	163.7b±5.5
17 (33–36)	160.9a±3.7	171.6a±3.6	156.9b±4.1	168.8ab±5.4	157.6b±5.7	166.7b±5.8

[a, b] Averages followed by different letters in the row differ significantly ($p < 0.05$).

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The HH of Nellore and Nellore Mocho males showed greater development in category 1 (8–9 months) with 140.52 and 138.38 cm, compared to Tabapuã with 135 cm (p < 0.05). In the final category 17 (33–36 months), HH was 171.59 cm for Nellore, 168.75 cm for Nellore Mocho and 166.68 cm for Tabapuã, with Nellore males were superior to Tabapuã in all categories (p < 0.05).

When comparing the differences between HH and FH in the males evaluated in category 1, there was an increase of 8.63 cm in the hind limb for Nellore, 7.8 cm for Nellore Mocho and 7.72 cm for Tabapuã. When evaluating males in category 17, WH was 10.69 cm higher than HH for Nellore, 11.86 cm for Nellore Mocho and 9.08 cm for the Tabapuã. Therefore, as these males grow, the difference between the hindlimb and forelimbs increases, resulting in animals with less linearity in the lumbosacral region. Mota et al. (2010) reported a similar pattern (higher hindquarters) for Brahman animals, reporting values of 10.6 cm higher. Therefore, these bulls had lower front and hindquarter heights, making them shorter animals. This difference in HH over FH can at first guarantee heavier and more valuable carcasses because most of the prime meat is in the hindlimb, but it disrupts the body balance.

Body biometrics: body length (LE) of males

The biometric evolution of the length of the males of the Nellore, Nellore Mocho and Tabapuã breeds showed higher LE values (p < 0.05) for Nellore in 7 of the 17 categories evaluated compared to Tabapuã (Table 3). Nellore males in category 1 (8–9 months) showed similar LE values compared to Nellore Mocho and were superior to Tabapuã, with 132.66 cm compared to 130.69 and 128.71 cm for Nellore Mocho and Tabapuã, respectively (p < 0.05) (Table 3).

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Table 3
Adjusted length averages of Nellore, Nellore Mocho and Tabapuã males in different age categories who took part in Expozebu between 2000 and 2019 in Uberaba, MG, Brazil

Category	Length, cm		
	Nellore	Nellore Mocho	Tabapuã
1 (8–9)	132.7a ± 5.5	130.7ab ± 6.2	128.7b ± 6.1
2 (9–10)	136.3a ± 4.8	134.7ab ± 5.0	132.0b ± 6.8
3 (10–11)	141.1a ± 5.8	137.3ab ± 5.5	136.0b ± 7.2
4 (11–12)	143.9a ± 5.5	142.6a ± 5.5	141.4a ± 7.0
5 (12–13)	147.1a ± 5.7	143.9ab ± 5.0	143.8b ± 7.5
6 (13–14)	149.8a ± 5.8	146.9a ± 6.8	149.5a ± 7.4
7 (14–15)	152.8a ± 5.3	148.6b ± 6.0	152.6ab ± 7.2
8 (15–16)	154.8 ± 6.1	152.6a ± 7.9	153.3a ± 7.9
9 (16–18)	158.5a ± 6.2	155.8b ± 5.9	153.8b ± 8.3
10 (18–20)	162.6a ± 5.8	159.0b ± 6.9	160.0ab ± 7.5
11 (20–22)	166.6a ± 6.4	162.2b ± 6.4	164.4ab ± 8.7
12 (22–24)	170.0a ± 6.2	168.0a ± 6.7	167.4a ± 8.3
13 (24–26)	172.9a ± 6.5	169.9a ± 6.2	170.1a ± 8.2
14 (26–28)	176.8a ± 6.6	172.1b ± 6.0	171.3b ± 7.8
15 (28–30)	178.3a ± 6.1	176.0b ± 6.9	174.3b ± 8.7
16 (30–33)	180.1a ± 6.3	177.0a ± 7.1	175.3a ± 4.7
17 (33–36)	182.9a ± 6.3	181.4a ± 6.3	174.3b ± 6.7

[a, b] Averages followed by different letters on the line differ significantly (p < 0.05).

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In category 17 (33–36 months), Nellore and Nellore Mocho males stood out compared to Tabapuã, showing LE values of 182.92, 181.37 and 174.32 cm, respectively (p < 0.05). Comparing measurements of LE (Table 3) with FH and HH (Table 2), it can be inferred that the males of the evaluated breeds are longer than they are tall. In this same category, animals of the Brahman breed had a height of 178.2 cm, making them longer than Tabapuã (Mota et al., 2010). When comparing the height of the limbs with the length, the Brahman animals were shorter but longer.

Body biometrics: thoracic perimeter (TP)

Another important body parameter in the evaluation of zootechnical performance is TP, which showed a higher growth curve in Nellore males in 14 categories compared to Nellore Mocho and higher in only two categories compared to Tabapuã (Table 4). TP showed the highest correlation with weight (0.97) in all three breeds; thus, males with a higher TP have a higher WE, which suggests their use in animal breeding programs with the aim of gaining weight. Characteristics with a high correlation have a greater relationship.

Table 4
Adjusted thoracic perimeters of Nellore, Nellore Mocho and Tabapuã males in different age categories who took part in Expozebu from 2000 to 2019 in Uberaba, MG, Brazil

Category	Length, cm		
	Nellore	Nellore Mocho	Tabapuã
1 (8–9)	172.0a ± 9.6	165.2 ± 7.5	165.2a ± 7.5
2 (9–10)	177.0a ± 7.5	170.6b ± 7.5	170.2b ± 10.3
3 (10–11)	182.0a ± 8.1	175.3b ± 7.3	176.0b ± 8.5
4 (11–12)	186.0a ± 11.7	181.3b ± 7.9	184.4ab ± 7.7
5 (12–13)	191.6a ± 8.1	185.8b ± 8.2	187.6ab ± 11.1
6 (13–14)	196.1a ± 8.	188.0b ± 13.6	197.0a ± 8.3
7 (14–15)	201.1a ± 10.3	193.4b ± 7.8	200.5a ± 10.8
8 (15–16)	204.2a ± 8.5	195.6b ± 9.7	202.6a ± 12.8
9 (16–18)	209.2a ± 8.6	202.9b ± 12.1	206.9ab ± 9.3
10 (18–20)	215.0a ± 11.7	207.7b ± 7.8	213.3a ± 8.9
11 (20–22)	221.8a ± 10.0	212.0b ± 9.0	220.2a ± 10.0
12 (22–24)	227.3a ± 11.0	220.6b ± 7.5	225.4ab ± 8.9
13 (24–26)	232.2a ± 10.0	225.4b ± 7.1	229.3ab ± 12.1
14 (26–28)	236.9a ± 9.3	228.1b ± 8.7	231.9ab ± 7.7
15 (28–30)	240.1a ± 9.5	236.1a ± 9.5	235.8a ± 10.1
16 (30–33)	244.1a ± 11.5	236.1b ± 9.5	239.7ab ± 5.4
17 (33–36)	247.3a ± 9.7	241.9a ± 7.7	242.5a ± 7.3

a, b Averages followed by different letters in the row differ significantly (p < 0.05).

When analysing category 1 in Table 4, the TP was 171.95 cm for Nellore males and 165.21 cm for Nellore Mocho and Tabapuã males. In category 17, TP was 247.28 cm for Nellore, 241.94 cm for Nellore Mocho and 242.48 cm for Tabapuã, showing statistically similar values (p > 0.05). For this trait, Tabapuã males had a more expressive evolution of body biometrics proportionally, being animals of medium height and length but with a large TP. The animals evaluated in this study have a higher TP than Brahman in all categories (Mota et al., 2010). Therefore, they have a greater thoracic amplitude, providing a greater respiratory and circulatory capacity and body volume.

Reproductive traits: scrotal circumference (SC)

Among the reproductive characteristics, SC stood out in Tabapuã males, with a higher SC than Nellore and Nellore Mocho males in category 6 and standing out together with Nellore in the other categories (Table 5). SC is one of the most widely used selection criteria for reproductive efficiency, as it is an easy-to-measure trait, has high heritability, and is related to weight gain, weaning weight, age at first calving, sexual precocity and sperm production (Siqueira et al., 2013). Tabapuã males showed a steeper growth curve from category 6 to 8, and from category 15 onwards (Table 5). Studying male animals of the Brahman breed, Mota et al. (2010) found that they presented a SC similar to Tabapuã, which were superior in some categories to Nellore and Nellore Mocho males. Males with a higher SC have a greater number of cells and histological structures for spermiogenesis, such as seminiferous tubules, Sertoli cells, Leydig cells and germ cells.

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Table 5
Adjusted mean scrotal circumference of Nellore, Nellore Mocho and Tabapuã males in different age categories who took part in Expozebu between 2000 and 2019 in Uberaba, MG, Brazil

Category	Scrotal circumference, cm		
	Nellore	Nellore Mocho	Tabapuã
1 (8–9)	23.4a ± 2.9	21.5b ± 2.8	22.9ab ± 2.7
2 (9–10)	24.8a ± 3.3	23.4a ± 3.3	23.9a ± 3.4
3 (10–11)	25.8a ± 3.2	24.4a ± 3.2	24.8a ± 3.2
4 (11–12)	27.3a ± 3.4	26.2a ± 3.8	27.2a ± 3.3
5 (12–13)	29.0a ± 3.2	27.2a ± 3.1	29.2a ± 3.7
6 (13–14)	30.4b ± 3.0	29.7b ± 3.3	32.8a ± 4.0
7 (14–15)	32.3a ± 3.5	29.9b ± 3.3	33.8a ± 3.3
8 (15–16)	33.6ab ± 3.6	31.8b ± 3.6	34.7a ± 4.1
9 (16–18)	34.8a ± 3.2	34.0a ± 3.3	34.7a ± 3.7
10 (18–20)	36.0a ± 3.5	34.8a ± 3.2	36.2a ± 3.2
11 (20–22)	37.5a ± 3.3	36.1a ± 3.2	37.7a ± 3.4
12 (22–24)	38.0a ± 3.3	37.5a ± 3.0	38.7a ± 3.7
13 (24–26)	38.5a ± 3.1	37.6a ± 2.9	39.3a ± 3.0
14 (26–28)	39.4a ± 3.0	38.6a ± 2.8	39.3a ± 3.5
15 (28–30)	39.8a ± 3.0	39.6a ± 3.3	41.0a ± 3.0
16 (30–33)	40.3a ± 2.9	40.1a ± 2.8	42.3a ± 3.1
17 (33–36)	40.6a ± 2.8	40.2a ± 3.2	43.0a ± 3.2

[a, b] Averages followed by different letters in the row differ significantly ($p < 0.05$).

Carcass traits: loin eye area (LEA) of males

The LEA of Nellore males was higher ($p < 0.05$) than that of Nellore Mocho and Tabapuã in categories 8, 9 and 11 (Table 6). In category 13 males (aged over 24 months) going to slaughter, the LEA was 106.23 cm² for Nellore, 99.87 cm² for Nellore Mocho and 107.08 cm² for Tabapuã. LEA is used to identify a carcass with a better grade of prime meat since it refers to the Longissimus dorsi muscle.

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Table 6
Adjusted mean values for loin eye area of Nellore, Nellore Mocho and Tabapuã males in different age categories who took part in Expozebu between 2000 and 2019 in Uberaba, MG, Brazil

Category	Loin eye area, cm^2		
	Nellore	Nellore Mocho	Tabapuã
1 (8–9)	71.3a ± 10.2	65.8a ± 12.2	64.8a ± 11.8
2 (9–10)	74.6a ± 11.2	68.7a ± 8.8	66.0a ± 13.2
3 (10–11)	78.6a ± 11.2	72.6a ± 11.5	69.2a ± 11.8
4 (11–12)	81.9a ± 10.7	77.5a ± 9.6	77.3a ± 12.1
5 (12–13)	85.7a ± 11.1	81.1a ± 9.6	77.1a ± 10.8
6 (13–14)	87.1a ± 12.4	80.4a ± 9.9	83.4a ± 12.6
7 (14–15)	91.0a ± 13.0	82.0a ± 9.5	86.3a ± 12.1
8 (15–16)	93.1a ± 12.5	86.9b ± 11.6	88.0b ± 12.1
9 (16–18)	94.8a ± 13.3	89.1b ± 10.7	90.3b ± 14.7
10 (18–20)	99.0a ± 13.3	91.0b ± 10.6	95.5ab ± 13.2
11 (20–22)	101.3a ± 14.7	92.2b ± 12.1	98.4b ± 12.9
12 (22–24)	104.5a ± 14.6	100.5b ±12.2	98.2b ± 13.6
13 (24–26)	106.2a ± 14.3	99.9a ± 12.2	107.1a ± 12.9
14 (26–28)	108.3a ± 17.4	101.8a ± 15.7	110.2a ± 14.5
15 (28–30)	110.9a ± 14.6	106.4a ± 15.0	111.4a ± 16.1
16 (30–33)	111.4a ± 15.9	102.9a ± 16.0	113.8a ± 12.8
17 (33–36)	112.0a ± 17.8	115.6a ± 17.0	115.0a ± 11.9

[a, b] Averages followed by different letters in the row differ significantly (p < 0.05).

When evaluating the LEA growth curve, Tabapuã males in category 13 or higher showed a steeper slope, overlapping the Nellore curve (Table 5). According to Bertrand et al. (2001), the LEA is related to growth, weight gain and moderate to high heritability values. This variable is related to the yield of meat cuts and carcass composition, highlighting the muscle and bone tissue ratio and the animal's degree of muscularity (Luchiari, 2000)

Carcass traits: subcutaneous fat thickness (SFT) of males

Another important carcass characteristic is SFT, which results in better carcass quality for slaughter and meat preservation, especially during the carcass cooling and freezing process. This fat deposition is related to the supply of a diet with a higher energy density, which is used when animals are being prepared for shows. SFT showed a general precocity in carcass finishing in the evaluated breeds (Table 7). Among categories 11–13 (ages 20–26

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months), Nellore males stood out with the highest SFT (p < 0.05). The SFC growth curve for Nellore males showed a steeper slope, standing out from categories 10–14 months, where it stabilised (Table 7). Both traits evolved in parallel in the evaluated breeds.

Table 7
Adjusted mean values of the subcutaneous fat thickness (mm) of Nellore, Nellore Mocho and Tabapuã males in different age categories who took part in Expozebu from 2000 to 2019

Category	Subcutaneous fat thickness, mm		
	Nellore	Nellore Mocho	Tabapuã
1 (8–9)	5.2a ± 2.1	4.2a ± 1.8	4.1a ± 1.8
2 (9–10)	5.7a ± 2.2	4.4a ± 1.5	4.4a ± 1.8
3 (10–11)	6.3a ± 2.4	5.4a ± 1.9	5.0a ± 2.3
4 (11–12)	6.7a ± 2.6	6.0a ± 2.4	5.9a ± 2.3
5 (12–13)	7.4a ± 2.9	5.8a ± 2.6	6.0a ± 2.2
6 (13–14)	7.7a ± 2.8	6.2a ± 2.5	6.8a ± 2.8
7 (14–15)	8.9a ± 3.4	7.0a ± 2.9	7.9a ± 3.7
8 (15–16)	9.8a ± 4.0	6.9b ± 2.5	7.7b ± 3.5
9 (16–18)	10.2a ± 4.2	7.7b ± 2.9	9.8ab ± 7.9
10 (18–20)	11.7a ± 4.8	8.8b ± 4.1	10.2ab ± 4.6
11 (20–22)	13.0a ± 5.1	10.2b ± 5.6	10.0b ± 4.6
12 (22–24)	14.8a ± 5.6	12.1b ± 5.3	11.2b ± 4.8
13 (24–26)	16.0a ± 6.1	13.0b ± 5.2	11.9b ± 4.3
14 (26–28)	17.6a ± 7.0	12.2a ± 4.1	12.4a ± 4.4
15 (28–30)	17.5a ± 6.4	14.2b ± 6.3	14.6b ± 6.0
16 (30–33)	17.9a ± 7.3	13.1a ± 6.9	15.9a ± 6.5
17 (33–36)	18.6a ± 7.8	16.3a ± 6.9	16.6a ± 5.1

[a, b] Averages followed by different letters in the row differ significantly (p < 0.05).

SFC adds value to the carcass due to its importance in preserving meat and is also highly valued in prime cuts, such as round. Factors such as breed, age, sex and farming system affect this trait. When considering the data from this study at a commercial herd level, at approximately 12 months of age, Nellore males had a live weight of 520 kg and SFT of 6.73 mm. Nellore Mocho males had values of 478 kg and 5.99 mm, and Tabapuã had values of 477 kg and of 5.94 mm. The males of these breeds produce precocious and well-finished carcasses in intensive breeding systems, demonstrating the genetic potential of these zebu beef breeds. In a literature review, when analysing British animals and their crossbreeds at 2 years of age, Boito et al. (2018) reported that

an SFT of 6.0 mm provided adequate yields of hot and cold carcass weight and produced carcasses with a high edible meat content.

Carcass traits: subcutaneous croup fat (SFC) of males

Nellore males had the greatest SFC (p < 0.05) in categories 9–14, which correspond to ages 16–28 months, similar (p > 0.05) to males in category 12 when compared to Nellore Mocho and Tabapuã (Table 8). In category 13 (24–26 months), Nellore had 17.08 mm of fat in the croup, which would be the ideal age at slaughter, a number that was higher (p < 0.05) compared to the Nellore Mocho and Tabapuã, which registered 14.23 mm and 14.01 mm, respectively. The recommended values for a good carcass are from 3 to 18 mm, when the SFC provides a sufficient layer of fat to promote the preservation of the chilled meat and does not have an excess of fat that is harmful to the cut (Abrahão et al., 2005).

Table 8
Adjusted averages for croup fat thickness (SFC) (mm) of Nellore, Nellore Mocho and Tabapuã males in different age categories that took part in Expozebu between 2000 and 2019 in Uberaba, MG, Brazil

Category	Croup fat thickness, mm		
	Nellore	Nellore Mocho	Tabapuã
1 (8–9)	6.7a ± 1.9	5.6a ± 1.9	5.4a ± 1.8
2 (9–10)	7.2a ± 1.9	6.3a ± 2.0	5.8a ± 1.9
3 (10–11)	7.9a ± 2.3	6.9a ± 1.8	6.7a ± 2.4
4 (11–12)	8.4a ± 2.3	7.7a ± 2.0	7.3a ± 2.3
5 (12–13)	9.1a ± 2.6	7.4a ± 2.5	7.7a ± 2.3
6 (13–14)	9.7a ± 2.7	8.1a ± 2.8	8.7a ± 2.6
7 (14–15)	10.7a ± 3.0	9.6a ± 2.5	9.5a ± 3.2
8 (15–16)	11.2a ± 3.6	9.0a ± 2.2	9.5a ± 3.2
9 (16–18)	12.1a ± 3.7	9.9b ± 3.1	10.1b ± 2.9
10 (18–20)	13.3a ± 4.0	10.7b ± 3.3	11.6b ± 3.8
11 (20–22)	14.5a ± 4.3	12.4b ± 4.9	11.9b ± 3.1
12 (22–24)	16.6a ± 4.8	14.5a ± 4.8	12.6a ± 4.3
13 (24–26)	17.1a ± 5.0	14.2b ± 5.2	14.0b ± 4.6
14 (26–28)	17.9a ± 5.2	14.0b ± 3.7	13.7b ± 4.0
15 (28–30)	17.9a ± 4.8	16.3ab ± 5.1	14.7b ± 4.1
16 (30–33)	18.3a ± 5.5	15.1a ± 5.0	15.3a ± 4.4
17 (33–36)	19.0a ± 7.1	17.7a ± 6.3	18.6a ± 6.5

[a, b] Averages followed by different letters in the row differ significantly (p < 0.05).

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The high carcass quality presented by these males of the evaluated breeds meets the standards of the external market. Brazil is the largest beef exporter in the world, which pre-determines quality standards that are currently classified in the Brazilian market as "Hilton Beef", "European Beef", and "China Beef", among others. The China Beef demands around 40% of this market, with animals having a maximum of 4 incisor teeth and being less than 30 months of age and healthy according to international standards (Carvalho, 2025).

Correlations among biometric traits evaluated in males of Nellore, Nellore mocho and Tabapuã breeds

Correlation analysis between animal production traits enabled us to quantify the degree of transmission of these characteristics, especially those with the greatest economic impact. After measuring or quantifying these variables, this tool can be used to guide animal selection. Traits with high positive correlation generally allow simultaneous gains, while those with low or negative correlation may require trade-offs or balanced selection to avoid losses (Silva Neto et al., 2023). Figures 1–3 illustrate the correlation values between the biometric, reproductive and carcass traits of Nellore, Nellore Mocho and Tabapuã males, highlighting the statistical relationships that reflect the interaction and degree of association between these productive attributes. These correlations are fundamental to understanding the phenotypic and genetic patterns that influence herd selection and improvement, providing a solid foundation for effective management and genetic evaluation strategies.
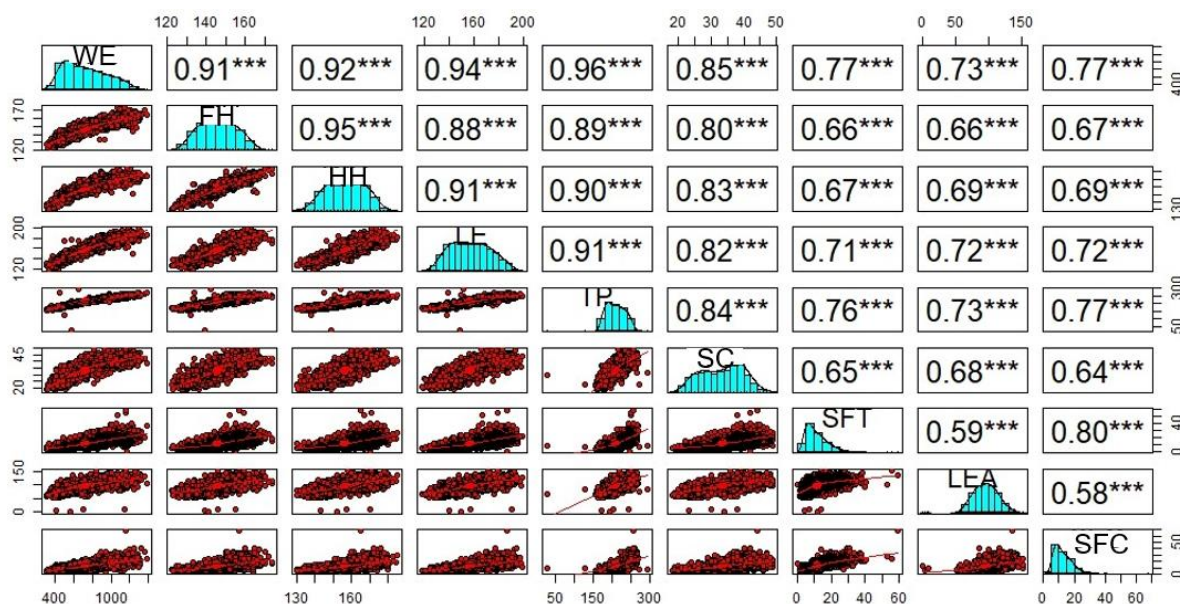

Figure 1. Correlations between the variables weight (WE), forelimb height (FH), hindlimb height (HH), length (LE), thoracic perimeter (TP), scrotal circumference (SC), loin eye area (LEA), subcutaneous fat thickness (SFT) and subcutaneous fat thickness of the croup (SFC) of Nellore males who took part in Expozebu between 2000 and 2019 in Uberaba, MG, Brazil. *** (p < 0.001).
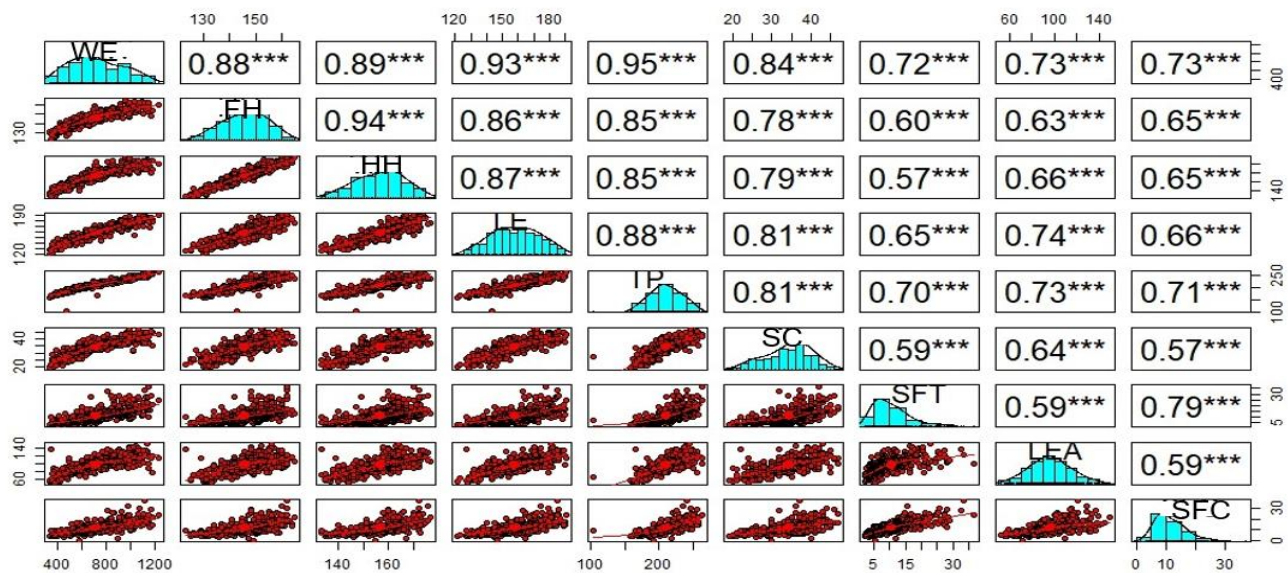
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Figure 2. Correlations between the variables weight (WE), forelimb height (FH), hindlimb height (HH), length (LE), thoracic perimeter (TP), scrotal circumference (SC), loin eye area (LEA), subcutaneous fat thickness (SFT) and croup subcutaneous fat thickness (SFC) of Nellore Mocho males that took part in Expozebu between 2000 and 2019 in Uberaba, MG, Brazil.*** (p < 0.001).
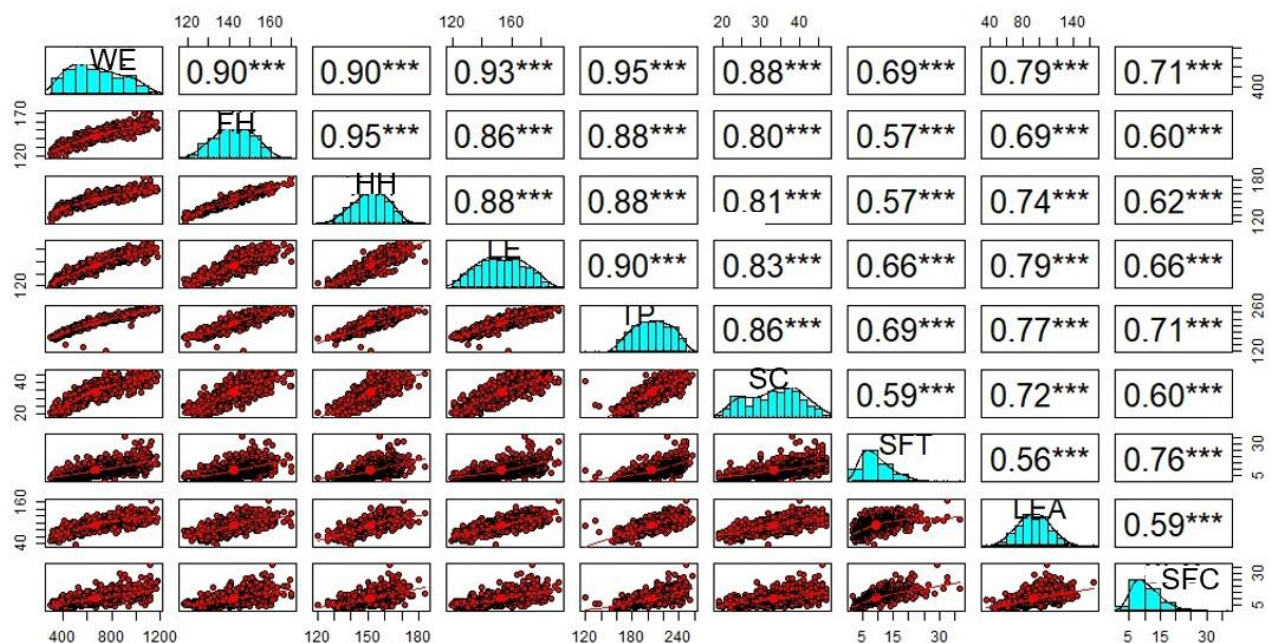

Figure 3. Correlations between the variables weight (WE), forelimb height (FH), hindlimb height (HH), length (LE), thoracic perimeter (TP), scrotal circumference (SC), loin eye area (LEA), subcutaneous fat thickness (SFT) and subcutaneous fat thickness of the croup (SFC) of Tabapuã males who participated in Expozebu between 2000 and 2019 in Uberaba, MG, Brazil. *** (p < 0.001).

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Productive trait WE and biometric trait TP showed a higher degree of correlation for all analysed breeds (0.96, 0.95 and 0.95 for Nellore, Nellore Mocho and Tabapuã, respectively). These values were close to those found by Mota et. al. (2010) when working with Brahman males (0.96). These results corroborate those found by Firdaus et al. (2023) when using meta-analysis, as TP presented an average correlation of 0.88, indicating that these measurements are excellent predictors of weight. Herrera-Camacho et al. (2025) observed high effectiveness using the XGBoost and LightGBM algorithms for estimating live weight, with a wide range of biometric measurements in these advanced models.

There was also a high correlation between WE and LE, showing values of 0.94, 0.93 and 0.93 for Nellore, Nellore Mocho and Tabapuã, respectively. It can therefore be inferred that selecting males with higher TP and LE will result in heavier animals.

Tabapuã males showed a higher correlation between WE and SC compared to other breeds, with values of 0.85 for Nellore males, 0.84 for Nellore Mocho and 0.88 for Tabapuã, corroborating the close correlation of 0.87 for Brahman males (Mota et al., 2010) and for body biometry traits. SC showed a moderate correlation with carcass quality traits, such as LEA, SFT and SFC. Analysing the carcass quality traits, there was a moderate to high correlation with WE in the three studied breeds.

Carcass quality traits showed moderate correlation values. SFT and SFC showed a moderate to high correlation among Nellore, Nellore Mocho and Tabapuã males (0.80, 0.79 and 0.76, respectively).

These values are similar to that observed for Brahman males (0.80) (Mota et al., 2010). Freitas et al. (2022) reported a high correlation between SFT and SFC, but a low correlation with LEA in Tabapuã in a pasture-raised system.

An overview of the correlations between the male traits of the three breeds evaluated showed a high correlation between WE and biometric traits, such as FH, HH, LE and TP, with TP having the highest correlation. The breakdown of fat deposition seems to follow a fixed chronological order, starting with peri-renal fat, which is the first to be deposited, followed by intermuscular fat, subcutaneous fat and finally intramuscular fat (Paulino et al., 2009). Selection for SFC in Nellore males was indicated, as this characteristic was strongly correlated with other carcass quality measures, such as yield and marbling, affecting the ideal time for slaughter and value in the foreign market (Soares et al., 2021). The carcass traits showed the highest correlations with WE and TP, moderate to high correlations with the biometric traits, and moderate values among themselves.

In the beef production chain, genetic improvement is a necessary tool for the constant selection of genetically superior animals, thus guaranteeing the evolution of different cattle breeds. Animal reproduction biotechnologies, such as artificial insemination, embryo transfer and in vitro fertilisation, enable the rapid propagation of this genetic material, meeting national and international demand for beef cattle. This study obtained data on the performance of males of the Nellore, Nellore Mocho and Tabapuã breeds; thus, these values at

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different ages can be used as a reference for evaluating cattle development in preparation for exhibitions and/or intensive production systems. Given the large number of phenotypic variables collected, it is recommended that future studies explore the use of machine learning algorithms, such as random forest, XGBoost and artificial neural networks to develop more robust predictive models of productive, reproductive and carcass quality performance.

Conclusion

Nellore males showed better performance in weight, FH, HH, LE and TP. TP and SC showed greater improvement for Nellore and Tabapuã males. Nellore, Nellore Mocho and Tabapuã males showed the highest correlation between weight and TP, followed by weight and LE. The carcass quality variables, such LEA, SFT and SFC, showed intermediate correlations with each other, and high correlations with weight and TP for all males of the evaluated breeds.

Acknowledgment

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