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Growth performance, and carcass and meat quality traits in progeny of Poll Nellore, Angus and Brahman sires under tropical conditions

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Abstract. This study aimed to characterise progeny of sires representing major families in the Poll Nellore breed. Fourteen Poll Nellore sires, two Angus sires and one Brahman sire were mated by AI to ~400 multiparous Poll Nellore dams. Calves were raised and stocked on pasture in central Brazil until reaching ~18 months of age, then fed a sugarcane bagasse-based diet on an *ad libitum* basis until reaching market weight and finish (average 23 months). There were 236 Poll Nellore (N), 38 Angus × Poll Nellore (AN) and 31 Brahman × Poll Nellore (BN) calves born in total. The weaning and 423-day weight weights, and growth rates and pre- and post-weaning were greater ($P < 0.05$) in males than in female calves, and were influenced by breed and by sire within the N animals. The weaning weights were higher ($P < 0.05$) in AN and BN than in N calves. The 423-day weight weights were greater ($P < 0.05$) in AN calves, followed by BN, with straightbred N being lightest. Feedlot average daily gain was unaffected ($P > 0.05$) by sex or by sire within N, but was lowest ($P < 0.05$) in N cattle, and highest in AN and BN animals, which did not differ ($P > 0.05$). Heifers reached the end of the study with lower bodyweight (BW) and dressing percentage than steers, resulting in lower carcass weights, smaller *longissimus* muscle areas (LMA), but greater 12th to 13th rib backfat (BF) and similar marbling score and mean shear force. However, the proportion of carcasses grading Choice or Prime was numerically greater in heifers than in steers (23.6% vs 9.8%). AN cattle reached greater harvest weights than BN, and those were heavier than N cattle ($P < 0.001$). However, dressing percentages were lowest in AN animals, so that there was no significant difference in carcass weight between AN and BN cattle. AN carcasses also had greater LMA, BF and marbling scores than the N carcasses. The proportion of carcasses grading Choice or Prime was numerically greater in AN cattle than in the BN and N groups (25.9%, 11.8% and 15.9%, respectively). Steaks from AN calves were more tender than N steaks, with the BN steaks being intermediate. There was significant variation among N sires for final BW, dressing percentage, carcass weight, LMA and marbling score, but not for BF or mean shear force. The percentages of carcasses of N cattle grading Choice or Prime ranged from 0% to 61.5%. Three N sires produced progeny with greater than 40% of carcasses grading Choice or above (Berílio OB, Furador OB, and Litoral OB). Likewise, three N sires (Blitz OB, Furador OB and Sossego OB) had progeny with 67%, 62% and 75%, respectively, of steaks classified as tender. This study confirmed that Zebu cattle have inferior carcass and meat quality relative to AN crossbreds under tropical conditions, however there is substantial variation within the N breed for these traits, and several sires have a proportion of their progeny comparable in terms of meat tenderness to those of Angus sires.

Additional keywords: carcass, cattle, crossbreeding, growth, meat quality, Poll Nellore.

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Introduction

To date, there is a tendency to value differentiated meat products (i.e. value-added products), in terms of meat organoleptic traits and consequences of meat consumption on human health. Recently, Brazil has become the world's largest beef exporter by volume, achieving 1.24 million tonnes in 2012 (ANUALPEC

2012). This has been largely due to expansion of grazing into the central Cerrado (tropical savannah) region, made possible by use of cattle breeds that are well adapted to tropical conditions. The Nellore breed stands out as the dominant beef cattle breed, making up ~80% of the roughly 200 million head in the national herd (ANUALPEC 2012). Therefore, a better understanding of the productive and quality potential of this breed is a priority for research.

The results obtained from the Germplasm Evaluation Program held at the Meat Animal Research Centre, where different beef cattle breeds were evaluated for various economic importance traits (Cundiff 2004), pointed out that, despite the Zebu (Nellore and Brahman) and their crosses (Brangus) demonstrating greater adaptation to the environment and resistance to parasites, they produced carcasses with less fat/lean ratio, lower meat tenderness and lower percentage of intramuscular fat than *Bos taurus* breeds. The genetic variation in both quantity and quality of beef is evident through differences between breeds and crossbreeds and between sires within a breed. Within-breed variation includes additive genetic effects and also the correlated impacts of additive genetic effects on other economically important productive and adaptive traits that affect beef production (Burrow *et al*. 2001). In most Brazilian Nellore breeding programs, the selection for meat and carcass traits is still limited, probably due to the difficulties and costs for obtaining them, since they are measured post mortem. In Brazil, there are few studies conducted with *Bos indicus* for carcass and meat traits. In this sense, Baldi *et al*. (2013) and Ferriani *et al*. (2013) concluded that these traits have genetic variation and should respond to selection.

Among the factors that define the carcass quality, the proportion of valuable meat cuts, and the percentage of fat (subcutaneous and intramuscular) on carcass and meat tenderness are important factors to be considered (Boleman *et al*. 1998). The meat produced from Zebu breeds in Brazil has organoleptic characteristics that are not well accepted in most demanding markets (Buainain and Batalha 2007). The Brazilian beef breeders are faced with the challenge of using vastly diverse production environments and systems to produce cattle that are both productive and profitable, and beef products that satisfy consumer requirements. Results from tropical and subtropical environments comparing breeds and crossbreds for carcass and meat quality traits are scarce (Schutt *et al*. 2009*a*, 2009*b*). Thus, this study aimed to characterise progeny of sires representing several major families in the Poll Nellore breed. In addition, these animals were compared with F_1 Angus × Poll Nellore and Brahman × Poll Nellore crosses. The studied traits were pre- and post-weaning gains, fat development, and carcass and meat quality.

Materials and methods

Animals and management

A total of 14 sires representing seven major families within the Poll Nellore breed were selected from the Germplasm Bank of the Guaporé farm, located at the Pontes de Lacerdacounty, Mato Grosso state, Brazil. These sires were considered to represent a major family if the common ancestor appeared at least three times in the pedigree going back three generations. The Poll Nellore sires, along with two Angus sires (GT Encore and Famous Players) and one Brahman sire (Mr V8 444/4) were mated by artificial insemination to ~400 multiparous commercial Poll Nellore dams. The Angus and Brahman sires were included to enable comparisons with breeds of known carcass and meat traits. The number of progeny per breed was 237 (114 females and 123 males), 38 (15 females and 23 males) and 31 (19 females and 12 males) for Poll Nellore, Brahman and Angus sires, respectively.

All calves were raised on pasture with their dams until ~8 months of age, then weaned and stocked on pasture on the same ranch (Fazenda Guaporé; Pontes e Lacerda, MT, Brazil) until reaching ~18 months of age. Male calves were castrated at 15 months. At 18 months of age, animals were transported to a feedlot at a sugarcane ethanol plant (Usina Vale do Rosário, Orlândia, SP, Brazil). The animals were fed *ad libitum* a bagasse-based diet (Table 1), and remained in the feedlot for a period of 127 days until they reached ~5 mm of subcutaneous fat thickness between the 12th and 13th ribs.

During the feedlot phase, five weighing records were measured. To perform the weighing, the animals were fasted for 12 h. Research protocols followed the guidelines stated in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching.

Carcass and meat traits

The animals were slaughtered between 22 and 24 months of age, at the Bertin Co. packing plant in Lins, SP, Brazil. At slaughter, carcasses were evaluated according to the company's internal standards as well as USDA grading standards (USDA 1999). After slaughter, the carcasses were weighed (hot carcass weight: HCW), and remained inside the cooling chamber at 0−2°C for 24 h. These measures were used to obtain the carcass yielding, percentage of HCW in relation to bodyweight (BW). Additional measurements including temperature and pH were taken in the *Longissimus dorsi* muscle in the hanging carcass. Twenty-four

Table 1. Ingredients, chemical and nutritional composition of diet utilised in the feedlot on a dry matter basis[A]

Ingredients	% of DM
Cracked corn	35.2
Soybean hulls	20.0
Hydrolised sugarcane bagasse	13.4
Sugarcane bagasse	10.0
Yeast	10.0
Soybean meal (45% crude protein)	6.0
Molasses	2.5
Trace mineralised salt	2.3
Urea	0.6
Rumensin	0.027
Estimated composition	
Crude protein (% DM)	14.2
Rumen-degradable protein (% DM)	8.3
Total digestible nutrients (% DM)	71.2
NE_m (Mcal/kg DM)	1.67
NE_g (Mcal/kg DM)	1.06
Calcium (% DM)	0.49
Phosphorus (% DM)	0.36

[A]The moisture content of the diet was 85%.

hours post mortem, samples from the *Longissimus dorsi* muscle were taken between the 10th and 13th ribs, vacuum-packed then aged for 14 days at 1°C before being frozen at −20°C pending analyses. These analyses included:

- Water loss by exudation (WLE): initially, the water loss by exudation of *Longissimus dorsi* [WLE = We/(We + Wb)] × 100; was calculated by weighing the steak (Wb) and exudate (We). The values were expressed as percentages.
- Cooking weight losses (CWL): the cooking weight losses was determined by the weight difference before and after baking [CWL = (Wi – Wf)/Pi] by weighing initial steak (Wi) and the final weighing (Wf), expressed as a percentage. All weighings were performed with the semi-analytical scale (Honikel 1998). Steaks for cooking loss and shear force were chilled overnight at 4°C.The initial weight of the steaks was on average 125 g approximate. The time and temperature of the cooking were ~15 min until the internal temperature reached 71°C in the steak.
- Tenderness: after weighing the samples, individual thermometers were inserted by drilling, reaching the geometric centre of the samples. The meat tenderness was measured according to the method given by Wheeler *et al*. (2001), using the Warner-Bratzler shear force equipment. The mean shear of each sample was considered as the average values of six cylinders. The six cylinders (1.27 cm diameter) were obtained from each steak parallel to the longitudinal orientation of the muscle fibres.

The percentage of carcasses with shear forces above 3.9 kg was calculated for each progeny group, as this value was shown to be a cut-off for slightly tender steaks (Shackelford *et al.* 1991).

Statistical analyses

The animals were divided in blocks according to the initial weight during the feedlot phase. The experimental design was randomised blocks in a 3 × 2 factorial arrangement (breed × sex). To compare the genetic groups, the fixed effects of genotype (genetic group), sex, genotype*sex interaction, block and age at slaughter as a linear covariable (only for meat and carcass traits), were considered in the model. For weaning weight, 423-day weight, 423-day scrotal circumference (SC), and weight gains during the post-weaning and feedlot phases, and the age of the animal at measurement was added in the model as a covariable (linear and quadratic effect). A factorial arrangement 14 × 2 (bulls × sex) was used for the analysis of differences between Poll Nellore sire group. The data were analysed by variance analyses using the PROC GLM procedure (SAS Institute, Cary, NC, USA) at 5% significance level. The means were compared by the Bonferroni test at the level of 5% significance. In the presence of significant interaction ($P < 0.05$) between the factors, the means for each breed were compared within sex by Bonferroni test at 5% significance level.

Results and discussion

Growth traits

There were 236 Poll Nellore (N), 38 Angus × Poll Nellore (AN) and 31 Brahman × Poll Nellore (BN) calves born in total. The pre-weaning growth was influenced ($P < 0.05$) by sex and genetic group (Table 2). The interaction between sex and genetic group was not significant ($P > 0.05$) for pre- and post-weaning growth traits. Male calves had higher weaning weights (+10%) than in females calves, and in AN and BN than N calves (+13%, Table 3). This superiority of *Bos taurus* × *Bos indicus* calves over straightbred *Bos indicus* calves is in agreement with previous studies (Brown *et al*. 1993; Riley *et al*. 2007). Comparisons between *Bos indicus* × *Bos taurus* calves and straightbred *Bos taurus* calves have been less consistent, with some studies showing superiority (Gregory *et al*. 1979; Cundiff *et al*. 1998) and others no difference (Thallman *et al*. 1999; Lunstra and Cundiff 2003) between crossbreds and straightbreds at weaning. Therefore, it is likely that the greater weaning weights of AN and BN (relative to N) calves in this study were at least partly due to individual heterosis and breed differences. There were no significant differences in weaning weights among progeny of N bulls.

The 423-day weight weights were heavier ($P < 0.05$) in AN calves, followed by BN, with straightbred N being lighter than the other groups (Table 3). These differences in BW reflected greater ($P < 0.05$) average daily gain (ADG) in AN calves, compared with BN and N calves, which had similar post-weaning gains ($P > 0.05$; Table 3). This superiority in post-weaning ADG and 15-months weight of *Bos taurus* × *Bos indicus*

Table 2. Least square means and standard error (between parentheses) for weaning weight (WW), 423-day weight (YW) and 423-day scrotal circumference (SC), and weight gains (kg/day) during the post-weaning and feedlot phases of progeny of Angus, Brahman and Poll Nellore sires
a,b: means in the same row with no letters or a common letter do not differ significantly ($P < 0.05$). x,y,z: means in the same column with no letter or a common letter do not differ significantly ($P < 0.05$)

Sire breed	WW (kg)[A] Gender: Females	WW (kg)[A] Gender: Males	Mean
Angus	204 (n = 19)[E]	217 (n = 12)	210 (3.91)x
Brahman	198 (n = 15)	217 (n = 23)	208 (4.0)x
Poll Nellore	176 (n = 114)	197 (n = 123)	186 (1.50)y
Mean	192 (2.66)b	210 (2.80)a	

Sire breed	YW (kg)[B] Gender: Females	YW (kg)[B] Gender: Males	YW (kg)[B] Mean	SC (cm)[B] Mean
Angus	289	309	299 (4.10)x	27.0 (0.90)x
Brahman	273	291	282 (4.13)y	23.3 (0.96)y
Poll Nellore	231	267	249 (1.60)z	22.2 (0.81)y
Mean	265 (2.80)b	289 (2.88)a	–	–

Sire breed	Post-weaning ADG (kg/day)[C,D] Gender: Females	Post-weaning ADG (kg/day)[C,D] Gender: Males	Post-weaning ADG Mean	Feedlot ADG (kg/day) Mean
Angus	0.538	0.591	0.565 (0.014)x	1.304 (0.03)x
Brahman	0.414	0.454	0.434 (0.014)y	1.205 (0.03)x
Poll Nellore	0.352	0.440	0.396 (0.005)y	1.067 (0.01)y
Mean	0.435 (0.01)b	0.495 (0.01)a	–	–

[A]Means are adjusted to a common age (260 days) by ANCOVA.
[B]Means are adjusted to a common age (423 days) by ANCOVA.
[C]Means are adjusted to a common age (423 days) by ANCOVA.
[D]Average daily gain from weaning to entry to the feedlot at ~18 months of age.
[E]Number of progeny per sire.

calves over straightbred *Bos indicus* calves confirms previous studies (Brown *et al.* 1993; Newman *et al.* 2002).

Within the N calves, there were no differences ($P > 0.05$) among progeny of different bulls for weight and ADG until 15 months of age (Table 3). In all genetic groups, males were heavier than females (+25 kg, $P < 0.05$). Male calves sired by Angus bulls had greater ($P < 0.05$) SC at 423 days of age than calves sired by Poll Nellore and Brahman bulls, which were not different from each other (Table 2). The selection for higher SC would increase the female sexual precocity (Martínez-Velázquez *et al.* 2003; Forni and Albuquerque 2005) in *Bos taurus* and *Bos indicus* breeds. Therefore, as stated more than 25 years ago (Turner 1980; Dow *et al.* 1982), Zebu cattle are later-maturing than *Bos taurus* and crossbreds. There were no differences ($P > 0.05$) in SC among progeny of Poll Nellore sires (data not shown).

Table 3. Least square means for weight gains (kg/day) of progeny of Poll Nellore sires and Poll Nellore dams during the post-weaning and feedlot phases[A]

Sire	Post-weaning ADG (kg/day)[B]	Feedlot ADG (kg/day)
Berílio (n = 12)[C]	0.371	1.083
Blitz (n = 18)	0.406	1.073
Dalamu (n = 22)	0.374	1.121
Dólar (n = 22)	0.399	1.027
Furador (n = 13)	0.405	0.945
Itaú (n = 22)	0.398	1.144
Laiko (n = 22)	0.377	0.993
Litoral (n = 9)	0.436	1.154
Modello (n = 22)	0.400	1.031
Pagode (n = 25)	0.425	1.130
Plato (n = 20)	0.425	1.079
Sanduíche (n = 4)	0.298	0.889
Simpático (n = 18)	0.388	1.070
Sossego (n = 8)	0.338	1.054
Overall P-value	0.88	0.06
Pooled s.e.m. value	0.15	0.27

[A]Means are adjusted to a common age (423 days) by ANCOVA.
[B]Average daily gain from weaning to entry to the feedlot at ~18 month of age.
[C]Number of progeny per sire.

As shown in Fig. 1, animals entered their second dry season while still on pasture, and growth was essentially zero during this time.

Upon placement in the feedlot, growth rate accelerated to an average ADG of 1.113 kg/day. The feedlot ADG was unaffected ($P > 0.05$) by sex, but was lowest ($P < 0.05$) in N cattle, and highest in AN and BN animals, which did not differ ($P > 0.05$; Table 2). Similarly, Ribeiro *et al.* (2005) compared ADG in steers finished on *Brachiaria* (Guinea grass) pasture and also found no difference between BN and N steers. Moreover, Paschal *et al.* (1995) found that Brahman × Hereford, Poll Nellore × Hereford and Angus × Hereford steers had similar feedlot ADG. By contrast, Gregory *et al.* (1979) and Huffman *et al.* (1990) found that Brahman crossbreds had greater feedlot ADG than straightbred (Angus) or crossbred (Angus × Hereford) *Bos taurus* steers, suggesting a strong effect of heterosis. Similarly to post-weaning weight gains, feedlot weight gains were not different ($P > 0.05$) among progeny of Poll Nellore sires (Table 3).

Carcass and meat quality traits

The differences between females and castrated males with regard to carcass and meat traits are shown in Table 4. Heifers

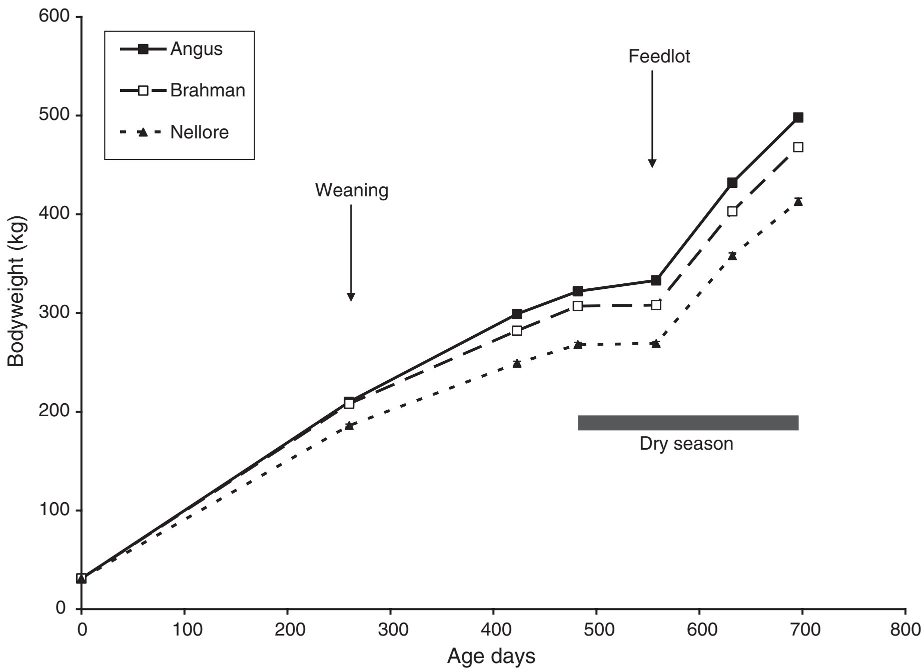

Fig. 1. Evolution of least square means for age-adjusted weights from birth to slaughter for progeny of Angus, Brahman and Poll Nellore sires. The birthweights were adjusted to an age of zero.

Table 4. Effects of sire breed and sex on carcass and meat quality traits[A]

Trait	Sire breed					Gender			
	Angus	Brahman	Poll Nellore	s.e.m.[B]	P^C	Heifers	Steers	s.e.m.	P
Final BW (kg)	507a	469b	413c	6.10	<0.001	440b	479a	5.89	<0.001
Hot carcass weight (kg)	274a	262a	232b	3.38	<0.001	242b	270a	3.26	<0.001
Dressing %	55.2b	55.8ab	56.1a	0.28	0.004	54.9b	56.5a	0.27	<0.001
Longissimus muscle area (cm^2)	65.6a	60.2b	56.5c	0.97	<0.001	58.5b	63.1a	0.93	<0.001
12th rib fat thickness (mm)	8.6a	7.3ab	7.1b	0.58	0.035	9.0a	6.3b	0.56	<0.001
Marbling score[D]	279	242	255	15.4	0.18	265	253	14.9	0.41
% of carcasses grading – Choice and Prime	25.9	11.8	15.9	–	–	23.6	9.8	–	–
pH at 24 h	5.70	5.73	5.72	0.018	0.49	5.66b	5.74a	0.016	0.022
Cooking loss (%)	15.7	15.8	16.3	0.88	0.80	15.7	15.9	0.85	0.80
Drip loss (%)	3.9	4.1	4.4	0.43	0.43	2.7b	5.6a	0.41	<0.001
Warner-Bratzler shear force (kg)	3.30b	3.86ab	4.15a	0.27	0.016	3.63	3.91	0.26	0.29
% of carcasses with shear force >3.9 kg	25.9	41.2	46.6	–	–	30.7	41.8	–	–

[A]Values are least square means adjusted to a common age (23 months) by ANCOVA.
[B]s.e.m., mean standard error.
[C]P, probability of a Type I error.
[D]Marbling scores: 200 = Select^0, 300 = Small^0.

reached the end of the study with lower BW and dressing percentage than steers, resulting in much lower carcass weights. Along with the lighter carcasses, heifers had smaller *longissimus* muscle areas (LMA) than steers; but they had greater 12th to 13th rib backfat (BF). Other differences included lower 24-h pH and drip loss in heifers as compared with steers. There was no difference ($P > 0.05$) between heifers and steers in mean marbling score, cooking loss and shear force, although heifers had a numerically smaller proportion of steaks above 3.9 kg (Table 4). Moreover, the proportion of carcasses grading Choice or Prime was numerically greater in heifers than in steers (23.6% vs 9.8%, Table 4). These results are in partial agreement with those of Choat *et al*. (2006), who found that heifers had lighter carcasses, but similar LMA and BF to steers. In that study, heifers had greater marbling scores than steers; shear force was similar (at equal BF) or higher (at equal marbling) in heifers than steers (Choat *et al*. 2006).

Calves sired by Angus bulls reached higher slaughter weights than those sired by Brahman bulls, and those were heavier than N calves ($P < 0.001$, Table 4). However, dressing percentages were lowest in AN animals, so that there was no significant difference in carcass weight between AN and BN cattle. In previous studies, BN steers were heavier at slaughter than NN steers (Ribeiro *et al*. 2005), BN steers were heavier than N steers (Franke 1997). In those studies, carcass weights were similar between BN and N (Franke 1997; Ribeiro *et al*. 2005) steers, indicating that NN cattle had greater dressing percentages. Many previous reports have shown that *Bos indicus* cattle (and crossbreds) have greater dressing percentages than *Bos taurus* breeds (Menezes *et al*. 2007), probably due to smaller internal organs such as heart, lungs, liver and gastrointestinal tract (Menezes *et al*. 2007). The AN carcasses had greater LMA, BF and marbling scores than the Zebu carcasses. The lower BF and marbling of *Bos indicus* cattle compared with *Bos taurus* breeds is well known (Pringle *et al*. 1997; Wheeler *et al*. 2001; Newman *et al*. 2002). The proportion of carcasses grading Choice or Prime was numerically greater in AN cattle than in the BN and N groups (25.9%, 11.8% and 15.9%, respectively; Table 4), in agreement with the results of Wheeler *et al*. (2001).

Although the genetic groups had similar pH values, drip and cooking losses, the steaks from AN calves were more tender than N steaks, with the BN steaks being intermediate (Table 4). The percentage of steaks with shear forces above 3.9 kg (Shackelford *et al*. 1991) followed the same pattern. Similarly, many authors have reported that *Bos indicus* cattle (and crossbreeds) produce tougher meat than *Bos taurus* breeds (Shackelford *et al*. 1995; Pringle *et al*. 1997; Wheeler *et al*. 2001). This relative toughness of Zebu meat appears to be at least partly due to higher activity of calpastatin in the muscle of these breeds (Wheeler *et al*. 1990; Shackelford *et al*. 1991; Pringle *et al*. 1997) compared with *Bos taurus* breeds. Although N calves produced tougher meat on average than AN and BN animals, half of the loin steaks from these animals could be classified as tender (Shackelford *et al*. 1991). Although the number of crossbred animals was considerable and the results showed that crossbred animals had better carcass and meat quality attributes than the Poll Nellore, the comparisons need to be treated with caution when there was only a single Brahman-sire involved and only two Angus sires.

The results of carcass and meat quality traits for progeny of each bull within the Poll Nellore breed are presented in Table 5. There was considerable (and statistically significant) variation among sires for final BW, dressing percentage, carcass weight, LMA and marbling score. These results are expected, since the heritability estimates for final BW, carcass weight, LMA and BF in Brahman cattle were 0.59, 0.57, 0.50 and 0.37 (Smith *et al*. 2007). There were no significant differences ($P > 0.05$) among sire progeny groups for BF, pH, cooking loss, drip loss or shear force. Even so, the mean shear force ranged from 3.45 kg to 4.87 kg, and the percentage of steaks above 3.9 kg ranged from 24% to 83% among sires. The mean shear force obtained in this study for the Poll Nellore

Table 5. Effect of Poll Nellore sire on carcass and meat quality traits[A]

Trait	Berílio	Blitz	Dalamu	Dólar	Furador	Itaú	Laiko	Litoral	Modello	Pagode	Plato	Sanduiche	Simpático	Sossego	s.e.m.[B]	P^C
Final BW(kg)	414ab	414ab	417ab	407b	404b	422a	405b	418ab	412ab	420a	416ab	404b	410ab	398ab	9.72	0.008
Hot carcass weight (kg)	236bc	233bc	243bc	230c	225c	243a	221c	237bc	232bc	235b	230bc	230bc	233bc	231bc	5.72	0.008
Dressing %	55.7bcd	56.1bcd	55.7cd	55.5cd	56.2bcd	57.6a	55.9bcd	55.2c	55.9bc	55.9bcd	55.6cd	56.7ab	56.8ab	55.7bcd	0.33	<0.001
Longissimus muscle area (cm^2)	54.3c	56.3bc	57.1bc	54.2c	56.3bc	55.7bc	55.0bc	56.8bc	53.6c	60.0a	58.5ab	57.2ab	60.1a	55.6ab	1.26	<0.001
12th rib fat thickness (mm)	8.7ab	6.1c	6.8bc	6.9abc	7.7a	7.6ab	6.1bc	7.2abc	7.6ab	7.3abc	7.1abc	6.2abc	7.0abc	4.7c	0.73	0.199
Marbling score[D]	318ab	259c	231c	252c	361a	229c	216c	275bc	269bc	246c	245c	231c	235c	271bc	19.6	<0.001
% of carcasses grading Choice and Prime	41.7	16.7	4.4	9.5	61.5	4.6	10.5	44.4	19.1	4.4	0.2	0.0	6.7	12.5	–	–
pH at 24 h	5.7	5.7	5.7	5.8	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.8	0.028	0.928
Cooking loss (%)	15.6	14.9	16.1	17.7	15.3	16.3	16.2	15.5	16.7	15.2	16.4	15.4	17.4	12.5	1.95	0.547
Drip loss (%)	3.34	4.35	4.97	4.39	4.32	4.96	3.84	3.76	4.77	4.19	4.07	4.30	5.65	5.01	0.93	0.435
Warner-Bratzler shear force (kg)	4.18	4.13	3.85	4.87	4.27	4.27	4.21	3.70	4.43	3.91	4.18	4.78	4.54	3.45	0.67	0.804
% of carcasses with shear force <3.9 kg	50.0	66.7	47.8	47.6	61.5	59.1	42.9	44.4	42.9	52.2	40.0	50.0	33.3	75.0	–	–

[A]Values are least square means adjusted to a common age (23 months) by ANCOVA.
[B]s.e.m., mean standard error.
[C]P, probability of a Type I error.
[D]Marbling scores: 100 = Traces^0, 200 = Select^0, 300 = Small^0, 400 = Modest^0.

breed was lower than those reported by Burrow *et al*. (2001), Schutt *et al*. (2009*b*) and Pinto *et al*. (2010) also working with Zebu breeds. Probably, this lower mean value for shear force is explained by differences at slaughter age, genetic background and nutritional management. The Pearson correlation estimate between shear force and cooking losses was positive and moderate (0.71) indicating that tough meat is associated with higher cooking loss. In this sense, Silva *et al*. (1999) reported that the cooking loss and juiciness were related to the assessment of softness. It is known that a higher water retention capacity of the muscles contributes to the meat softness (Bouton *et al.* 1973). The percentages of carcasses of N cattle grading Choice or Prime ranged from 0% to 61.5%. Admittedly, these values are based on very small sample sizes, but they suggest substantial genetic variability within this breed. It is worth noting that three Poll Nellore sires produced progeny with greater than 40% of carcasses grading Choice or above (including one Prime): Berílio OB, Furador OB, and Litoral OB. Likewise, three of the 14 Poll Nellore sires (Blitz OB, Furador OB and Sossego OB) had progeny with 67%, 62% and 75%, respectively, of steaks classified as tender (i.e. with mean shear force less than 3.9 kg).

The results of this study showed that crossbreeding is an effective tool to explore the effects of heterosis and complementarity between breeds. Burrow *et al*. (2001) reported that the effects of heterosis for carcass and meat traits were relatively small (3% or less) compared with heterosis obtained for reproductive traits. These results are expected, since the carcass and meat traits have moderate to high heritability estimates. Despite heterosis effects not significantly improving carcass composition and meat quality, crossbreeding may indirectly improve these traits through higher growth rates, lower age at slaughter, as well as, by combining the desirable traits of each breed in a single individual (complementarity effect). Crossbred animals have greater weight and weight gains, and better carcass and meat quality attributes. The farmers should guide their matings in order to exploit the advantages of crossbreeding on carcass and meat traits, through crossbreeding systems or synthetic breeds, but also aim to maximise the benefits on reproductive traits, such as sexual precocity, longevity and/or cow mature size, which are important traits of the beef production system.

Finally, to take full advantages of crossbreeding it is also necessary have genetically evaluated animals, since crossbreeding and selection are complementary tools for genetic improvement. The results of this study demonstrated that there is considerable phenotypic variability for meat and carcass traits within the Poll Nellore breed. In these sense, Baldi *et al*. (2013) and Ferriani *et al*. (2013) working with Nellore concluded that these traits have enough phenotypic and genetic variation for response to selection. However, the meat and carcass traits have late expression, are difficult and expensive to measure, which hampers the availability of young animals evaluated for carcass and meat traits with reasonable accuracy. To overcome these difficulties, one possibility is the identification of genetic markers or polymorphisms in genes that influence carcass and meat traits to improve these traits through marker-assisted selection or genomic selection (Garrick 2011).

Conclusions

This study confirms previous reports and much common knowledge regarding the advantages of F_1 *Bos taurus* × *Bos indicus* over the straightbred *Bos indicus* breeds. Crossbreds have superior weight gains and on average produce heavier carcasses with superior fat cover and meat quality, than straightbred Zebu under tropical conditions. This is most likely due to a combination of the inherent superiority of the Angus breed for these traits, as well as heterosis effect.

The Zebu cattle had inferior carcass and meat quality relative to the AN crossbreds, as determined by marbling scores and shear force. This study, however, demonstrated that there is substantial variation within the Poll Nellore breed for these traits, and several sires have a proportion of their progeny comparable in terms of meat tenderness to those of Angus sires. To our knowledge this is the first report in which these observations have been made in a rigorous fashion using a known genetic base. These observations are merely phenotypic, but ongoing work is aimed at determining genetic and genomic components of this variation.

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