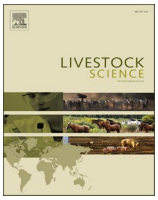
Livestock Science 243 (2021) 104374

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci



Breed direct, maternal and heteros is effects due to Angus, Caracu, Hereford and Nelore on carcass and meat quality traits of cull cows

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HIGHLIGHTS

- The Caracu breed can be used in crossbreeding with Angus to take heterosis and also to improve meat tenderness.
- The carcass weight and meat tenderness can be obtained by crossing taurine breeds.
- The cross between taurine and Zebu breeds leads to higher carcass yield and ribeye area.

ARTICLE INFO

Keywords:
Genetic effect
indicine
meat tenderness
taurine

ABSTRACT

Meat is an end-of-life by-product from cows that fail to reproduce. Thus, the objective of this study was to determine breed additive and heterosis effects on carcass traits and characteristics of the meat from beef cows raised in southern Brazil. Angus (A), Hereford (H), Nelore (N), A × H (AH), H × A (HA), A × N (AN), N × A (NA) and Caracu (C) × A (CA) cows were slaughtered when they did not become pregnant for a second season. Slaughter weight (SW), hot carcass weight (CW), carcass yield (CY), ribeye area (REA), pH value, water holding capacity (WHC), tenderness (MT), moisture (MM), ether extract (EE), carcass fat score (CFS), marbling score (MS), subcutaneous fat thickness (SFT) and L*, a* and b* measures of color of the fat and meat color were evaluated. Taurine x taurine heterosis effects increased SW and to a lesser degree CW, and improved MT. Taurine x indicine heterosis increased REA, a* and b*, and decreased L* and EE. Direct breed additive effects attributable to A increased SW but decreased CY and thus had no detectable effect on CW. Direct breed additive effects of C decreased CFS, SFT, CY and MM. Finally, direct breed additive effects of H and C similarly decreased CFS and SFT. Maternal breed additive effects were generally unremarkable except for slight effects of H reducing a* and b*. Thus, SW and MT may be increased by crossbreeding with taurine breeds, while CY and REA can be increased by using zebu-influenced cattle. The desirable carcass composition of CA cows and their MT and color comparable to taurine crossbred cows make this crossbred cow a viable alternative for producers in southern Brazil.

1. Introduction

The benefits of beef cattle crossbreeding systems, mainly related to heterosis and breed complementarity, are already well understood. The scientific literature documents improvements in reproduction, growth, maternal ability, carcass and meat quality traits through the use of crossbreeding (Cundiff, Gregory, & Koch, 1974; Perotto et al., 2000; Vaz et al., 2001; Rodrigues et al., 2014; Leal et al., 2018). The genetic effects that give rise to these benefits can be easily and efficiently estimated from multi-breed data sets through the use of multiple regression (Robison et al., 1981; MacNeil et al., 1982). However, commercial producers remain uncertain about crossbreeding due to the lack of genetic information pertinent to the performance of various genotypes in some specific environments such as the subtropics. Identifying cows that produce better meat quality is important because 46.1% of the cattle slaughtered in Brazil are cows and their meat is primarily supplied to the

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https://doi.org/10.1016/j.livsci.2020.104374
Received 24 July 2020; Received in revised form 7 December 2020; Accepted 8 December 2020
Available online 11 December 2020
1871-1413/

domestic market (Anualpec, 2018). Previous work on growth curves of straightbred and crossbred cows involving Angus, Caracu, Hereford and Nelore germplasm has shown the effects of breed additive and heterosis effects on mature weight to be relatively small (Mendonça et al., 2019). Thus, the objective of this study was to evaluate direct and maternal breed additive effects and heterosis on carcass and meat traits for the aforementioned germplasm. The data arose from cows that were culled after failing to become pregnant in a production system that was typical of Southern Brazil.

2. Material and methods

All experimental procedures that involved animals were approved by the Committee for Ethics in Animal Experimentation from the Federal University of Pelotas (Pelotas, Brazil; Process CEEA N°. 8250-2015). The study was conducted at Embrapa South Livestock Center of the Brazilian Agricultural Research Corporation, near the city of Bagé, Rio Grande do Sul, Brazil. The region has a subtropical climate, with an average annual temperature of 17.6°C, ranging between 12.5°C in June and 24°C January, and with extremes of –4°C and 41°C. Average annual rainfall is 1,350 mm, with approximately 25%, 34%, 25%, and 16% occurring in autumn, winter, spring, and summer, respectively.

The data originated from 169 cows of the following breed groups: 28 Angus (A), 14 Hereford (H), 12 Nelore (N), 16 1/2A × 1/2H (AH), 29 1/2H × 1/2A (HA), 15 1/2A × 1/2N (AN), 24 1/2N × 1/2A (NA) and 31 1/2Caracu (C) × 1/2A (CA). Breed of sire was first identified in crossbred groups. Sires were chosen to represent commercial seedstock from locally available semen and clean-up bulls. The cows were born between 2006 and 2009, sired by 14 A, 8 H, 8 C, and 9 N bulls that were mated to A, H and N cows. Within a year, cows that had failed to become pregnant for the second time in their reproductive live were finished on grass in the same paddock and were slaughtered when they had at least 3 mm of subcutaneous fat on the longissimus thoracis muscle as measured with ultrasound (ALOKA SSD-500 model, with a 17.2 cm, 3.5MHz linear probe model UST-5044). The images were captured and analyzed using the Lince® software. The average slaughter age (years) of each genetic group were as follows: A = 7.54; H = 7.68; N = 7.27; CA = 7.61; HA = 8.25; AH = 7.08; NA = 8.88 and AN = 7.96. On the day before slaughter the cows were weighed using a Tru-Test XR3000 digital scale (Tru-Test Group, Auckland, New Zealand), with a maximum capacity of 1,500 kg and precision of 100 g. The cows were fed exclusively on oats (*Avena strigosa L.*) and ryegrass (*Lolium multiflorum Lam.*) that was grown in cultivated pastures.

The amount of carcass fat was subjectively scored (CFS) immediately after slaughter on a scale from 1 to 5, where 1 represents a carcass devoid of fat and 5 represents an overly fat carcass. Carcass yield (CY) was determined as the ratio of warm carcass weight (CW) to the pre-slaughter weight (SW), multiplied by 100.

After slaughter and being cooled at 5° C for approximately 24 h, carcass pH was measured in the Longissimus thoracis using a penetrating electrode (LoT406-M6-DXK-S7/25, Mettler-Toledo). The pH meter was calibrated using two buffer solutions as standards (pH 7.00 and pH 4.01). The pH meter was the SevenGo Duo model of Mettler-Toledo with automatic functions for buffer recognition, temperature compensation and data capture from the electrode. For the temperature compensation was carried out through a probe that was used both in the calibration and the reading of the samples. Samples of the Longissimus thoracis were collected at the interface of the 12th and 13th ribs. These samples were taken to the Laboratory of Meat Science and Technology of Embrapa Livestock South in Bagé-RS, vacuum-packed and immediately transferred to the freezing tunnel at -38°C. They were stored frozen at -20° C between 4 and 8 months until they were processed.

The day before each sample was analyzed it was thawed for 24 h at 4°C. Colors of the fat and meat were measured with a Minolta Konica CR-410 colorimeter, calibrated to a white standard, using the International Commission of the Color System of I'Eclairage (1976). The standard observer was to represent an average human's chromatic response within a 2° arc inside the fovea (Commission International De I' Eclairage, 1932), with D65 illuminant and 50 mm aperture and an open cone. Color was recorded 30 minutes after cutting the sample perpendicular to the long axis of the muscle fibers. These colors were quantified using scales for lightness [L* 0 = black, 100 = white], redness (a*: positive values indicate the intensity of red and negative values indicate the intensity of green) and yellowness (b*: positive values indicate the intensity of yellow and negative values indicate the intensity of blue). Subcutaneous fat thickness (SFT) was measured with a digital caliper. The degree of marbling was determined through subjective scores that correspond to a percentage of intramuscular fat: traces (<2.30%), slight (2.30 to 3.99%), small (4.00 to 5.79%), modest (5.80 to 7.69%), moderate (7.70 to 9.89%), slightly abundant (9.90 to 12.10%) or moderately abundant (>12.10%) (USDA, 1997). The rib-eye area (REA) was measured by tracing the contour of the muscle on acetate and scanning the tracing with Adobe Acrobat®.

Tenderness (MT) was evaluated as shear force. Steaks of approximately 3 cm thickness were obtained as cross-sections of the Longissimus muscle. The samples were deboned and roasted on an electric oven rack at a temperature of 180°C until the temperature in the center of the steak reached 71°C. After cooling the samples, seven 1.27 cm cylinders were cut from the sample and MT was measured with a "TA. XTPlus Texture Analyser (Stable Micro Systems and Software Ezponent)" equipped with "Warner-Bratzler" meat cell (AMSA, 1995).

Next, uncooked samples were cut into 2g aliquots. Water holding capacity (WHC) was determined by placing a 2 g of sample between sheets of filter paper, and placing a 10 kg weight atop the sample for a period of 5 minutes. The WHC was estimated from the following equation (Hamm, 1960):

$$WHC(\%) = \frac{W2}{W1} \times \ 100$$

where: WHC = water holding capacity, W2 = final weight (after loading) and W1 = initial weight (before loading). To evaluate the moisture content of the meat (MM), 1.5 g sample of previously ground meat was placed in a porcelain crucible which was then dried in oven with air circulation at 100°C ± 2°C until weight stasis was attained (AOAC, 1991). The MM determined from the difference between the weights before and after drying as:

$$MM(\%) = \frac{W1 - W2}{W1} \times \ 100$$

where: MM = moisture content, W1 = sample weight before drying, and W2 = sample weight after drying.

Fat content was measured using 2.5 g samples of the previously ground and dried meat. These samples were placed in 2μm porosity nylon sachets, loaded in crucibles, and oven-dried for 3 hours at 105°C. Then, the samples were placed in desiccator containing silica for 15 minutes. Next the sachets containing the samples were extracted for 60 minutes in petroleum ether in an Ankon XT-10 Fat Analyzer. After extraction, they were again dried 30 minutes at 105°C and desiccated with silica for another 15 minutes (AOCS, 2009). The percentage of ether extract (EE), expressed in dry matter, was determined as:

$$EE(\%) = \frac{S1 - S2}{S1} \times \ 100 - MM(\%)$$

where: EE = ether extract, S1 = sachet weight before extraction and S2 = sachet weight after extraction.

The data were analyzed in two ways using R (R Core Team, 2018). First, the dependent variables (Y_{ijklm}) were modeled as:

$$Y_{ijklm} = \mu + BG_i + CS_j + \mathrm{CY}_k + \mathrm{SD}_l + e_{ijklm}$$

where: Y_{ijkl} = a recorded measurement of a carcass or beef trait from the mth,cow, μ = the overall mean, BG_i = the fixed effect of the ith breed

group, CS_j = the fixed effect of the j[th] season of birth ("Early" = birth of the calf in September and October and "Late" =November and December), CY_k = the fixed effect of the k[th] birth year (2006 to 2009), SD_l= the fixed effect of the slaughter date, and e_{ijklm} = the random residual effect attributable to the l[th] cow.

Thereafter, the BG effects were replaced by a series of linear regression effects as specified in the following model:

$$BG_i = b_1 g_A^i + b_2 g_C^i + b_3 g_H^i + b_4 g_A^m + b_5 g_H^m + b_6 h_t^i + b_7 h_z^i$$

where g_j^i represents the direct breed additive effect for the subscripted breed (A = Angus, C = Caracu, and H = Hereford), g_j^m represents the maternal breed additive effect for the subscripted breed of dam and h^i represents the assumed increase in heterozygosity in crossbreds relative to straightbreds (Gregory and Cundiff, 1980). The heterosis effects were further partitioned to those resulting from combinations of alleles from a taurine breed and an indicine breed (subscript z) or from two taurine breeds (subscript t). This formulation of the model required restricting the direct and maternal breed additive effects for Nelore to zero in order to obtain a unique solution. The genetic expectations of each BG are shown in Table 1. Finally, the parameters b_1, b_2, b_3 = direct breed additive effects of A, C and H, respectively; b_4, b_5 = maternal breed additive effects of A and H coefficients, respectively; b_6, b_7 = individual heterosis effects expressed in crosses of taurine breeds and in taurine by indicine breed crosses, respectively. Predicted values were estimated by standard regression methods applying the R/base contrast function to the parameter estimates (O'Callaghan et al., 2019).

3. Results

Average slaughter weight (SW) was greater for HA, AH and CA cows than for the N and NA cows (Table 2). This pattern was also observed for carcass yield (CY), but the differences among breed groups were not significant ($P>0.05$). Despite N and NA cows being lighter at slaughter, they had greater CY ($P<0.05$). Additive effects attributable to A increased slaughter weight (SW) but decreased carcass yield (CY) and thus had no detectable effect on carcass weight (CW) (Table 3). Although N cows had less ribeye area (REA), the NA and AN crossbred cows were had greater REA due to the significant positive taurine x indicine heterosis effect (Table 3). There were no significant differences among breed groups for the carcass fat score (CFS), subcutaneous fat thickness (SFT) and marbling score (MS) (Table 4), despite significant negative effects of g_C^i and g_H^i on CFS, and SFT (Table 5).

The pH of the meat samples in this study were ≤5.8, a threshold above which Viljoen et al. (2002) and Wulf et al. (2002) suggested could compromise meat quality. There we no significant differences in pH among the breed groups ($P>0.05$; Table 6). There were also no differences among the breed groups in WHC ($P>0.05$). However, the meat from these breed groups varied in tenderness with CA being most tender, meat from A, AH and HA being intermediate, and the meat from H, N, AN and NA being least tender (Table 6). The CA cross also produced the meat having the lowest moisture content (MM). The genetic effects g_A^i and h_t^i resulted in significantly more tender meat (Table 7). The h_z^i effect indicated reduced EE content of the meat from zebu crosses compared to the parental means.

Effects of h_t^i indicated reduced L*, increased a*, and together with g_H^i, reduced b* for the color of fat (Table 8). In addition, negative g_H^m effects on the meat color metrics a* and b* were observed. The g_A^m effect on b* also being negative for meat color. No significant genetic effects on L* were observed for the color of either fat or meat from the various breed groups (Table 9). When the genetic effects were manifest as breed group means, fat from H and HA had lower values of a* than fat from AN with the other breed groups being intermediate. Fat from H likewise had the lowest values of b*, with fat from NA and AN having the highest values, and the other breed groups being intermediate. Meat from the various breed groups was similar in a* parameters. However, b* coloration was lowest for H and AH and highest for AN, and again the remaining breed groups were intermediate.

Table 1
Genetic effects coefficients for breed groups in the study: g_j^i = individual additive effect, g_j^m = maternal additive effect, h_j^i= individual heterosis; with subscripts A = Angus, C = Caracu, H = Hereford, N = Nelore, t = taurine breed crosses, and z_z^i= taurine-indicine crosses.

Breed group[1]	Genect effects								
	g_A^i	g_C^i	g_H^i	g_N^i	g_A^m	g_H^m	g_N^m	z_z^i	h_t^i
Angus (A)	1	0	0	0	1	0	0	0	0
Hereford (H)	0	0	1	0	0	1	0	0	0
Nelore (N)	0	0	0	1	0	0	1	0	0
AH	0.5	0	0.5	0	0	1	0	0	1
HA	0.5	0	0.5	0	1	0	0	0	1
NA	0.5	0	0	0.5	1	0	0	1	0
AN	0.5	0	0	0.5	0	0	1	1	0
CA	0.5	0.5	0	0	1	0	0	0	1

[1] Breed of sire is identified by the first symbol in crossbred groups.

4. Discussion

Crossbreeding systems in the beef cattle industry aim to exploit heterosis and complementarity to improve the efficiency of production under different environmental conditions (Koch et al., 1976; Perotto et al., 2000, Prayaga, 2003). In the present study, additional results were generate regarding the beef production from cull cows to inform breeding decisions at the margin between the tropical and temperate climatic zones in places like the gulf coast of the USA, Southern Brazil an sub-Saharan Africa. On the present study, the direct breed additive effect attributable to A, and the taurine x taurine individual heterosis effect were found to increase SW. The breed additive effect on CY offset those on SW and thus only the taurine x taurine individual heterosis effect increased CW. In contrast to the present results, DeRouen et al. (1992) and Williams et al. (2010) observed greater effects of heterosis on CW and REA in taurine x zebu crosses than in taurine x taurine crosses. It has also been observed that indicine cows have greater CY than taurine cows due to differences in the non-carcass components of SW (Wheller et al., 1996; Restle et al., 1999; Lopes et al., 2012). The observed significance of the taurine x indicine heterosis effect on REA may be a consequence of greater genetic distance between the respective breeds (Roso & Fries, 2000). Because CW and REA are highly correlated, some studies suggest adjustment of REA to a constant carcass weight (Leme et al., 2000, Restle et al., 2002, Arboitte et al., 2004, Pacheco et al., 2005). This adjustment would potentially mask the effects of heterosis (Alenda et al., 1980) and the present results were thus obtained without such an adjustment.

Traits that are indicative of subcutaneous fat deposition were affected by negative breed additive effects of C and H. However, these effects were not manifest as significant differences among breed groups. Marbling score was unaffected by the genetic effects and the breed groups did not differ. These results may be a consequence of the use of ultrasonically measured subcutaneous fat depth as a criterion for slaughter to insure that the cows had satisfactory finish at harvest. Historical adaptation of N cattle to restricted nutritional environments may reduce their nutritional requirements (Calegare et al., 2009) and thus provide an advantage in the extensive conditions of the present study. Previously Ríos-Utrera et al. (2006) and Williams et al. (2010) observed significant effects of heterosis on MS.

Lower WHC implies a reduction in the dining experience due to a lack of juiciness in drier and less tender meat (Reardon et al., 2010). However, in the present study, the WHC was unaffected by the genetic effects, possibly because the pH values were likewise unaffected and within the desirable limits (Viljoen et al., 2002; Wulf et al., 2002).

Table 2
Estimated breed group means for slaughter weight (SW), hot carcass weight (CW), carcass yield (CY) and ribeye area (REA).

Breed group[1]	SW (kg)			CW (kg)			CY (%)			REA (cm^2)		
Angus (A)	540	±9.47	bc	260	±6.02	a	46.9	±0.46	a	69.60	±1.61	ab
Hereford (H)	543	±13.35	abc	259	±8.90	a	47.2	±0.68	ab	74.00	±2.27	ab
Nelore (N)	485	±14.52	a	247	±9.36	a	49.9	±0.72	b	65.40	±2.47	a
CA (Caracu x A)	560	±8.42	c	272	±6.13	a	47.0	±0.48	a	73.90	±1.49	ab
HA	564	±9.25	c	264	±6.11	a	46.9	±0.48	a	73.00	±1.69	ab
AH	567	±13.23	c	277	±8.51	a	47.7	±0.65	ab	72.80	±2.35	ab
NA	510	±10.91	ab	257	±6.35	a	49.7	±0.49	b	75.30	±1.82	b
AN	542	±13.33	abc	247	±9.36	a	48.7	±0.63	ab	76.10	±2.15	b

[1] Breed of sire is identified by the first symbol in crossbred groups. Means within column not sharing a common suffix are significantly different (P<0.05) by the Tukey test.

Table 3
Estimates and standard errors of breed additive and heterosis effects on for slaughter weight (SW), hot carcass weight (CW), carcass yield (CY) and ribeye area (REA).

Genetic effect[1]	SW (kg)		CW (kg)		CY (%)		REA (cm^2)	
g_A^i	85,88	±23,81***	23,61	±14,74	-3,99	±1,13***	5,00	±3,93
g_C^i	35,39	±28,88	15,29	±19,43	-2,28	±1,51*	8,79	±5,05
g_H^i	42,75	±23,61	-1,69	±15,31	-2,51	±1,18	7,09	±4,07
g_A^m	-31,39	±16,71	-10,36	±10,07	0,95	±0,77	-0,80	±2,70
g_H^m	14,59	±20,07	14,45	±12,90	-0,22	±1,00	1,51	±3,47
h_z^i	13,71	±12,39	9,03	±7,64	0,82	±0,59	8,20	±2,09***
h_t^i	45,89	±12,03***	16,45	±7,84*	-0,68	±0,60	2,33	±2,07

*** (P<0.001); ** (P<0.01); * (P<0.05).
[1] g^i = individual additive effect, g^m = maternal additive effect, h^i= individual heterosis; with subscripts A = Angus, H = Hereford, C = Caracu, z = taurine-indicine crosses and t = taurine breed crosses.

Table 4
Estimated breed group means for carcass fat score (CFS), subcutaneous fat thickness (SFT) and marbling score (MS).

Breed groups[1]	CFS (scale)			SFT (mm)			MS (scale)		
Angus (A)	3.69	±0.15	a	5.96	±0.47	a	2.07	±0.14	a
Hereford (H)	3.10	±0.21	a	4.26	±0.68	a	1.88	±0.21	a
Nelore (N)	3.98	±0.23	a	6.25	±0.75	a	1.75	±0.21	a
CA (Caracu x A)	3.26	±0.13	a	4.12	±0.45	a	2.22	±0.14	a
HA	3.33	±0.15	a	4.61	±0.47	a	1.79	±0.15	a
AH	3.74	±0.21	a	6.25	±0.65	a	1.96	±0.21	a
NA	3.70	±0.17	a	6.31	±0.56	a	1.62	±0.17	a
AN	3.81	±0.21	a	5.36	±0.70	a	1.69	±0.20	a

[1] Breed of sire is identified by the first symbol in crossbred groups. Means within column not sharing a common suffix are significantly different (P<0.05) by the Tukey test.

Table 5
Estimates and standard errors of breed additive and heterosis effects on for carcass fat score (CFS), subcutaneous fat thickness (SFT) and marbling score (MS).

Genetic effect[1]	CFS (scale)		SFT (mm)		MS (scale)	
g_A^i	-0,21	±0,38	-1,25	±1,21	0,38	±0,35
g_C^i	-1,32	±0,46**	-4,95	±1,49**	0,69	±0,45
g_H^i	-1,18	±0,38**	-3,96	±1,19**	-0,16	±0,36
g_A^m	-0,11	±0,27	0,95	±0,85	-0,06	±0,25
g_H^m	0,30	±0,32	1,97	±1,01	0,29	±0,30
h_z^i	-0,06	±0,20	-0,27	±0,63	-0,25	±0,18
h_t^i	0,16	±0,19	0,01	±0,61	-0,01	±0,18

*** (P<0.001); ** (P<0.01); * (P<0.05).
[1] g^i= individual additive effect, g^m = maternal additive effect, h^i= individual heterosis; with subscripts A = Angus, H = Hereford, C = Caracu, z = taurine-indicine crosses and t = taurine breed crosses.

Formation of lactic acid meat with a consequent reduction of pH during postmortem glycolysis affects the ability of meat to retain water (Bouton et al., 1971; Vaz et al., 2007). Here, only the breed additive effect of C diminished MM of the meat.

Crouse et al. (1989) evaluated fed cattle with different indicine: taurine proportions in their breed composition (0:100, 25:75, 50:50 and 75:25). The authors observed that an increased proportion of indicine breeding resulted in increased shear force and decreased tenderness as measured by tasting panels, and decreased CW and MS. Johnson et al. (1990) also noted decreased tenderness and increased in the shear force in beef from animals with a higher proportion of indicine breeding. In a Brazilian study, Restle et al. (1999) also reported reduced tenderness of beef as the proportion of N increased at the expense of H breeding. Here, the negative breed additive effect of A relative to N leads to a similar conclusion regarding MT. Meat from the CA cross cows benefited not only from the favorable breed additive effect of A but also from the favorable taurine x taurine heterosis effect.

In the present study, taurine x indicine heterosis effect decreased L*, and the intensities of red and yellow in the fat covering the Longissimus thoracis. The breed additive effect of H also reduced yellowness of the fat cover. The breed group means for L*, a*, and b* observed here are within the range of results from other studies of grass-finished beef (Baublits et al., 2004; Rodrigues & Andrade, 2004; Costa et al. al., 2008; Fernandes et al., 2008; Fernandes et al., 2009). The color of the meat may be associated with an increase in the age of the animals, since older

Table 6
Estimated breed group means for pH, water holding capacity (WHC), tenderness (MT), moisture content (MM), ether extract (EE) of meat.

Breed groups[1]	pH			WHC (%)			MT (kg)			MM (%)			EE (%)[2]		
Angus (A)	5.46	±0.04	a	62.21	±0.62	a	5.72	±0.22	ab	72.99	±0.19	ab	3.74	±0.17	a
Hereford (H)	5.52	±0.05	a	62.85	±0.87	a	6.40	±0.31	b	73.64	±0.27	b	3.14	±0.24	a
Nelore (N)	5.45	±0.06	a	63.58	±0.96	a	6.75	±0.33	b	72.97	±0.30	ab	3.26	±0.26	a
CA (Caracu x A)	5.46	±0.03	a	63.38	±0.58	a	5.11	±0,20	a	72.19	±0.18	a	3.86	±0.17	a
HA	5.44	±0.04	a	63.32	±0.65	a	5.52	±0.23	ab	73.33	±0.20	b	3.43	±0.18	a
AH	5.53	±0.06	a	63.91	±1.21	a	5.65	±0.33	ab	73.29	±0.28	b	3.44	±0.25	a
NA	5.39	±0.05	a	62.08	±0.71	a	6.36	±0.24	b	72.93	±0.22	ab	3.19	±0.19	a
AN	5.31	±0.07	a	61.84	±0.83	a	6.30	±0.29	b	73.01	±0.26	ab	3.05	±0.23	a

[1] Breed of sire is identified by the first symbol in crossbred groups. Means within column not sharing a common suffix are significantly different (P<0.05) by the Tukey test.
[2] The percentage of EE is expressed in dry matter.

Table 7
Estimates and standard errors of breed additive and heterosis effects on for pH, water holding capacity (WHC), tenderness (MT), moisture content (MM), ether extract (EE) of meat.

Genetic effect[1]	pH		WHC (%)		MT (kg)		MM (%)		EE (%)[2]	
g_A^i	-0,08	±0,11	-1,60	±1,52	-1,09	±0,53*	0,11	±0,47	0,05	±0,41
g_C^i	-0,07	±0,12	-1,45	±1,97	-0,82	±0,69	-1,53	±0,61*	0,14	±0,58
g_H^i	-0,05	±0,10	-1,56	±1,58	0,01	±0,56	0,74	±0,49	-0,80	±0,46
g_A^m	0,09	±0,08	0,24	±1,04	0,06	±0,36	-0,09	±0,32	0,18	±0,32
g_H^m	0,12	±0,09	0,83	±1,34	-0,36	±0,48	-0,07	±0,42	0,46	±0,40
h_z^i	-0,11	±0,05	-0,94	±0,81	0,10	±0,28	-0,01	±0,25	-0,47	±0,21*
h_t^i	-0,03	±0,05	1,08	±0,80	-0,75	±0,28**	0,02	±0,25	0,08	±0,24

*** (P<0.001); ** (P<0.01); * (P<0.05).
[1] g^i = individual additive effect, g^m = maternal additive effect, h^i= individual heterosis; with subscripts A = Angus, H = Hereford, C = Caracu, z = taurine-indicine crosses and t = taurine breed crosses.
[2] The percentage of EE is expressed in dry matter.

Table 8
Estimates and standard errors of breed additive and heterosis effects on for lightness (L*), red color intensity (a*) and yellow color intensity (b*) for the fat and meat coloring parameters.

Genetic effect[1]	Fat color						Meat color					
	L*		a*		b*		L*		a*		b*	
g_A^i	-1,12	±1,17	0,39	±1,40	-0,98	±1,78	0,19	±0,90	0,74	±0,80	0,69	±0,54
g_C^i	-0,93	±1,42	-0,45	±1,70	-2,32	±2,16	0,40	±1,10	0,49	±0,97	0,47	±0,66
g_H^i	-0,53	±1,16	-1,99	±1,39	-5,43	±1,76**	-0,18	±0,90	0,08	±0,79	-0,19	±0,54
g_A^m	1,60	±0,82	-0,96	±0,99	-0,61	±1,25	-0,51	±0,63	-1,00	±0,56	-0,90	±0,38*
g_H^m	1,12	±0,99	-0,05	±1,18	-0,23	±1,50	-0,59	±0,77	-1,38	±0,68*	-1,01	±0,46*
h_z^i	-1,30	±0,61*	1,72	±0,73*	2,44	±0,92**	-0,67	±0,47	0,14	±0,42	0,06	±0,28
h_t^i	-0,61	±0,59	0,19	±0,71	0,88	±0,90	-0,10	±0,46	0,00	±0,41	0,11	±0,27

*** (P<0.001); ** (P<0.01); * (P<0.05).
[1] g^i = individual additive effect, g^m = maternal additive effect, h^i= individual heterosis; with subscripts A = Angus, H = Hereford, C = Caracu, z = taurine-indicine crosses and t = taurine breed crosses.

Table 9
Estimated breed group means for lightness (L*), red color intensity (a*) and yellow color intensity (b*) for the fat and meat coloring parameters.

Breed group[1]	Fat color									Meat color								
	L*			a*			b*			L*			a*			b*		
Angus (A)	71.54	±0.47	a	14.34	±0.56	ab	28.24	±0.71	bc	36.92	±0.37	a	22.65	±0.32	a	7.57	±0.22	ab
Hereford (H)	71.65	±0.66	a	12.87	±0.79	a	24.17	±1.00	a	36.48	±0.50	a	21.61	±0.45	a	6.58	±0.30	a
Nelore (N)	71.06	±0.72	a	14.91	±0.86	ab	29.82	±1.08	bc	37.25	±0.55	a	22.91	±0.49	a	7.79	±0.33	ab
CA (Caracu x A)	71.03	±0.41	a	14.11	±0.50	ab	28.45	±0.63	bc	36.93	±0.32	a	22.53	±0.28	a	7.58	±0.19	ab
HA	71.23	±0.46	a	13.34	±0.55	a	26.9	±0.69	ab	36.64	±0.35	a	22.32	±0.31	a	7.24	±0.21	ab
AH	71.3	±0.65	a	14.10	±0.78	ab	27.8	±0.98	abc	36.56	±0.70	a	21.95	±0.44	a	7.13	±0.30	a
NA	70.8	±0.54	a	15.87	±0.64	ab	31.2	±0.81	c	36.16	±0.41	a	22.42	±0.37	a	7.29	±0.25	ab
AN	69.2	±0.66	a	16.82	±0.79	b	31.78	±0.99	c	36.68	±0.50	a	23.42	±0.45	a	8.19	±0.30	b

[1] Breed of sire is identified by the first symbol in crossbred groups. Means within column not sharing a common suffix are significantly different (P<0.05) by the Tukey test.

animals have a greater amount of myoglobin (Rodrigues & Andrade, 2004). In this study, the similarity between slaughter ages between genetic groups may have resulted in few differences in meat color parameters. The fat of pasture-fed animals, has generally been characterized as having a higher intensity of yellow color due to a high concentration of fat-deposited beta-carotene pigments in their diet (Fernandes et al., 2008; Muchenje et al., 2009; Daley et al., 2010).

In the present study, only maternal additive genetic effects were found to influence meat color. Progeny of A dams had meat with a greater intensity of yellow and progeny of H dams had meat with greater intensities of red and yellow than the progeny of N dams. Grazing animals are generally found to have meat with greater redness than confined animals (Buablits et al., 2004; Costa et al. 2008; Fernandes et al., 2008; Fernandes et al., 2009) which may be a manifestation of the physical demands of foraging (Rodrigues & Andrade., 2004).

5. Conclusions

Slaughter weight and tenderness may be increased by crossbreeding with taurine breeds, and while carcass yield and ribeye area can be increased by using zebu-influenced cattle. The desirable carcass composition of CA cows and their tenderness and color comparable to taurine crossbred cows make this crossbred cow a viable alternative for producers at the margin between the temperate and tropical zones.

Author statement

Fábio Souza Mendonça: Conceptualization, Data collect, Methodology, Wording, Statistical analysis. Michael D MacNeil: Visualization, Statistical analysis, Supervision. Elen Nalerio: Methodology.Lenadro Lunardini Cardoso: Data collect. Citieli Giongo: Methodology. Fernando Flores Cardoso: Conceptualization, Statistical analysis, Supervision

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

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