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REGULAR ARTICLES

Performance, carcass, and meat traits of locally adapted Brazilian cattle breeds under feedlot conditions

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Abstract
Little is known about the performance, carcass, and meat traits of locally adapted cattle in Brazil. This study aimed to compare the growth, slaughter, and carcass traits as well as meat quality of two local breeds (Curraleiro Pé-Duro and Pantaneiro) with the Nelore breed. Fifteen 30-month-old steers of each breed were weighted (Curraleiro Pé-Duro = 264.80 kg; Nelore = 346.80 kg; Pantaneiro = 316.20 kg) and raised in a feedlot condition for 112 days, with measurements to assess growth and slaughter, visual and carcass and meat traits. Data were submitted to variance and multivariate analyses. Nelore and Curraleiro Pé-Duro had similar *Gluteus medius* depths. Pantaneiro and Curraleiro Pé-Duro were superior for leg compactness index ($P < 0.05$) and had higher eye muscle area than Nelore ($P < 0.05$). Although there was no difference in daily weight gain and slaughter weight between breeds, Curraleiro Pé-Duro had a lower initial weight (264.80 kg) when compared to Nelore (346.80 kg; $P < 0.05$). Nelore and Curraleiro Pé-Duro deposited more fat than Pantaneiro ($P < 0.05$), while Curraleiro Pé-Duro and Pantaneiro had more muscle than Nelore ($P < 0.05$), which also had more bone and a higher percentage of second-quality cuts ($P < 0.05$). Meat from Nelore also showed lower succulence than Pantaneiro ($P < 0.05$) and higher shear force than the other breeds ($P < 0.05$). Pantaneiro's meat had the most capacity to retain water ($P < 0.05$), lower shear force ($P < 0.05$), and was more succulent ($P < 0.05$) when compared to the other breeds. Multivariate analysis showed that Pantaneiro, Curraleiro Pé-Duro, and Nelore breeds can be considered distinct in growth, carcass, and meat traits, with the local breeds showing superior meat traits. The local breeds Curraleiro Pé-Duro and Pantaneiro presented characteristics similar or better to those of the Nelore, proving to be animals with great productive potential and generate high meat quality under feedlot conditions.

Keywords Bone · Curraleiro Pé-Duro · Muscle · Nelore · Pantaneiro · Tenderness

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Introduction

The locally adapted Curraleiro Pé-Duro and Pantaneiro breeds are thought to show lower production efficiency and carcass quality than meat breeds under commercial conditions (Blackburn et al. 1998). This probably arises from their small frame size (McManus et al. 2011), usually obtained in harsh environmental conditions such as parasites, drought, high ambient temperature, and low food availability.

In Brazil, native-adapted cattle breeds originated from *Bos taurus ibericus* cattle brought from the Iberian Peninsula during the colonisation period (Felix et al. 2013; Egito et al. 2016). These have adapted to the local environments, including the Brazilian Cerrado (savannah and semi-arid hinterland) and Pantanal (world's most extensive wetlands), where the Curraleiro Pé-Duro and Pantaneiro breeds have developed, respectively (Felix et al. 2013). These ecosystems are characterised by high ambient temperatures and prolonged dry seasons (approximately 6 months) with seasonal flooding in the Pantanal. The arrival of zebu type cattle (mainly Nelore derived from the Indian Ongole breed) in the early twentieth century led to replacing these breeds in commercial production systems (Egito et al. 2002). This was followed by the rapid expansion of Brazilian cattle production in the last 30 years, which means Brazil now has the world's largest commercial beef herd. The Zebu breed undergoes genetic improvement programs (Carvalheiro 2014), mainly focused in improving animal performance, especially weights at different ages and, consequently, average daily gain (Zuin et al. 2012; Paterno et al. 2017).

Even in their native regions (Oliveira et al. 2021; Façanha et al. 2014), Curraleiro Pé-Duro and Pantaneiro breeds are rarely considered for production or crossbreeding due to their perceived low performance in relation to commercial breeds in situations favourable to exotic species (Felix et al. 2013). Little information exists on the performance, carcass, and meat quality of these locally native-adapted breeds, especially in comparison with commercial breeds. Bianchini et al. (2006) showed that Curraleiro Pé-Duro and Pantaneiro were similar in size to Nelore cattle for several body measurements, although the weight of the animals was not recorded. Nevertheless, McManus et al. (2011) showed that shoulder height, body length, and heart girth were critical in differentiating between these breeds for heat tolerance.

Since these locally adapted breeds are of *Bos taurus* origin, they have also been assumed to present lower growth rates but superior meat quality to the *Bos indicus* breeds under field conditions in the Brazilian Cerrado (Fioravanti et al. 2010), once again without comparative studies in similar environments. For example, birth weights, weaning weights, and average daily gain (ADG) in Pantaneiro (Abreu et al. 2002) and Curraleiro Pé-Duro (Carvalho et al. 2013) were 26 kg and 21.3 kg; 68.68 kg and 114 kg; and 0.429 kg/day and 0.215 kg/day. These are lower than similar weights for Nelore cattle on native pasture (29.5 kg; 157.95 kg; 0.625–0.650 kg/day, Itavo et al. 2008; Holanda et al. 2004). These studies were pre-weaning and not comparative as they were carried out with individual breeds. Nevertheless, Rezende et al. (2014) related a postweaning gain in Nelore of 0.430 kg/day in the Pantanal in animals born between 1978 and 2007, similar to the Pantaneiro in Abreu et al. (2002).

Studies have been carried out comparing the meat quality of the *Bos taurus indicus* (Nelore, Brahman) with *Bos taurus taurus* breeds such as Angus (Martins et al. 2015; Pereira et al. 2015; Rodrigues et al. 2017), Wagyu (Dias et al. 2016), Senepol (Schatz et al. 2020), Hereford and Caracu (Mendonça et al. 2021), composites such as Canchim (Giusti et al. 2013), or crossbreds (Bressan et al. 2016). The locally adapted Curraleiro Pé-Duro and Pantaneiro breeds have adapted to the environment over 500 years. Therefore, more information is available on characteristics such as growth and meat quality from crossbreeding experiments (Carvalho et al. 2015; Rodrigues et al. 2018; Afonso et al. 2020) than purebreds. Therefore, the present study aimed to compare performance, carcass, and meat traits in Pantaneiro and Curraleiro Pé-Duro cattle with Nelore under commercial feedlot conditions.

Material and methods

Animals and diet

In vivo invasive procedures were not performed, and the animals were slaughtered for commercial purposes with subsequent analysis performed.

Fifteen 30-month-old steers of each breed (Curraleiro Pé-Duro, Nelore, and Pantaneiro, Fig. 1) were kept in individual pens, in a feedlot with covered area and shade for food, at Veterinary School of the Federal University of Goiás, for 112 days of the experiment after 21 days adaptation to the experimental diet and feedlot conditions. The number of repetitions (fifteen per breed) was calculated using Cox's formula (Chow et al. 2018).

Curraleiro Pé-Duro (shortened to Curraleiro) came from two herds. Six animals were acquired from a breeder in the municipality of Monte Alegre-GO and nine from a breeder in the municipality of Mimoso - GO. The Pantaneiro and the Nelore both originated from a single herd. The Nelore were not involved in a breeding program. Pantaneiro animals were acquired from the Conservation Nucleus of the Pantaneiro

Fig. 1 Curraleio Pé-Duro (**a**), Pantaneiro (**b**), and Nelore (**c**) breeds used in the study

breed of Embrapa. Nelore animals came from a breeder in the region of Petrolina-GO. The breeds, Curraleiro and Pantaneiro cattle, used in the study had not been selected to improve their productive traits. Therefore, the animals only had the same conditions in the last 112 days of their life, which did not erase the previous different conditions.

The animals received a balanced diet, according to their requirements, twice a day, following the National Research Council – NRC (1996) recommendations, with 74.30% of total digestible nutrients (NDT) and 15% of crude protein. The diet had 70% of the nutrients from concentrate and 30% from roughage (sorghum silage), with orts of 5 to 10%. Mineral salt and water were provided ad libitum.

Growth and slaughter

At the beginning of the experiment, animals were weighed (Curraleiro Pé-Duro = 264.80 kg; Nelore = 346.80 kg; Pantaneiro = 316.20 kg) and then every 14 days until the day before slaughter. An Aloka SSD-500 ultrasound with a linear 17.2 cm and a 3.5MHz transducer was used to determine eye muscle measurements (eye muscle area (EMA); subcutaneous fat thickness (FT); hip fat (HF); and depth of *Gluteus medius* muscle (GMD)) every 28 days for the first three measurements, then every 14 days, immediately following the weight measurements. Measures were performed manually without the use of software.

The animals were slaughtered in a commercial abattoir after a 24-h fast on three consecutive days, with one third of each genetic group on each day with the objective of facilitating their handling and the evaluation of their performance during the experiment and at the abattoir. The animals were bled out, and the viscera, internal organs, feet, tail, skin, and head were removed. The hot carcass weight (HCW) was taken before dividing the carcass in half. The half carcasses remained in a cold chamber for 24 h at 4 °C and the left half carcass of each animal was weighed to determine the weight of the cold carcass (CCW).

Visual measurements

Using the parameters defined by the Ministry of Agriculture (MAPA), Federal Inspection Service (SIF) age was also defined (Bungenstab 2012: D = male or female bovine with teething milk without falling from the clamps; J2 = young male or female bovine with two permanent incisor teeth (tweezers), without losing the first dentition; J4 = young male or female bovine with four permanent incisor teeth, without dropping the second average of the first dentition; I = male or female cattle with more than four and up to six permanent incisor teeth, without falling from the corners of the first dentition; A = male or female cattle with more than six incisor teeth in the second dentition).

The carcasses were subjectively typified for marbling, physiological maturity, texture, and conformation. Carcass marbling was classified according to the degree of intramuscular fat deposition in the *Longissimus thoracis* by comparing the muscle with the standards and following the point scale, where 1 corresponds to trace, 2- light, 3- small, 4- medium, 5- moderate, and 6- abundant (Felício 2005).

Physiological maturity (USDA 2017) was determined by determining cartilage ossification of the spinous processes of the thoracic and lumbar vertebrae and between the sacral vertebrae. The cartilage ossification scale varies from A to E, where A: corresponds to the animal that is between 9 and 30 months, B: animal that is between 30 and 42 months, C: between 42 and 72 months, D: between 72 and 96 months, and E: over 96 months. These were then subdivided in three (+, 0 and -, - being younger and + being older), and then transformed to a scale of 1 (E+) to 15 (A-).

Carcass texture was evaluated by visual examination of the granulometry of the cross-section of the *Longissimus thoracis*, in the EMA, whose granulometric degree depends on the calibre of the muscle fibre bundles, that is, on the diameters of the muscle bundles (Müller 1987) and the degree of delimitation between the muscle bundles imposed by the thickness of the perimysium. This connective tissue sheath surrounds each of these muscle bundles. Carcass texture was rated on a scale of 1 (very coarse) to 5 (very fine). Conformation was measured on a 12-point scale (Muller 1987) ranging from 12- very good+; 11- very good; 10- very good-; 9- good+; 8- good; 7- good-; 6- regular+; 5- regular; 4- regular-; 3- bad+; 2- bad; and 1- bad-.

Carcass and meat traits evaluations

To calculate the compactness index, the following measurements were performed, according to Sañudo and

Sierra (1986): leg length (distance between the perineum and the anterior edge of the tarsus metatarsal articular surface), croup width (maximum width between the trochanters of both femurs, taken with a compass), the internal length of the carcass (maximum distance between the anterior edge of the ischiopubic symphysis and the anterior border of the first rib at its midpoint). Carcass compactness (CCI) was calculated as the cold carcass weight divided by internal carcass length, and leg compactness (LCI) was the leg circumference divided by leg length.

Physical measurements of eye muscle area (EMA13) and fat thickness (FT13) were carried out on the left carcass through a cross-section between the 12th and 13th rib using a standard transparent graph template (1 cm^2).

From each right cooled half-carcass, the *Longissimus thoracis* was cut between the 11th and 13th ribs, called HH section (Hankins and Howe 1946). This was divided into two subsamples of approximately 8 cm wide each, which were identified, vacuum packed, and frozen immediately to determine the percentages of muscle, bone, and fat.

Dressing percentage was calculated as $DP(\%) = \frac{hot\ carcass\ weight \times 100}{slaughter\ weight}$; and shrinkage percentage as $SP(\%) = 100 - \left(\frac{cold\ carcass\ weight \times 100}{hot\ carcass\ weight}\right)$.

The pH was verified from the right half of carcasses using a pH metre (Model HI 99163, Brand Hanna, Brazil), which were then separated between the fifth and sixth thoracic vertebra to form fore and hind ends. The hind end was boned in commercial cuts: tenderloin, top sirloin, bottom sirloin, rump cap, the eye of round, knuckle, topside, and silverside.

The frozen samples from the HH section were slowly thawed for evaluation of the tissue composition of the carcass. CieLab colour space was determined on three points of the carcass and the section of the 12th rib to determine L* (luminosity), a* (green to red spectrum), and b* (blue to yellow spectrum) using a Minolta CR-300 (Osaka, Japan). In addition, two new traits were calculated. Chroma (C*) and hue angle (h*) were then calculated using the following equations in AMSA (2012):

$$C^* = \left[\left(a^{*2} + b^{*2}\right)\right]^{1/2}$$

$$h^* \left[\left(b^*/a^*\right)tan^{-1}\right]$$

Larger C* values indicate greater red colour intensity and larger h* values indicate a less red and more discoloured.

After the physical separation of these components, the percentages of bone, muscle, and fat were determined according to the technique described by Hankins and Howe (1946), and adapted by Müller et al. (1973). The proportion of muscle, adipose tissue, and bones in the carcass was estimated based on the proportions of these components in the HH section, using the equations described below (where × is the percentage of the component of the HH section), developed by Hankins and Howe (1946):

$$(\%M)\ Muscle = Y = 16.08 + 0.80\times$$

$$(\%F)\ Fat\ tissue = Y = 3.54 + 0.80\times$$

$$(\%B)\ Bone = Y = 5.52 + 0.57\times$$

Losses in the thawing and cooking process were determined in the same frozen samples and were carried out consecutively. To determine the water holding capacity of the meat, 2.5-cm thick steaks were extracted from the cranial portion of the *Longissimus thoracis*. The steak was weighed frozen (FZ), then placed on racks and thawed under refrigeration at a temperature of 7 °C for 24 h. The steaks were weighed again (T) to determine drip losses, which were expressed as a percentage of the initial weight (QDrip) according to Arboitte et al. (2011). After weighing, thermometers with a metallic penetration sensor were inserted into the geometric centre of the samples and placed in a pre-heated (170 °C) oven. The samples were turned over when they reached 40 °C, allowing for uniform cooking until the core temperature of the samples reached 71 °C (15 min) and then removed (Wheeler et al. 1994). The samples were weighed to determine cooking loss (QCook), allowed to cool at room temperature (25 °C), and refrigerated at 7 °C for 24 h. Losses were expressed as a percentage of initial weight. The total loss was calculated considering the drip and cooking losses (Qtot).

Shear force (SF) was determined on roasted steaks after cooling for 24 h at 7 °C. Eight cylinders of 12.7 mm diameter per steak were extracted. Cylinders were cut perpendicularly to the fibre at an angle of 45° and diameter of 2 cm each. These were used to determine the shear force in kgf/cm^2, using the Warner-Bratzler Meat Shear equipment (Zwick GmbH&Co. KG, Ulm, Germany) equipped with a 1.016-mm thick cutting blade, a load speed of approximately 20 cm per minute, and a load capacity of 25 kgf/cm^2. The average of all readings was calculated after disconsider the maximum value (Arboitte et al. 2011).

Meat quality and taste characteristics were measured in a sensory panel trained by Embrapa Gado de Corte, Mato Grosso do Sul, using Dutcosky (2007) methodology. A hedonic scale from 1 (worst) to 9 (best) was used to evaluate texture, juiciness, and palatability. Before the analysis, the HH subsection samples were defrosted at 4 °C inside a standard refrigerator for 24 h. A 5% common salt (NaCl) solution was added. After roasting, each sample was cut into portions of approximately 20 g each. The samples were heated at the maximum potency in a microwave oven for 30 s to reach 45 to 50 °C. The heated samples were subjectively evaluated for texture, juiciness, and palatability in an individual cabin under white light.

Statistical analyses

Data were tested for normality of distribution and homogeneity of residues using Shapiro Wilk and Levene tests, respectively, subjected to variance analysis (PROC GLM) with fixed effects including breed as well as the date of slaughter and initial/final weight on test used as a covariate. Means were compared by Tukey test ($P < 0.05$). The following statistical model was used:

$$Yijk = \mu + \alpha i + \delta j + \beta(Xijk + \overline{X}) + \varepsilon ijk$$

where Yijk represents dependent variables; μ is the overall mean of the observations; αi is the fixed effect of the breed (i = Curraleio, Pantaneiro and Nelore); δj is the fixed effect of the date of slaughter (j = days 1 to 3); β is the coefficient of linear regression between the covariate (initial/final weight) and the response variable (Y), with $\beta = 0$; Xijk = observed value of the covariate (initial/final weight); $\overline{X}$ = mean of the covariate (initial/final weight); and εijk is the random residual experimental error.

Multivariate analyses were carried out on standardised (STANDARD) data following Sneath and Sokal (1973). The associations between growth and slaughter, carcass, and meat traits were investigated using principal component analysis (PRINCOMP). Correspondence analysis (CORRESP) compared animals and traits with visual traits (dental age, conformation, physiological maturity, and marbling). Cluster analysis was used to form groups with homogeneous properties (Härdle and Simar 2012). The method adopted was the minimum variance method (Ward's method). This method calculates the intra-group variance for all possible clusters, choosing the arrangement that provides the most negligible variance. Stepwise (STEPDISC) discriminant analysis was carried out to verify the discriminatory capacity of the original traits in forming these groups. Statistical analyses were carried out using SAS® v.9.4 (Statistical Analysis System Institute, Cary, North Carolina).

Results

Visual

No differences between breeds were seen for conformation (regular to good+), physiological maturity (D- to A+), or marbling (trace- to light+). In contrast, differences were seen for SIF age (A to J4), where Curraleiro had a marginally higher classification (Fig. 2).

Growth and slaughter

The Curraleiro animals were lighter than Nelore at the beginning of the experiment ($P < 0.05$) (Table 1), although they did not differ in the ultrasound measures. At slaughter, Curraleiro showed no significant difference in live weight with the other breeds due to its increased growth rate. Both Pantaneiro and Curraleiro showed higher eye muscle area than Nelore ($P < 0.05$), as measured by ultrasound at slaughter, but no differences were seen between breeds for fat at slaughter (Table 1). The Curraleiro showed greater hip fat ($P < 0.05$) and *Gluteus medius* depth growth rates at slaughter ($P < 0.05$), not differing from Nelore for the former and Pantaneiro for the latter.

While there was no difference between Nelore and Curraleiro for carcass compactness index (CCI), Pantaneiro and Curraleiro were superior for leg compactness index (LCI) ($P < 0.05$). This is because Nelore has longer legs without having a significantly larger perimeter.

Regarding subjective carcass measures, breeds only differed in physiological maturity, with Nelore being more mature than the other two breeds ($P < 0.05$). Left carcass weight did not vary between breeds.

Carcass traits

There was no difference in carcass traits between the three genetic groups (Table 2). No differences were seen between breeds for carcass colour (CieLab), with carcasses being more red than green and more yellow than blue. There was no difference in dressing percentage among the breeds. The Curraleiro showed higher pH values differing from Nelore and Pantaneiro ($P < 0.05$).

Breed affected several cut weights ($P < 0.05$) (Table 3). Nelore had a heavier hind end without rump and sirloin, top sirloin, eye of round, knuckle, topside, and silverside. Nelore had a higher percentage of hind end without rump and sirloin, top sirloin, eye of round, knuckle, and silverside (Table 3).

Meat traits

Nelore had a higher percentage of bone in the cut than Curraleiro ($P < 0.05$) (Table 4), and less muscle than both *Bos taurus ibericus* breeds ($P < 0.05$). The values found for percentage of water lost in thaw, percentage of water lost in cooking, and percentage of water lost in total (Table 4), evidenced both after thawing and after cooking, demonstrate that Pantaneiro had a greater capacity to retain water than Curraleiro and Nelore ($P < 0.05$). Curraleiro and Nelore retained water equally.

Nelore meat showed higher luminosity, indicating lighter coloured meat, while Pantaneiro and Curraleiro had darker meat ($P < 0.05$) (Table 4). Nelore had the meat more green than red when compared to Pantaneiro ($P < 0.05$). In terms of meat hue angle (h*m), Nelore was higher indicating higher discoloration ($P < 0.05$).

Fig. 2 Distribution of animals by breed and dental age, conformation, marbling, and physiological maturity of the carcass

Shear force was significant for the breed ($P < 0.05$). Nelore meat had higher shear force than other breeds, followed by Curraleiro meat and Pantaneiro, which had the lowest shear force (Table 4).

Breed had a significant effect on meat tenderness ($P < 0.05$). The meat from Pantaneiro had the highest tenderness and juiciness compared to the other two breeds, but this differed only from the Nelore (Table 4).

Table 1 Least squared means and significance levels for growth and slaughter traits in Brazilian cattle breeds

Traits	R^2	CV	Breed	Date of slaughter	Initial weight	Breed		
						Curraleiro	Nelore	Pantaneiro
Beginning								
Initial weight (kg)	0.25	19.56	***			264.8[b]	346.8[a]	316.2[ab]
Initial eye muscle area (cm^2)	0.10	20.78	ns			44.6	41.2	45.3
Initial eye muscle fat (mm)	0.09	22.25	ns			3.4	2.9	3.4
Initial hip fat (mm)	0.09	23.32	ns			2.8	2.5	3.0
Initial *Gluteus medius* depth (mm)	0.03	12.46	ns			70.0	68.0	66.0
Slaughter								
Slaughter weight (kg)	0.84	1.96	ns	ns	***	403.8	475.4	443.1
Slaughter eye muscle area (cm^2)	0.68	10.60	*	*	***	69.1[a]	61.8[b]	67.3[a]
Slaughter eye muscle fat (mm)	0.06	36.91	ns	ns	ns	60.0	48.0	51.0
Slaughter hip fat (mm)	0.24	10.51	ns	ns	***	4.0	4.0	3.9
Slaughter *Gluteus medius* depth (mm)	0.64	9.84	***	ns	***	91.3[a]	95.3[a]	82.1[b]
Rates (Initial to slaughter)								
Daily weight gain (kg/day)	0.11	23.04	*	ns	ns	1.24[a]	1.15[b]	1.13[b]
Rate of growth of eye muscle area (cm^2/day)	0.21	43.51	ns	ns	***	0.26	0.22	0.17
Rate of growth of fat thickness (mm/day)	0.23	79.79	ns	ns	ns	0.40	0.30	0.30
Rate of growth of hip fat (mm/day)	0.10	59.48	ns	ns	ns	0.013	0.015	0.009
Rate of growth of *Gluteus medius* (mm/day)	0.28	54.91	*	ns	ns	0.20[ab]	0.20[a]	0.10[b]
Carcass								
Carcass length (cm)	0.67	3.25	ns	ns	***	131.5	133.0	134.2
Leg length (cm)	0.74	5.48	*	***	***	64.1[c]	74.5[a]	68.6[b]
Leg thickness (cm)	0.64	6.95	*	*	***	23.3[ab]	24.1[a]	22.5[b]
Arm perimeter (cm)	0.79	4.48	ns	ns	***	34.6	34.2	34.1
Arm length (cm)	0.90	10.05	***	***	ns	45.0[b]	53.6[a]	48.4[b]
Left half carcass weight (kg)	0.87	8.64	ns	ns	***	114.6	117.9	110.8
Carcass compactness index	0.85	7.43	***	***	***	1.69[ab]	1.77[a]	1.61[b]
Leg compactness index	0.91	8.56	***	***	**	0.36[a]	0.32[b]	0.33[b]
Width of eye muscle at 13th rib (mm)	0.39	9.23	*	ns	***	66.9[a]	59.8[b]	65.2[ab]
Length of eye muscle at 13th rib (mm)	0.54	7.44	ns	*	*	138.8	135.8	142.2
Subjective								
Texture	0.36	28.52	ns	ns	ns	2.80	2.52	2.64
Marbling	0.17	38.24	ns	*	ns	3.61	3.13	3.42
Physiological maturity	0.58	11.91	***	ns	***	11.7[b]	13.2[a]	11.4[b]
Conformation	0.42	8.98	ns	ns	***	10.0	10.2	9.80

R^2, coefficient of determination; *CV*, coefficient of variation. Different letters in the column indicate significant differences using the Tukey test ($P < 0.05$). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; *ns*, not significant

Multivariate analyses

The first two principal components showed that most growth and slaughter (Fig. 3a) traits were positively associated, with initial and slaughter weight closely related to the linear body and carcass measurements. There are animals with high eye muscle areas but low fat and fat growth in the second component, possibly indicating less physiologically mature animals. The texture was better at lower weights. Animals with higher physiological maturity had lower marbling. This may be a bias of the evaluator as these are subjective scores, and the locally adapted breeds with higher marbling tend to be smaller (shorter arms and legs).

In general, larger animals have heavier carcass cuts as expected (Fig. 3b). Nevertheless, in the second factor, a longer carcass length and proportion are reflected in smaller fat and bone composition. This finding was especially evident in Nelore cattle, which had more bone and less muscle. There is a strong relationship between the silverside, topside, and knuckle cuts, but the ties decrease for more noble cuts

Table 2 Least squared means and significance levels for carcass traits in Brazilian cattle breeds

Traits	R^2	CV	Breed	Date of slaughter	Slaughter weight	Breed		
						Curraleiro	Nelore	Pantaneiro
Carcass luminosity	0.14	12.78	ns	ns	ns	28.2	30.2	30.5
Carcass green to red spectrum	0.03	31.72	ns	ns	ns	4.51	5.05	4.62
Carcass blue to yellow spectrum	0.14	25.69	ns	0.06	ns	6.57	6.90	6.88
Carcass chroma angle	0.40	17.74	ns	*	ns	8.08	9.20	8.54
Carcass hue angle	0.04	19.50	ns	ns	ns	0.95	0.97	0.98
pH 24	0.28	2.37	**	ns	ns	5.86[a]	5.72[b]	5.74[b]
Cold carcass weight (kg)	0.86	8.97	ns	ns	***	113.1	117.8	109.0
Hot carcass weight (kg)	0.86	8.91	ns	ns	***	229.5	238.7	221.4
Dressing percentage (%)	0.51	4.24	ns	ns	**	50.2	50.2	49.5
Shrinkage percentage (%)	0.11	88.22	ns	ns	ns	1.41	1.27	1.55
Bone (%)	0.85	0.90	ns	**	***	21.1	21.0	21.2

R^2, coefficient of determination; *CV*, coefficient of variation. Different letters in the column indicate significant differences using the Tukey test ($P < 0.05$). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; *ns*, not significant

Table 3 Least squared means and significance levels for weights and percentages of carcass cuts in Brazilian cattle breeds

Traits	R^2	CV	Breed	Date of slaughter	Slaughter weight	Breed		
						Curraleiro	Nelore	Pantaneiro
Weights (kg)								
Front end	0.85	10.77	ns	ns	***	49.8	48.9	46.1
Hind end	0.84	8.56	*	ns	***	63.3[ab]	68.8[a]	62.8[b]
Hind end without rump and sirloin	0.87	8.16	***	ns	***	34.7[b]	40.4[a]	34.8[b]
Tenderloin	0.72	10.23	*	ns	***	1.55[ab]	1.70[a]	1.52[b]
Rump cap	0.65	13.00	ns	ns	***	1.55	1.62	1.46
Top sirloin	0.82	10.32	***	ns	***	2.93[b]	3.33[a]	2.76[b]
Bottom sirloin	0.56	7.06	ns	ns	ns	1.17	1.15	1.17
Eye of round	0.83	10.56	***	ns	***	2.00[b]	2.50[a]	2.02[b]
Knuckle	0.84	9.67	***	ns	***	4.17[b]	4.83[a]	4.12[b]
Topside	0.80	11.26	**	ns	***	6.94[b]	8.03[a]	6.60[b]
Silverside	0.86	10.74	***	ns	***	4.04[b]	4.57[a]	3.82[b]
Percentages (%)								
Front end	0.50	4.22	ns	**	**	0.43	0.42	0.42
Hind end	0.50	3.10	ns	**	**	0.57	0.58	0.58
Hind end without rump and sirloin	0.63	3.29	***	0.08	***	0.32[b]	0.33[a]	0.32[b]
Tenderloin	0.28	8.75	ns	ns	<0.10	0.015	0.014	0.014
Rump Cap	0.66	9.73	ns	**	ns	0.014	0.013	0.014
Top Sirloin	0.40	5.86	**	ns	ns	0.026[b]	0.028[a]	0.025[b]
Bottom Sirloin	0.19	14.21	ns	ns	ns	0.010	0.010	0.011
Eye of Round	0.65	6.69	**	*	ns	0.018[b]	0.021[a]	0.018[b]
Knuckle	0.48	6.12	**	*	ns	0.038[b]	0.040[a]	0.038[b]
Topside	0.27	9.42	*	ns	ns	0.063[ab]	0.067[a]	0.060[b]
Silverside	0.47	7.87	**	**	ns	0.035[b]	0.039[a]	0.035[b]

R^2, coefficient of determination; *CV*, coefficient of variation. Different letters in the column indicate significant differences using the Tukey test ($P < 0.05$). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; *ns*, not significant

Table 4 Least squared means and significance levels for cooking parameters and meat composition percentages in Brazilian cattle breeds

Traits	R^2	CV	Breed	Date of slaughter	Slaughter weight	Breed		
						Curraleiro	Nelore	Pantaneiro
pH	0.02	5.34	ns	ns	ns	5.65	5.54	5.62
Frozen weight (g)	0.28	15.29	0.06	ns	ns	4.61	3.94	4.39
Thawed weight (g)	0.30	15.91	0.06	ns	ns	4.30	3.66	4.17
Cooked weight (g)	0.22	19.38	0.06	ns	ns	2.99	2.57	3.09
Percentage of water lost in thaw (%)	0.22	32.23	*	ns	ns	0.07^a	0.07^a	0.05^b
Percentage of water lost in cooking (%)	0.15	16.99	*	ns	ns	0.30^a	0.30^a	0.26^b
Percentage of water lost in total (%)	0.20	14.84	**	ns	ns	0.35^a	0.35^a	0.30^b
Percentage of bone (%)	0.30	14.21	**	ns	**	17.3^b	20.2^a	18.4^{ab}
Percentage of muscle (%)	0.42	6.09	**	*	ns	57.5^a	53.0^b	56.1^a
Percentage of fat (%)	0.22	13.39	ns	ns	ns	25.1	26.7	25.4
Length (cm)	0.53	7.46	ns	*	***	139.8	136.3	140.8
Width (cm)	0.33	9.52	0.07	ns	***	66.9	60.6	64.4
Meat luminosity	0.58	7.00	***	ns	ns	39.6^b	42.9^a	37.2^b
Meat green to red spectrum	0.29	9.42	0.06	ns	ns	22.8	23.2	21.4
Meat blue to yellow spectrum	0.40	11.67	***	*	ns	15.5^{ab}	17.2^a	14.7^b
Meat chroma angle	0.35	9.06	*	**	ns	27.4^b	29.1^a	26.1^b
Meat hue angle	0.31	6.11	**	ns	ns	0.60^b	0.63^a	0.60^b
Shear force (kgf/cm^2)	0.17	29.4	*	*	ns	8.44^b	9.51^a	7.55^c
Taste panel								
Tenderness	0.25	18.77	*	*	ns	5.73^{ab}	5.41^b	5.94^a
Juiciness	0.30	10.34	***	ns	ns	6.02^a	5.57^b	6.52^a
Palatability	0.18	10.01	ns	ns	ns	5.97	5.90	6.32

R^2, coefficient of determination; *CV*, coefficient of variation. Different letters in the column indicate significant differences using the Tukey test ($P < 0.05$). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; *ns*, not significant

such as rump cap and tenderloin. As expected, the higher the percentage of second quality cuts, the lower the prime cuts.

For meat traits, pH negatively affected frozen, thawed, and cooked (Fig. 3c), inferring those with higher pH are more susceptible to weight loss between the freezing, thawing, and cooking processes. Low succulence and tenderness were related to high shear, high cooking, and total water losses. Juiciness and tenderness were also positively associated with taste. Higher shear was positively associated with higher meat green to red spectrum, meat blue to yellow spectrum, and meat luminosity.

Curraleiro and Nelore breeds showed a more heterogeneous pattern of conformations and physiological maturity than Pantaneiro (Fig. 4). Nelore were considered younger in general than Curraleiro, with the conformation of these two breeds considered better than Pantaneiro. Curraleiro had more marbling.

While the Pantaneiro clustered with the Curraleiro for growth and slaughter as well as for carcass traits, it clustered with Nelore for meat traits (Fig. 5).

Discriminatory traits varied when comparing the breeds 2×2. Nelore had lower dressing percentage than the two local breeds, with longer arms and legs, but these latter had shorter carcasses (Table 5). Conformation scores were higher for Nelore. Curraleiro and Pantaneiro had higher succulence and tenderness than the Nelore. Curraleiro showed higher marbling and water loss than Pantaneiro.

Discussion

Curraleiro Pé-Duro and Pantaneiro breeds are typically reared in small farms in Brazil's centre-west and Northeast, with few herds (Fioravanti et al. 2011). The Nelore breed and its crosses make up the major part of the beef cattle herd in Brazil (Brito et al. 2013; Lima et al. 2021), with the centre-west region being the most important (McManus et al. 2016) and herd sizes can be up to 10,000 animals or more. Genetic programs have been common with Nelore to increase weight at specific ages and to reduce the age at slaughter, and more recently, to reduce greenhouse gas emissions and improve meat quality (Lima et al. 2013; Terakado et al. 2015 Paterno et al. 2017; Silva et al. 2017; Magalhães et al. 2019). Curraleiro and Pantaneiro have not undergone artificial selection programs. The fact that the Nelore have a higher physiological maturity in the present study may be due to selection for earlier slaughter (Brunes et al. 2021).

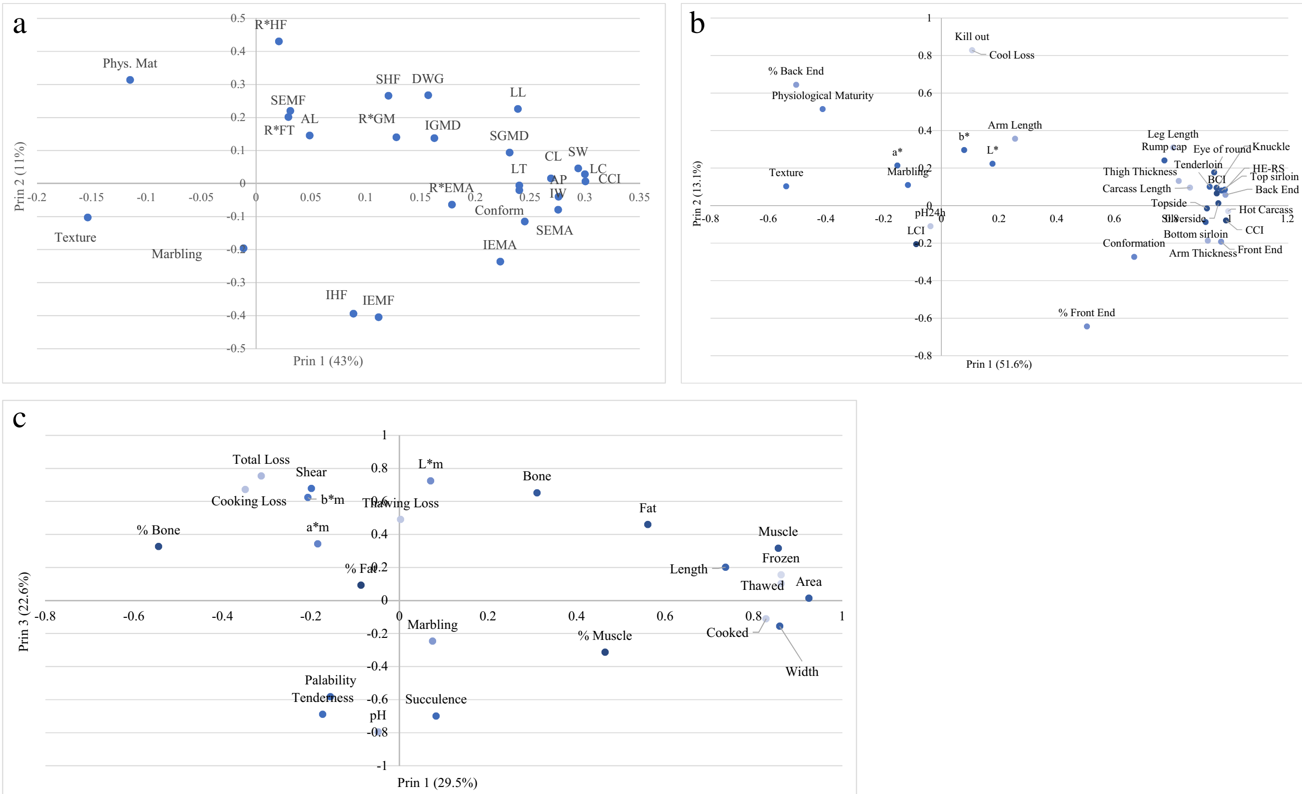

Fig. 3 First two principal components for growth and slaughter (**a**), carcass (**b**), and meat (**c**) traits in Brazilian cattle breeds. Phys. Mat, physiological maturity; Conform, conformation; R*HF, rate of growth of hip fat; SEMF, slaughter eye muscle fat; AL, arm length; R*FT, rate of growth of fat thickness; LL, leg length; SHF, slaughter hip fat; DWG, daily weight gain; R*GM, rate of growth of *gluteus medius*; IGMD, initial gluteus medius depth; SGMD, slaughter *gluteus medius* depth; CL, carcass length; SW, slaughter weight; conform, conformation; LC, left carcass; CCI, carcass compactness index; AP, arm perimeter; IW, initial weight; LT, leg thickness; R*EMA, rate of growth of eye muscle area; LEM, length of eye muscle; IEMA, initial eye muscle area; IGMD, initial *Gluteus medius* depth; SEMA, eye muscle area at slaughter; IEMF, initial eye muscle fat; IHF, initial hip fat; HE-RS, hind end without rump and sirloin; a*m, meat green to red spectrum; b*m, meat blue to yellow spectrum; DP, dressing percentage; SP, shrinkage percentage; Frozen, frozen weight; Thawed, thawed weight; Cooked, cooked weight

These locally breeds are usually reared in extensive systems and often under adverse conditions, with the scarcity of food and water and under high environmental temperatures (Cardoso et al. 2016). Unlike the animals in this study, Britto (1987) stated that the Curraleiro is a small animal, with adults weighing 380 kg for males and 300 kg for females. The slaughter weight observed in the present study showed that Curraleiro could be much larger, with weights on average 452 kg after they were kept in a feedlot for 112 days.

Nelore, although raised predominantly in Brazil, has a global impact on the beef market, considering that the country is one of the largest beef producers and exporters in the world. It has been subjected to genetic improvement programs for at least 40 years (Carvalheiro 2014), mainly focused in improving animal performance (Zuin et al. 2012; Paterno et al. 2017) and, more recently, in improving meat quality traits (Zuin et al. 2012; Silva et al. 2017; Magalhães et al. 2019). Even in the Pantanal (Oliveira et al. 2021) or Cerrado (Façanha et al. 2014), the locally adapted breeds are usually not considered for production or crossbreeding in commercial farms due to their perceived inferiority.

Carvalho et al. (2013, 2017) observed that Curraleiro Pé-Duro cattle, raised on pasture in the state of Piauí without supplementation, but with access to water and mineral salt ad libitum, presented variable average weight gain according to time of year and quality of pastures. These authors suggested that animals with additional food supply could perform better. This was confirmed in the present study where animals of the Curraleiro breed, when placed in feedlot with a diet containing concentrate, forage, mineral salt, and water ad libitum, despite initially presenting significantly lower live weight than Nelore, had a weight gain during the feedlot that led to non-significant differences in the slaughter weights of the two breeds. Another factor of supposed influence on similar slaughter weight may have been the thermoregulation capacity of these animals. Santos et al.

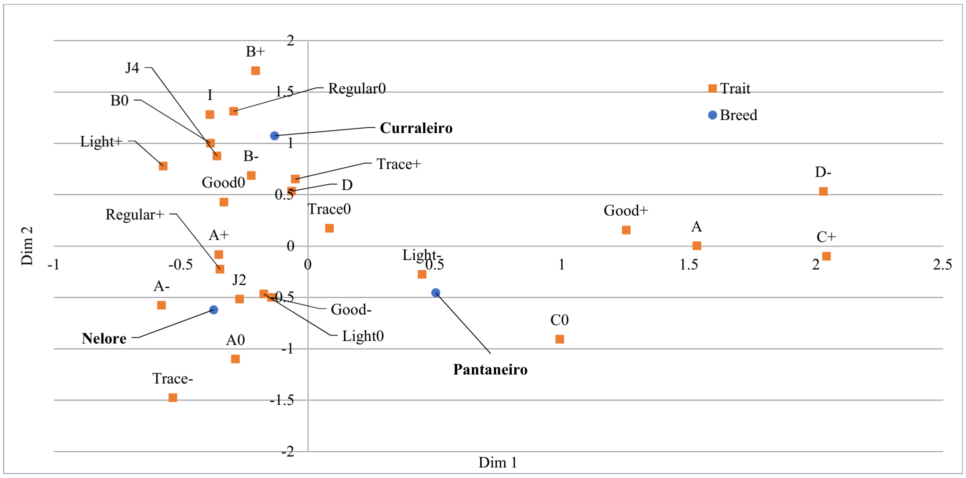

Fig. 4 Correspondence analysis for visual traits in Brazilian cattle breeds. Conformation: 12, very good+; 11, very good; 10, very good-; 9, good+; 8, good; 7, good-; 6, regular+; 5, regular; 4, regular-; 3, bad+; 2, bad and 1, bad-. Physiological maturity (cartilage ossification scale) where A — animal between 9 and 30 months; B — 30 to 42 months; C — 42 to 72 months; D — 72 to 96 months; and E — over 96 months; (+, 0 and -, - being younger and + being older). Marbling: trace-; trace0; trace+; light-; light0 and light+. SIF age: D — male or female bovine with teething milk without falling from the clamps; J2 — young male or female bovine with two permanent incisor teeth (tweezers), without falling from the first average of the first dentition; J4 — young male or female bovine with four permanent incisor teeth (forceps and first averages), without dropping the second average of the first dentition; I — male or female cattle with more than four and up to six permanent incisor teeth, without falling from the corners of the first dentition; A — male or female cattle with more than six incisor teeth in the second dentition

(2005ab) and Barbosa et al. (2014) found that both Nelore and Pantaneiro showed similar physiological characteristics and tolerance to heat. Cardoso et al. (2016) observed that Curraleiro Pé-Duro is a breed well adapted to challenging heat situations, and when compared to Nelore, the former presented lower rectal and surface temperatures.

Daily weight gain of Nelore, Curraleiro, and Pantaneiro was related to the initial weight. However, despite Nelore having a higher initial weight, the daily weight gain was similar for the three breeds. While there are no differences in weight at slaughter, there is a difference in weight distribution in the animal's body. Nelore cattle have undergone genetic selection programs, which may justify a greater weight of the hind end where nobler cuts are found (Luz et al. 2019). In the case of Curraleiro, its traditional use for pulling heavy loads probably leads to a more muscular front end. The cuts in which the Nelore had a higher percentage of weight, despite belonging to the back, are considered non-noble cuts. This demonstrates that, although they are not regarded as commercial breeds, Curraleiro and Pantaneiro have similar characteristics to Nelore, an important factor to promote their use in commercial meat production.

Under similar management and with a supply of higher quality food, all three breeds showed good carcass conformation and a similar pattern of marbling. A similar conformation pattern between locally adapted breeds and *B. indicus* can be explained by the fact that, although these animals adapt well to tropical and subtropical regions, they usually present carcasses with less marbling than commercial *B. taurus cattle*. This is mainly because of a reduction in the volume of intramuscular adipocytes (Cooke et al. 2020) as a mechanism to improve their thermotolerance. The relationship between concentrate supply and increased marbling (Strachan et al. 1993; Duckett et al. 2013; Rutherford et al. 2020) suggests that the improvement in the productive capacity of local breeds is an aspect that confers desirable carcass and meat characteristics on these animals.

Although there is no difference between slaughter weight and daily weight gain, Nelore had a higher bone percentage and lower muscle percentage when compared to Curraleiro and Pantaneiro, giving a lower carcass yield. This shows that weight at slaughter does not necessarily indicate a higher muscle proportion. It is common to find better carcasses in *Bos taurus taurus* cattle compared with *Bos taurus indicus* (Smith 2019; Cooke et al. 2020). The percentage values of bones, muscles, and fat estimated in this study are below those described by Climaco et al. (2006), Perotto et al. (2000), and Barcellos et al. (2017). The observed percentages contrast with Moura et al. (1998), identifying 20.22% for bone, 53.03% for muscle, and 26.74% for fat after feedlot for 135 days.

Most cattle production in Brazil is at pasture, but feedlot has been increasing in recent years (Lobato et al. 2014; Millen et al. 2013; Romanzini et al. 2020). In a comparative study, Cooke et al. (2020) reported that *B. taurus* grazes for less time

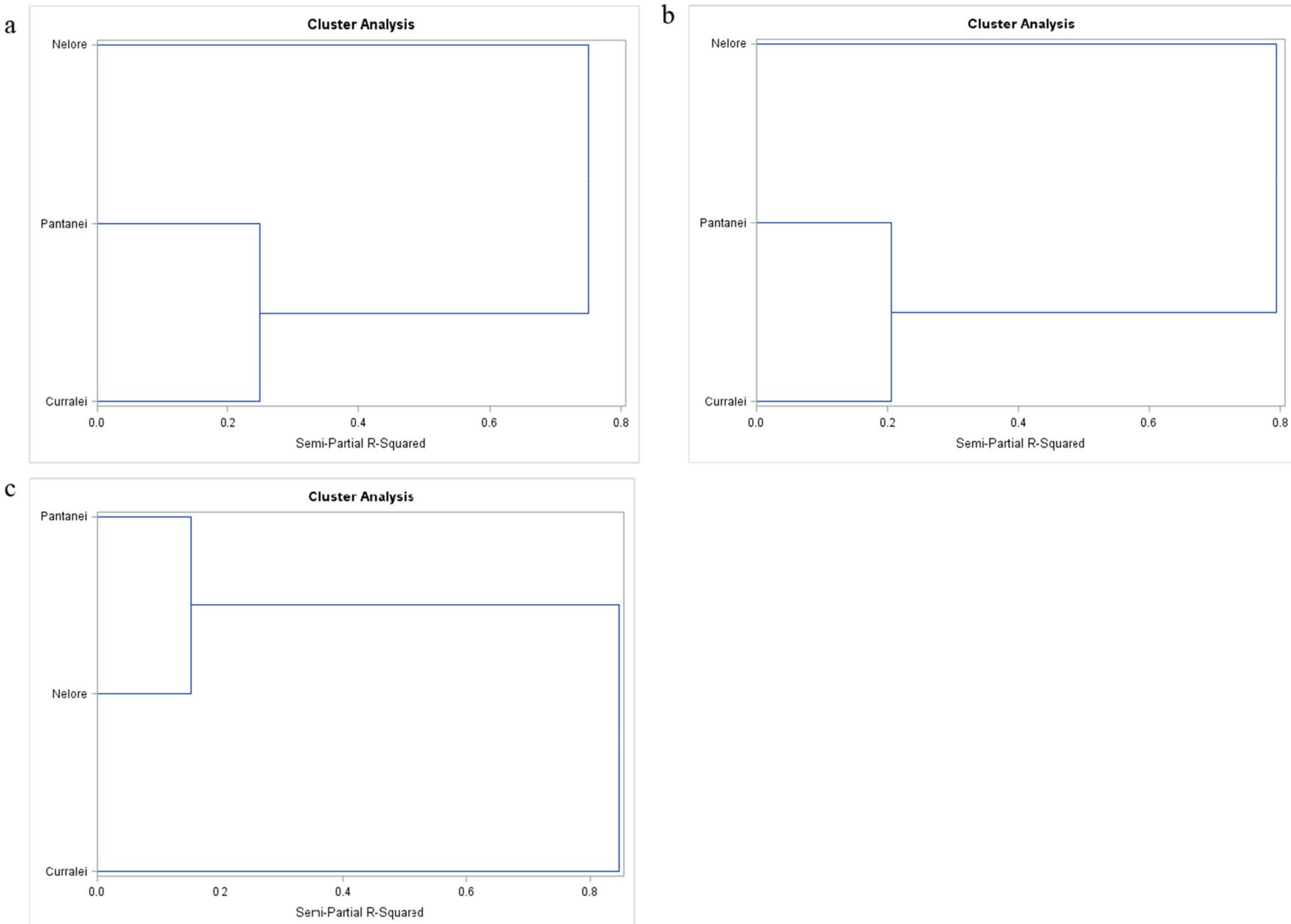

Fig. 5 Cluster analysis for growth and slaughter (**a**), carcass (**b**), and meat (**c**) traits in Brazilian cattle breeds. Pantanei, Pantaneiro; Curralei, Curraleiro Pé-Duro

Table 5 Significant traits from step by step two breed discriminatory analysis in Brazilian cattle breeds

	Pantaneiro vs Curraleiro	Pantaneiro vs Nelore	Curraleiro vs Nelore
Growth and slaughter	Rate of growth of fat thickness Initial weight Initial eye muscle fat	Rate of growth of hip height Initial hip fat Initial eye muscle fat	Initial weight Initial hip fat
Carcass traits	Conformation Carcass length Carcass luminosity pH 24 Carcass weight	Leg length Physiological maturity Carcass blue to yellow spectrum Carcass length Arm length Conformation Knuckle pH 24 Hind end without rump and sirloin	Eye of round Knuckle Conformation Carcass length Leg length Leg compactness index
Carcass cuts	Percentage of water lost in total Juiciness Marbling Tenderness Palatability	Bone Meat luminosity Thawed weight Meat hue angle Meat blue to yellow spectrum Tenderness Juiciness	Bone Meat luminosity %Muscle Palatability Meat hue angle Meat blue to yellow spectrum

than *B. indicus* and gains less weight until weaning but have a greater average daily weight gain when in the feedlot. Such facts may explain the divergent values found in the present study and by Britto (1987), whereby Curraleiro due to compensatory growth converted its lower initial weight to a final weight within the average of other breeds in feedlot.

Curraleiro and Pantaneiro showed a greater eye muscle area at slaughter than Nelore and had a higher compactness leg index. This is because they had shorter fore and hind limbs. According to Sousa et al. (2009), the carcass compactness index and the leg compactness index are indicators of a greater or lesser meat production specialization by the genetic groups. Better carcass conformation is an indication that they have better muscle distribution over the skeleton. This is important for marketing, as carcasses with better conformation are more appreciated by slaughterhouses because, theoretically, they have better quality cuts and, consequently, greater market acceptance (Fernandes Júnior et al. 2013).

While average carcass pH at 24 h after slaughter was within ranges seen by other authors, whereby a value ≤5.8 is desirable (Viljoen et al. 2002; Wulf et al. 2002), Curraleiro animals showed higher values. pH depends on lactic acid accumulation due to adenosine triphosphate production, using glycogen as a source of glucose. A comparative survey between bovine breeds carried out by Mendonça et al. (2017) observed that the final pH of the Zebu breed animals was 5.52±0.01, a value lower than that found in this study.

The greater capacity to retain water from Curraleiro could be associated with its pH values. A previous study demonstrated that high and low pH values were related to tenderer meats rather than intermediate pH, with variability in protein patterns and protein degradation rates (Wu et al. 2014). According to Silva et al. (1999), meats with higher pH are associated with a greater degree of tenderness, with a better final tenderness possibly associated with a greater water retention capacity. This may explain the higher values of percentage of water lost in thaw, percentage of water lost in cooking, and percentage of water lost in total in the Curraleiro. Hopkins et al. (2014) also found that a decrease in drip loss was accompanied by an increase in final pH.

The final pH values can be influenced by several variables, from sex, age to the season in which the animals are slaughtered. Węglarz (2010) found slightly lower pH values in cooler seasons, having a considerable increase when compared to bulls slaughtered in the summer, suggesting that external factors such as high temperatures generate more pre-slaughter stress. Ijaz et al. (2020) suggested that the reduced glycogen content of DFD meat favours spoilage by microorganisms, decreasing shelf life. The mean value seen in the present study (5.7) is therefore acceptable, but range shows animals reaching values of 6.43.

These results may be associated with situations of thermal stress or pre-slaughter management. Pérez-Linares et al. (2015) showed that changes in the handling of pre-slaughter animals such as transport at times of milder temperature, short waiting period at the slaughterhouse, protected from the sun, influenced the pH values.

The Warner-Bratzler shear force measures the maximum force to cut a meat sample (Novaković and Tomašević 2017), with the Nelore meat the hardest to break. Compared to other breeds (Simmental and the Simmental x Nelore cross), Bianchini et al. (2007) observed that Nelore cattle also had less tender meat, but the pH values found after 24 h of slaughter were lower than those observed in the present study. This is in line with Fidelis et al. (2017), in which the pH was slightly above 5.5. The cooking loss for Nelore was 23.33%. For the shear force, using the Warner Bratzler shear force device, they found a value of 4.98 kgf/cm^2 24 h after slaughter for fresh Nelore meat, a value below that shown when comparing naturalised and Nelore breeds.

Zebu genes can decrease tenderness through muscle structure, physiology, and enzymatic activity (Lawrie 2005). Rossato et al. (2010) obtained shear force of grilled steak of the *Longissimus thoracicis* of 36-month-old Nelore of about 9.13 kg and 7.86 kg for Angus bulls. Nunes et al. (2011), comparing meat quality between different *Bos taururs taurus* breeds and their crosses with Nelore and Caracu, found higher shear force values for Nelore. The higher shear force from Nelore meat could be associated with a higher slaughter weight. According to Gularte et al. (2000), the slaughter weight can influence the tenderness of the meat because, with the increase in weight, there are changes in collagen and myofibrillar proteins that make the meat harder.

Despite differences in the sensitivity of sensory panels, when compared to more objective tests, Destefanis et al. (2008) compared the shear strength test results with the consumer's ability to differentiate different levels of softness in a sensory panel. More than 55% of consumers differentiated between tough and intermediate and soft meats, and about 62% differentiated between tender, medium, and hard meats.

Carvalho et al. (2017) found that meat from Curraleiro was redder than from Nelore and crossbred (50% Curraleiro + 50% Nelore), but no significant differences between breeds for the other quality traits. While these authors collected data from several herds in Piaui state, the present study looked at animals reared under the same management system for 112 days pre-slaughter.

The colour of the carcass meat, defined by pigments, depends on tissue composition and muscle structure (Weglarz 2010). The pigment myoglobin is responsible for the colour of the meat that, when exposed to air, forms the most intense red-coloured oxymyoglobin complex. Continuous exposure causes the colour to turn brownish red, reddish-brown, and brownish-green (Pearson and Dutson 1994). In an experimental study in which luminosity and marbling tests were compared to results observed in the sensory panel, Jackman et al. (2009) obtained results showing that the colour and marbling characteristics of the *Longissimus thoracis* provide reliable information on the quality of beef.

For the studied breeds, there was no significant difference for these carcass parameters. Luminosity (L*) and redness (a*) are marginally lower than those reported by Muchenje et al. (2009), while yellowness (b*) is within the reported range. According to these authors, the yellow colour comes from beta-carotene contained in forages. Low L* values may be caused by increased myoglobin, decreased muscle glycogen, or both, as well as yellow fat (Priolo et al. 2001).pH had an important effect on the colour, taste, and texture of food. In meat with higher pH, the myoglobin associated with muscle structure absorbs light rather than reflecting it, which leads to darker looking meat (Andrés-Bello et al. 2013). For the CIEL*a*b* system, L* = 0 indicates black, and L* = 100 indicates diffuse white, a* is the green (negative) to red (positive) space, and b* varies from blue (negative) to yellow (positive). The meat examined in this study was seen to be positive for all values. According to Muchenje et al. (2009), normal values of luminosity (L*) in beef range between 33.2 and 41.0, redness (a*) ranges between 11.1 and 23.6, and yellowness ranges between 6.1 and 11.3. At pasture in Brazil, results show L* ranging from 32.3 to 39.1, a* ranging from 19 to 23.7, and b* from 4 to 9.3 (Rossato et al. 2010, Devincenzi et al. 2012, Amatayakul-Chantler et al. 2013). Our results showed wider ranges, with b* being higher than those found in the two previous studies, especially for Nelore.

Lima et al. (2021) showed that breed distribution is affected by climatic, technical, and socioeconomic factors. Under climate change, we can expect changes in breed distribution (McManus et al. 2016). As the native-adapted breeds used in this study were not selected for carcass traits, as in the case of the Nelore breed (Carvalheiro 2014), improving existing qualities in locally adapted breeds can bring productive and sensory benefits. Therefore, the demand for improved product quality can use genetic features of locally adapted breeds that combine traits from *Bos taurus* (meat quality) and *Bos indicus* (heat tolerance) cattle. The present study shows that technological changes in animal rearing can potentialize the use of local breeds.

In this line, multivariate analysis simultaneously analyses associated experimental variables involving reduction processes, optimisation, sorting, and classification of multidimensional data (Gonçalves and Fritsche-Neto 2012). In this study, the multivariate analyses showed clear breed definition, with important traits being leg length, physiological maturity, carcass length, conformation, rump cap, top sirloin, and eye of round. The Nelore animals were larger, more mature, with longer legs but more bone. On the other hand, the local breeds Curraleiro and Pantaneiro were more compact, showing superior meat quality (succulence, palatability, marbling, tenderness), especially the Curraleiro.

Conclusions

The locally adapted *Bos taurus ibericus* breeds, when subjected to adequate environmental and dietary conditions, showed great productive potential comparable to Nelore, the largest commercial breed. The fact that local animals have not gone through genetic improvement programs combined with the growth, slaughter, carcass, and meat results observed in this study demonstrates that Curraleiro Pé-Duro and Pantaneiro may have their desirable characteristics enhanced if genetic improvement programs are adopted. These animals can have an economically viable production and generate better quality meat for new market niches.

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Author contribution MCPB, MCSF, AAE, RSJ, AFR, GLDF, JR, and MFOC conceived, designed the research work, and contributed new methods or models; DC, KML, CSP, RGVJ, NAO, PLPR, and GLC performed research; MCPB and MCSF wrote the manuscript draft; VP and CM did the statistical analysis and review and editing the manuscript draft. All authors read and approved the final manuscript.

Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval Animal care throughout the study followed animal welfare protocols for animal production and approved by Universidade Federal de Goiás Animal Experiments Local Ethics Committee.

Conflict of interest The authors declare no competing interests.

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