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The energy requirement for maintenance of Nellore crossbreds in tropical conditions during the finishing period

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Abstract

This study determined the energy requirement for maintenance of purebred Nellore cattle and its crossbreds using data from a comparative slaughter trial in which animals were raised under the same plane of nutrition from birth through slaughter and born from a single commercial Nellore cowherd. A total of 79 castrated steers (361 ± 54 kg initial body weight [**BW**]) were used in a completely randomized design by age (22 mo ± 23 d of age) with four genetic groups (**GG**): Nellore (**NL**), ½ Angus × ½ Nellore (**AN**), ½ Canchim × ½ Nellore (**CN**), and ½ Simmental × ½ Nellore (**SN**). The experimental design provided ranges in metabolizable energy (**ME**) intake (**MEI**), BW, and average daily gain needed to develop regression equations to predict net energy for maintenance (**NEm**) requirements. Four steers of each GG were slaughtered to determine the initial body composition. The remaining 63 steers were assigned to different nutritional treatments (**NT**) by GG; ad libitum or limit-fed treatments (receiving 70% of the daily feed of the ad libitum treatment of the same GG). Full BW was recorded at birth, weaning, 12, 18, and 22 mo. In the feedlot, steers were fed for 101 d a diet containing (DM basis) 60% corn silage and 40% concentrate. No difference in age at weaning (P = 0.534) and slaughter (P = 0.179 and P = 0.896, for GG and NT, respectively) were observed. AN steers were heavier at weaning weight, yearling weight and had higher empty BW (**EBW**; P = 0.007, P = 0.014, and P < 0.001, respectively) in comparison to NL, CN, and SN. There were no interactions (P > 0.05) between GG and NT for any variable evaluated. When fed ad libitum, AN steers had higher daily MEI (Mcal/d; P < 0.001) in comparison to NL, CN, and SN. On a constant age basis, differences were observed on body composition (P < 0.05) between GG. The slope (P = 0.600) and intercept (P = 0.702) of the regression of log heat production on MEI were similar among GG. Evaluating at the same age and the same frame size, there were no differences in NEm requirement between Nellore and AN (P = 0.528), CN (P = 0.671), and SN (P = 0.706). The combined data indicated a NEm requirement of 86.8 kcal/d/kg$^{0.75}$ EBW and a ME required for maintenance requirement had a common value of 137.53 kcal/d/kg$^{0.75}$ EBW. The efficiency of energy utilization for maintenance and the efficiency of energy utilization for growth values were similar among GG (P > 0.05 and P > 0.05, respectively) and were on average 63.2% and 26.0%, respectively. However, although not statistically different, the NEm values from NL showed a decrease in NEm of 5.76% compared with AN steers.

Lay Summary

Although several studies have shown that the maintenance energy expenditures vary with breeds, there has been no available data comparing the energy requirements of different genetic groups of beef cattle determined during the finishing phase when raised under the same plane of nutrition from birth through slaughter born from a single cowherd. This study evaluated the influence of purebred Nellore and its crosses with Simmental, Angus, and Canchim slaughtered at the same age and body composition on their net energy requirement for maintenance (**NEm**). Animals were reared in tropical conditions, receiving only free-choice minerals from birth through the beginning of the feedlot phase, potentially altering the intake, carcass composition, mature weight, and consequently, affecting the energy requirement for maintenance during the finishing period. The pooled data analysis for Nellore and its crosses resulted in common NEm requirement of 86.9 kcal/d/kg$^{0.75}$ of empty body weight (**EBW**). However, although not statistically different, the NEm values from Nellore (NL) and Angus × Nellore (**AN**) were 85.5 and 90.8 kcal/d/kg$^{0.75}$ EBW, respectively, showing a decrease in NEm of 5.76% for NL in comparison with AN steers.

Key words: *Bos indicus*, comparative slaughter, efficiency, growth curve, net energy, weaning weight

Abbreviations: BF, backfat; DE, digestible energy; EBF, empty body fat; EBP, empty body protein; EBW, empty body weight; HP, heat production; kg, the efficiency of energy utilization for growth; km, the efficiency of energy utilization for maintenance; ME, metabolizable energy; MEI, metabolizable energy intake; MEm, metabolizable energy required for maintenance; NEm, net energy for maintenance; RE, retained energy; SBW, shrunk body weight

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Introduction

Purebred Nellore cattle and its crossbreds represent about 80% of the total national herd in Brazil; consequently, over 180 million animals carry mostly Nellore germplasm (Ferraz and Felício, 2010). However, the use of *Bos taurus* × Nellore crosses to increase productivity through heterosis has become an established practice in the beef cattle industry in Brazil over the past decades. The heterosis and complementarity effects and the plane of nutrition of crossbreds have the potential to increase weight at puberty, change in body composition, following changes in maintenance energy requirements based on a constant age analysis, which could result in lower efficiency, especially in nutritionally restricted environments (Dickerson et al., 1974; Jenkins and Ferrell, 1983; Birkelo et al., 1991; NASEM, 2016). It is essential to point out that few studies have compared different genetic groups (**GG**) under the same experimental conditions from birth to slaughter.

Traditionally, especially in tropical environments such as Brazil, the seasonal fluctuations in the quantity and quality of pasture during the year affect the animal performance, altering the net energy requirements of the animals (Cartens et al., 1991; Detmann et al., 2014). Cartens et al. (1991) showed that restricting growth to 0.40 kg/d in early maturing beef steers (Angus × Hereford crossbred) for 6 mo before the feedlot phase would alter the composition of carcass and noncarcass tissue growth, feed efficiency, and consequently, alter the net energy requirements for maintenance (**NEm**) and growth (**NEg**). Therefore, understanding that cattle's body composition and net energy requirements could be altered during the feedlot phase when feeding restriction occurs during the previous feeding period, studies evaluating the environmental influences on nutrient requirements of beef cattle using the comparative slaughter will give valuable information.

Overall, the nutrient requirements recommended by NRC (1984, 2000), Lanna et al. (1999), and NASEM (2016) were based on *B. taurus* cattle, with adjustments to NEm for *Bos indicus* breeds and *B. indicus* × *B. taurus* crosses. The maintenance energy requirement has been defined as the quantity of feed energy intake that will result in no net loss or gain of energy from the tissues of the animal's body (NRC, 1996; Tedeschi and Fox, 2020). The NEm of beef cattle has been estimated by Lofgreen and Garrett (1968) as 77 kcal per shrunk body weight (**SBW**)$^{0.75}$, being this value more applicable for penned animals in nonstressful environments with minimal activity (NRC, 1996; Tedeschi et al., 2017; Oltjen, 2019; Tedeschi, 2019).

The majority of studies that evaluated breed differences in maintenance did not have the GG of cattle from the same group of dams, the animal performance was not evaluated in the same environment from birth, or the response to previous nutritional deprivation was highly variable between breeds of cattle in the same research. Thus, there is a need for careful and long-term evaluation of breed and crossbreeding systems in which animals originate from the same herd and in the same breeding season, as well as in which animals were reared under the same management and exposed to the same feeding system throughout life, therefore allowing for the understanding and evaluation of the system as a whole. The objective of this study was to evaluate the influence of purebred Nellore and its cross with Continental or British *B. taurus* breeds (Simmental, Angus, and Canchim) on performance, carcass characteristics, body composition, and energy requirements for maintenance and growth when slaughtered at the same age.

Material and Methods

Animals were handled and managed according to the Institutional Animal Care (Brazilian Agricultural Research Corporation – Embrapa, São Carlos, São Paulo, Brazil).

Cow–calf management and postweaning description

All cattle used in this study, to evaluate the performance, carcass characteristics, body composition, and determine the energy requirements for maintenance and growth, were raised in the same plane of nutrition from birth through slaughter and were born from a single Nellore cowherd, at Embrapa Pecuária Sudeste, São Carlos, São Paulo, Brazil. During the breeding season (Summer; January 2002), cows were maintained on *Panicum maximum cv. Tanzânia* pasture with free-choice of an inorganic trace mineral supplementation to meet or exceed requirements of Nellore cows according to the NRC (2000). Cows were bred by natural service to Nellore (n = 2) or Canchim bulls (n = 3; a tropically adapted breed of 5/8 Charolais × 3/8 Zebu; Urbinati et al., 2016) or were artificially inseminated to Simmental (n = 7) or Angus bulls (n = 7). The EPD's of the sires shared a similar ranking within their respective breeds, and the selected calves were representative of all of the sires.

After calving (Spring; October 2002), the 80 cow–calf pairs (20 male calves of each GG) were raised in the same pasture with free-choice inorganic trace mineral supplementation as described above until weaning (Winter; May to July 2003; 246 ± 11 d of age). During the backgrounding period (postweaning phase), all animals were maintained on *Brachiaria decumbens* pasture and received the same free-choice inorganic trace mineral supplement, as mentioned before, until 22 mo of age (Winter; July 2004). Animals were surgically castrated at 18 mo of age (Autumn; March 2004). Full BW was recorded at birth, weaning (approximately 8 mo of age), 12, 18, and 22 mo of age (1 d before the feedlot phase). Due to limitations of farm management at Experimental Station, it was necessary to split the whole herd (the 80 cow–calf pairs) in 3 groups of weight management in each period (birth, weaning, 12, 18, and 22 mo of age). Thus, the interval between each group of weighing was around 2 wk. The order of weighing was maintained during the entire experiment to avoid an experimental bias. Also, if we plot months instead of days, the differences disappeared.

Calf average daily gain (**ADG**) was calculated as the difference between weaning weight and birth weight divided by days of age at weaning. Furthermore, the rate of ADG between weaning and yearling phases, yearling and 18 mo of age, and 18 mo and the beginning of the feedlot phase were calculated to assess energy requirements during feed restriction.

Feedlot management and diets

A total of 79 castrated steers (361 ± 54 kg initial BW) were used in a completely randomized design by age (22 mo ± 23 d of age) with four GG: Nellore (**NL**), ½ Angus × ½ Nellore (**AN**), ½ Canchim × ½ Nellore (**CN**), and ½ Simmental × ½ Nellore (**SN**). The experimental design provided ranges in metabolizable energy (**ME**) intake (**MEI**), BW, and ADG needed to develop regression equations to predict NEm requirements.

At the beginning of the feedlot phase, four steers of each GG were slaughtered in a commercial abattoir (Abatedouro Municipal de São Carlos, SP, Brazil) to determine initial carcass composition (baseline cattle). The remaining 63 steers were assigned to different nutritional treatments (**NT**; ad libitum or limit-fed treatments) by GG as follows: NL (n = 8 + 8), AN (n = 8 + 8), CN (n = 8 + 8), and SN (n = 8 + 7), respectively. The limit-fed treatment received 70% of the daily feed of the ad libitum treatment of the same GG. The decision to restrict the limit-fed treatment in 70% of the daily feed of the ad libitum treatment was supported by previous studies conducted by Old and Garret (1987) and Tedeschi et al. (2002) for similar GG.

Prior to entry to the feedlot, cattle received a subcutaneous injection of clostridial vaccine (Merial, Paulínia, SP, Brazil); ivermectin for control of internal and external parasites (1 mL/50kg of BW; Zoetis, São Paulo, SP, Brazil); and albendazole for control of internal parasites (1 mL/40 kg of BW; OuroFino, Cravinhos, SP, Brazil). Steers had ear tags, full BW recorded, and measured at the hip height (cm) 1 d before the study began.

In the feedlot, steers were fed for 101 d (including adaptation period) a diet containing (DM basis) 60% corn silage, 20% of citrus pulp, 10.3% of cottonseed meal, 7.8% finely ground corn (flint corn; mean particle size = 3 mm), 0.9% urea, and 1.0% mineral premix (Table 1). Steers were allocated in individual pens (n = 62) and fed twice a day at 0800 and 1600 hours (50% of the total diet in each feeding). The experimental diet was formulated to contain 13.3% crude protein (**CP**), 9.35% rumen degradable protein, and 2.6 Mcal/kg of DM ME (Table 1). The metabolizable protein content was calculated to meet the highest requirement of all GG tested (SN group), since its deficiency could impact animal growth and performance (NRC, 2000; NASEM, 2016).

Table 1. Composition of experimental diets[1] (DM basis)

Ingredient	%
Corn silage	60.0
Citrus pulp	20.0
Cottonseed meal, 38% CP	10.3
Corn grain, ground[2]	7.8
Urea	0.9
Mineral premix	1.0
Chemical composition	
Total digestible nutrients[3]	68.7
Crude protein	13.3
Rumen degradable protein	9.3
Starch[4]	18.8
Metabolizable energy, Mcal/kg of DM	2.6

[1]One composite sample of each ingredient was analyzed. The composite sample was formed by weekly samples composited together over the entire feedlot period (101 d).
[2]The trial was conducted using flint corn (mean particle size = 3 mm).
[3]Total digestible nutrients was estimated using concentrations of crude protein, ether extract, ash, neutral detergent fiber, lignin, acid, and neutral insoluble crude protein as described by Weiss et al. (1992).
[d]According to Knudsen (1997).

Steers were not implanted and did not receive any additional feed additive in the diet. The starch content of the experimental diet was 18.2% DM determined according to an enzymatic colorimetric assay proposed by Knudsen (1997). Dry matter intake (**DMI**) was measured and adjusted daily with a minimum of 5% orts allowance to the ad libitum treatment only. Ingredients and orts were sampled weekly and pooled for chemical composition. All BW measures collected during the feedlot phase were taken following a 16 h fasting period (food and water withdrawal, i.e., shrunk weights) at the beginning of the feeding period (22 mo of age), at the end of each experimental period (subdivided into four subperiods of 28, 28, 21, and 24 d each), and at the end of feedlot period. Furthermore, steers were measured at the hip height (cm) at the beginning and the end of the feedlot period. The frame size of the experimental steers was determined by measuring hip height at a given age according to the Guidelines for Uniform Beef Improvement Programs (BIF, 2010).

Analyses of feed samples

The DM content of corn silage was analyzed weekly to adjust diet composition. Feed samples and orts were taken weekly, frozen, and composited over each period to determine chemical composition (Table 2). Dried samples were ground through a 1-mm screen (Wiley Mill, Arthur H. Thomas, Philadelphia, PA) and subsamples were analyzed for DM in an air-forced oven at 105 °C for 24 h (AOAC, 1990), CP by the Dumas method (Wiles et al., 1998), ether extract (**EE**; AOAC, 1990), ash (AOAC, 1980), neutral detergent fiber (**NDF**), acid detergent fiber (**ADF**), and sulfuric acid lignin (nonsequential and ash-free; Van Soest et al., 1991). Sodium sulfite was used in the NDF assay and heat-stable amylase source as recommended by the National Forage Testing Association (Undersander et al., 1993). Alpha-amylase (Sigma A3306; Sigma–Aldrich) and sodium sulfite were added to each sample separately for NDF determination. Both NDF and ADF were expressed, including the residual ash. All samples were analyzed in triplicate.

Slaughter and body composition techniques

At the end of the experiment, on day 101 of the trial, steers were slaughtered after a 16 h fast in a commercial abattoir (Abatedouro Municipal de São Carlos). The slaughter

Table 2. Ingredients and chemical composition of the experimental diet (DM basis)

Components	Ingredients, %			
	Corn silage	Corn grain ground	Citrus pulp	Cottonseed meal
Dry matter	31.2	87.6	86.2	89.6
Crude protein	7.4	9.1	6.1	40.2
Ether extract	3.4	4.2	3.5	1.7
NDF[1]	43.8	13.4	20.4	34.4
ADF[2]	25.7	4.6	22.5	25.0
Lignin	3.7	1.2	3.2	2.7
NFC[3]	42.2	71.6	63.5	16.7
Ash	3.1	1.6	6.4	6.8

[1]NDF, neutral detergent fiber.
[2]ADF, acid detergent fiber.
[3]NFC, non-fibrous carbohydrates.

procedure followed the same process for the animals collected at the beginning of the feedlot period (baseline cattle).

Hot carcass weight (**HCW**), liver, kidneys, heart, and renal, pelvic, and inguinal fat weights were recorded. After a 24 h chill, the right and left sides of the carcass were weighed (chilled carcass weight), and the left side was separated. Carcass data included LM area and 12th-rib fat thickness.

The 9th to 11th-rib section was removed according to Hankins and Howe (1946) for body composition estimation. The 9th to 11th-rib sample was ground through a homogenizer (Hermann P-33A-3-789, 15 HP) and homogenized before sampling 400 g, divided into four Petri dishes. The partial water content of the samples was determined by freeze–drying the samples for approximately 80 h until a constant weight was reached. The lyophilized (freeze–dried) samples were fragmented into smaller portions, ground in a blender with dry ice (solid CO_2), and stored in an airtight plastic container for further analyses of DM (method 950.46), EE (method 960.39), CP (method 928.08), and ash (method 920.153), according to the AOAC (1997). Fractions of the lyophilized and ground samples were dried at 105 °C to determine the final DM content. EE content was determined by the Soxhlet method (AOAC, 1997; method 960.39), using 24 h extraction in petroleum ether. CP was determined using a LECO FP-528 apparatus (LECO Corp., St. Joseph, MI) and the quantity of nitrogen was multiplied by a factor of 6.25 (16% nitrogen in the protein). Ash was determined by burning the sample in a muffle furnace at 550 °C.

Empty BW (**EBW**) of the steers was estimated from HCW based on the equation developed by Berndt et al. (2017) following the same GG used in our study. Empty body chemical composition was estimated from linear regressions of percent water and fat in the 9th to 11th-rib, as described by Berndt et al. (2017). Protein and ash in the EBW were calculated from the estimated fat and water using the 80.23:19.74 ratio of protein and ash in the fat-free DM (Reid et al., 1955). The energy concentration used for protein and fat was 5.686 and 9.367 Mcal/kg of EBW, respectively (Blaxter and Rook, 1953).

Data calculation and analyses

Prediction of diet energy

The dietary digestible energy (**DE**) was estimated as 4.409 Mcal/kg of total digestible nutrients. The DE was converted to ME using an efficiency of 82% to convert DE to ME for the limit-fed treatment and the ad libitum group (NASEM, 2016). Although recent publications (Galyean et al., 2016; Seo et al., 2021) have indicated the DE to ME ratio might be greater than 82% and not constant, we adopted the 82% because of the high content of forage in our diets which is similar to those diets used to determine it in the past (Tedeschi and Fox, 2020).

Calculation of initial body composition

Lofgreen and Garrett (1968) method was used to compute energy retained and maintenance energy requirements. The initial EBW was computed from SBW, and then initial empty body fat (**EBF**) and empty body protein (**EBP**) were estimated from EBW for each animal and each GG, using the average EBW, SBW, EBF, and EBP data from the baseline cattle of the appropriate breed group, similar to that approach described by Tedeschi et al. (2002).

Calculation of net energy requirement

Empty body gains were calculated as the difference between initial EBW and final EBW. The caloric values of retained fat and protein were assumed to be 9.367 and 5.686 Mcal/kg, respectively (Blaxter and Rook, 1953). Heat production (**HP**, kcal/kg$^{0.75}$ of EBW per d) was calculated as the difference between MEI (kcal/kg$^{0.75}$ of EBW per d) and retained energy (**RE**, kcal/kg$^{0.75}$ of EBW per d). The average of the antilog of the intercept confidence interval (95% **CI**) of the linear regression between the log of HP on MEI was used to estimate the NEm (kcal/kg$^{0.75}$ of EBW per d; Lofgreen and Garrett (1968). The ME required for maintenance (**MEm**) was calculated by iteration, assuming that the maintenance requirement is the value at which HP is equal to MEI (kcal/kg$^{0.75}$ of EBW per d). The partial efficiency of energy utilization for maintenance (**km**) was calculated as NEm/MEm. The slope of the regression of RE on MEI above maintenance was assumed to be the partial efficiency of energy utilization for growth (**kg**), as described by Tedeschi et al. (2002).

Statistical analyses

Statistical analyses were performed using SAS (SAS Inst. Inc., Cary, NC). Performance of steers from birth to 18 mo of age was analyzed as a completely randomized design using the PROC GLM. Analyses of variance were performed assuming GG as a fixed effect (variable of interest) and steers were the experimental units. The comparisons of means were performed using least squares means using the Tukey test, assuming 5% as the cutoff for statistical significance.

The analyses of intake, diet energetic concentration, performance, and body composition were performed with PROC GLM, using a 4 × 2 factorial design of NT (i.e., ad libitum or limit-fed) and GG by the following statistical model:

$$\gamma = \mu + \alpha + \quad \beta + \quad \alpha\beta + \varepsilon,$$

where μ is the mean, α is the effect of the NT, β is the effect of GG, $\alpha\beta$ is the interaction of NT and GG, and ε is the random error.

The comparison of intercept and slope among NT and GG was performed using PROC GLM with the SOLUTION statement and the sum of squares type 3. The interaction or the main effects were removed from the statistical model, if not significant ($P > 0.05$). Because km and kg were obtained for the GG, and individual values for each steer were not available, the 95% CIs for different GG were computed by adding or subtracting one standard error to the intercept and slopes of the regressions used to compute NEm and NEg, so an approximate range for km and kg could be obtained as described earlier. Then, overlapping ranges of km and kg for different GG were assumed not significant at 5%.

Results and Discussion

Calf performance and cattle background

As mentioned previously, all cattle used in this study were raised on the same plane of nutrition from birth through slaughter and were born from a single Nellore cowherd; thus, no difference in age at weaning ($P = 0.534$) and slaughter ($P = 0.179$ and $P = 0.896$, for GG and NT, respectively) were observed (Tables 3 and 6). In our study, steers spent around 87% of their lives grazing tropical pasture and only 13%

Table 3. Least squares means and standard errors for the growth performance of Nellore and *B. taurus* × Nellore crosses steers from birth through 18 mo of age

Item	Genetic group[1]				SEM	*P*-value
	NL	CN	AN	SN		
No. of cattle	20	20	20	20	–	
Birth to weaning						
Birth weight, kg	32	31	31	29	0.99	0.1964
Age at weaning, d	243	243	248	247	2.98	0.5339
Weaning weight, kg	238[b]	249[b]	269[a]	247[b]	6.24	0.0066
ADG, kg/d	0.847[b]	0.894[b]	0.960[a]	0.878[b]	0.02	0.0088
Weaning to yearling						
Yearling weight, kg	238[b]	239[b]	260[a]	234[b]	5.95	0.0142
Age at yearling, d	381	367	363	394	3.86	0.0875
ADG, kg/d	−0.010	−0.081	−0.079	−0.119	0.03	0.1026
12 to 18 mo old						
Weight at 18 mo, kg	289[b]	296[b]	323[a]	296[b]	6.45	0.0019
Age at 18 mo, d	576	566	560	567	5.35	0.2054
ADG, kg/d	0.230[b]	0.292[a]	0.328[a]	0.310[a]	0.02	0.0139
18 mo to beginning of the feedlot phase						
Weight at the beginning of the feedlot, kg	297[b]	303[b]	336[a]	311[b]	6.68	0.0006
Age at beginning, d	661	661	649	651	5.39	0.2620
ADG, kg/d	0.060	0.054	−0.181	0.160	0.17	0.5805

[1]NL, Nellore; AN, one-half Angus + one-half Nellore; CN, one-half Canchim (five-eighths Charolais + three-eighths Zebu) + one-half Nellore; SN, one-half Simmental + one-half Nellore. Animals were surgically castrated at 18 mo of age.
[a,b]Distinct letters in the same row differ at $P < 0.05$ by the Tukey test for genetic group.

of their lives in feedlot conditions. According to Ferraz and Felício (2010), the Brazilian beef industry is characterized by long-term grazing followed by a short finishing period in feedlot, as reported in our study.

There was no difference ($P = 0.196$) in calf birth weight between NL and crossbred cattle (CN, AN, and SN; Table 3). However, AN calves were heavier at weaning ($P = 0.007$) and showed higher ADG from birth through weaning ($P = 0.009$) in comparison to NL, CN, and SN (Table 3 and Figure 1). AN calves weighed more than 24 kg at weaning and gained 90 g more daily between birth and weaning than the overall mean of NL, CN, and SN. The greater preweaning performance of crossbred calves compared with straightbred calves has been reported (Browning et al., 1995; Calegare et al., 2007). Calegare et al. (2007) stated that Nellore calves were lighter at birth and weaning and had the lowest ADG compared with crossbred calves (¾ Canchim × ¼ Nellore, ½ Canchim × ¼ Angus × ¼ Nellore, and ½ Canchim × ¼ Simental × ¼ Nellore). However, in our study, NL calves had similar weaning weight and ADG from birth through weaning in comparison to CN and SN, and the possibility of these results could be explained by the environmental condition, especially the milk production of the NL dams affecting the MEI from CN and SN progenies. Previous studies stated that milk production potential is limited in Nellore cows suckling *B. taurus* × Nellore calves compared with Continental or British *B. taurus* × Nellore crosses cows (Espasandin et al., 2001; Restle et al., 2003; Calegare et al., 2007; Albertini, et al., 2012). Calegare et al. (2007) documented that SN and AN cows had greater total milk production (1.179 ± 91.4 kg, 980 ± 85.2 kg, respectively) than NL cows (661 ± 90 kg). In agreement, Jenkins et al. (1991) reported that nutritional environment, age at weaning, the genetic potential for growth, milk production of dams, and the interactions among these factors could affect the progeny preweaning performance.

sAlthough AN steer had greater yearling weight ($P = 0.014$) than NL and any of the other *B. taurus* crossbreds, all GG lost BW between weaning and 12 mo of age, showing similar ADG ($P = 0.103$) from weaning to yearling (Table 3 and Figure 1). The postweaning stress of cattle may explain this finding mainly due to the low quality and reduced production of the tropical pasture (*B. decumbens* pasture) during the winter season (dry season from July to September) receiving only free-choice inorganic trace mineral supplement, without any concentrate supplementation. It is well documented that this loss of BW during the dry season can be remediated depending on the level and type of supplementation (Tedeschi et al., 1999, 2000a, 2000b). In contrast to the winter season (dry season), the better production and quality of the tropical pasture during the spring and summer seasons (rainy seasons, October to May) enabled all GG to increase BW; however, AN steers had higher weight at 18 mo of age ($P = 0.002$) in comparison to NL, CN, and SN (Table 3 and Figure 1). AN steers were 10% heavier at 18 mo of age compared with NL and the others crossbred steers. When evaluating the rate of gain from 12 to 18 mo of age, NL cattle had lower ADG ($P = 0.014$) than the other groups (Table 3).

A very low rate of gain from 18 mo of age until the beginning of the feedlot phase was observed in our study, with no difference ($P = 0.581$) in the ADG for all GG (Table 3). The nutritional deprivation related to the low quality and quantity of the pasture during the autumn season (dry season, March to June) beyond the stress of castration of the animals certainly impacted the performance during the feedlot

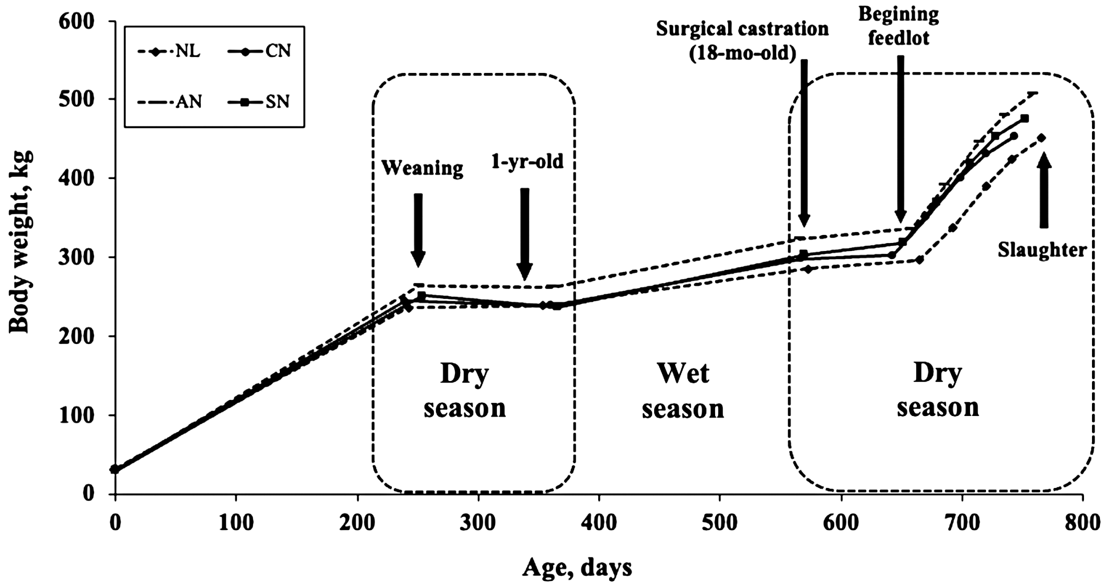

Figure 1. Growth performance of Nellore and *B. taurus* × Nellore crosses steers from birth through slaughter. NL, Nellore; AN, one-half Angus + one-half Nellore; CN, one-half Canchim (five-eighths Charolais + three-eighths Zebu) + one-half Nellore; SN, one-half Simmental + one-half Nellore. Animals were surgically castrated at 18 mo of age.

phase. The decision to castrate the animals in April was to reduce potential problems with flies due to the dry season. Furthermore, the management of castration of the animals almost 4 mo before entry into the feedlot usually prevents infections caused by dust and other contaminations inside the feedlot pens and consequently, prevents death loss in steers. In our study, the background phase was considered in average 410 d on pasture or approximately 62.6% of the cattle's lifetime when compared with the time from birth through entry into the feedlot. The variation in BW gain of all GG from birth through 22 mo of age, presented in this study, reflects the traditional beef production system under tropical conditions when only a mineral supplement is available during this period (Figure 1).

According to Detmann et al. (2014), because of seasonal fluctuations in the quantity and quality of pasture during the year, the cattle production on pasture in the tropics rarely has a balance between the supply and the requirement of nutrients of the animals, leading to a low ADG of cattle. In this perspective, Cartens et al. (1991) showed that restricting growth to 0.40 kg/d in early maturing beef steers (Angus × Hereford crossbred) for 6 mo before the feedlot phase would alter the composition of carcass and noncarcass tissue growth, feed efficiency, and consequently, change the NEm and NEg. In our study, the mean BW gain from birth through 22 mo of age of all GG was around 0.428 kg/d, suggesting the phenomenon of compensatory gain and consequently, changes in feed efficiency and NEm and NEg during the feedlot phase.

Steer performance, carcass characteristics, and visceral organs

Table 4 shows the mean body composition for the animals in each GG as computed from the baseline steers at the beginning of the feedlot period. The hip height of baseline steers ranged between 136 and 142 cm at 22 mo of age (with an average of 137 cm; Table 4), and according to BIF (2010), those animals were considered medium frame size. The initial SBW, EBW, and HCW were similar between NL, CN, and SN, but lighter when compared with AN steer evaluated on a constant age basis. For the baseline cattle, CN steers showed numerically low values of fat (% of EBW) and energy (Mcal/kg of EBW) compared with NL, AN, and SN steers (Table 4).

Table 4. Least squares means and standard errors means for weight, body composition, and visceral organs of baseline of Nellore and *B. taurus* × Nellore crosses steers with an average of 22 mo of age

Item[2]	Genetic group[1]				SEM
	NL	CN	AN	SN	
No. of cattle	4	4	4	4	–
Hip height, cm	142	136	134	138	1.47
SBW[2], kg	302	304	341	311	13.8
EBW[2], kg	272	275	310	281	13.28
HCW[2], kg	162	168	183	165	8.18
BFT[2], mm	0.27	0.25	0.27	0.00	0.21
LMA[2], cm[2]	44.0	50.0	53.6	47.4	3.62
Fat, % of EBW	12.0	11.1	12.0	12.0	0.50
Protein, % of EBW	19.8	19.8	19.7	19.8	0.14
Water, % of EBW	63.3	64.1	63.3	63.2	0.47
Ash, % of EBW	4.82	4.84	4.81	4.86	0.03
Liver, kg	3.42	3.27	3.96	3.53	0.18
Kidney, kg	0.56	0.52	0.66	0.53	0.04
Heart, kg	0.85	0.97	1.16	1.05	0.02
KPIF[2], kg	0.97	0.96	1.25	1.51	0.17
Energy, Mcal/kg of EBW	2.25	2.17	2.24	2.25	0.04

[1]NL, Nellore; AN, one-half Angus + one-half Nellore; CN, one-half Canchim (five-eighths Charolais + three-eighths Zebu) + one-half Nellore; SN, one-half Simmental + one-half Nellore. Animals were surgically castrated at 18 mo of age.
[2]SBW, shrunk BW; HCW, hot carcass weight; EBW, empty BW; BFT, back fat thickness; LMA, longissimus muscle area; KPIF, kidney, pelvic, and inguinal fat.

There were no interactions ($P > 0.05$) between GG and NT (ad libitum and limit-fed) for any variable presented in Tables 5–7. Although the NL and the other crossbred steers were considered a medium frame size, the final hip height differed ($P < 0.001$) among GG. A similar final hip height was observed for CN and SN, but a lower value was detected for AN steer. In contrast, NL steers had a higher final hip height than the other GG evaluated in our study (Table 5).

When fed ad libitum, AN steers had higher daily DMI (kg/d; $P < 0.001$) and MEI (Mcal/d; $P < 0.001$) in comparison to NL, CN, and SN. However, similar values of DMI and MEI were observed between NL, CN, and SN steers (Table 5). Similar daily DMI (% of BW; $P = 0.545$) was observed among GG. No difference ($P = 0.452$) in final hip height was observed for NT. The DMI (kg/d and % of BW/d) and MEI (kcal/kg$^{0.75}$ EBW) were, as designed, greater for ad libitum than for limit-fed steers ($P < 0.001$ and $P < 0.001$, respectively).

As expected, the age at slaughter was similar among GG ($P = 0.179$) and NT ($P = 0.896$), furthermore, no difference ($P = 0.697$) in initial SBW was observed for NT (Table 6). Based on the constant age analysis, AN steers had higher initial SBW ($P = 0.001$) at the beginning of the feedlot period than NL, CN, and SN. The AN steers were on average 39, 34, and 20 kg heavier than NL, CN, and SN steers, respectively, in terms of SBW. It was not expected that AN steers were heavier than SN crosses since the weaning period. Furthermore, considering that Simmental crossbred steers have a higher nutritional requirement than the others GG tested here (NASEM, 2016), the period of grazing *P. maximum* (Tanzania) and *B. decumbens* pasture with only free-choice inorganic trace mineral supplementation previous to the feedlot phase, may have permanently compromised the potential growth of SN steers when compared with the others GG. According to Owens et al. (1993), the retarded growth caused by nutrient restriction, particularly protein restriction, can reduce mature body size and increase the fat content of the carcass, especially with a large frame size of cattle. As a result, in our study, SN steers deposited fat on the carcass at a lower BW than the one expected for their biological type. Ferrell and Jenkins (1985) reported that Simmental was less efficient than Hereford at restricted levels, but at ad libitum intakes was more efficient during the postweaning phase. In contrast, in our study, SN steers fed ad libitum during the feedlot phase showed similar performance and carcass characteristics compared with NL and CN.

When ad libitum fed, AN steers had higher final SBW ($P < 0.001$) compared with NL, CN, and SN, but similar values were observed among CN and SN. In contrast, NL steers showed a lower final SBW than the other GG tested here (Table 6). AN steers had higher ADG ($P < 0.001$) than NL, CN, and SN; however, similar ADG was observed among NL, CN, and SL. AN steers had higher HCW ($P = 0.0009$) and backfat (**BF**; $P < 0.001$) than NL, CN, and SN. The AN group was 25 kg heavier in HCW and had 3.5 mm more BF on average compared with the other GG evaluated in our study (Table 6). As expected, final SBW ($P < 0.0001$), ADG ($P < 0.0001$), HCW ($P < 0.001$), and BFT ($P < 0.001$) was greater for steers fed ad libitum than limited-fed steers.

No difference in kidney weight ($P = 0.529$) and KPIF ($P = 0.311$) among GG were observed; however, AN steers had higher values of liver weight ($P < 0.001$) in comparison to NL, CN, and SN steers (Table 6). Liver weights in ad libitum-fed AN were 13% larger than NL, CN, and SN, whereas the mean liver weights of ad libitum steers were 30% larger than limited-fed steers. With exception of kidney ($P = 0.669$) and heart ($P = 0.095$), weights of liver ($P < 0.001$), kidney, pelvic, and inguinal fat (**KPIF**; $P < 0.001$) were influenced by NT (Table 6).

Body and gain composition

Despite beef breeds and diet variations, Simpfendorfer (1974) mentioned that 95.6% to 98.9% of the variation in the body's chemical components and energy value were associated with the variation in EBW. In our study, on a constant age basis, differences were observed for EBW ($P < 0.001$) and body composition ($P < 0.05$) between GG. AN steers had higher ($P < 0.001$) EBW compared with CN and SN,

Table 5. Least squares means and standard errors means for hip height and intake of Nellore and *B. taurus* × Nellore crosses steers fed ad libitum or limited amounts[1]

Item	NL		CN		AN		SN		SEM	*P*-value[2]		
	Ad libitum	Limit-fed	Ad libitum	Limit-fed	Ad libitum	Limit-fed	Ad libitum	Limit-fed		GG	NT	GG × T
No. of cattle	8	8	8	8	8	8	8	7	–	–	–	–
Final hip height, cm	145^{A}	144^{A}	140^{B}	139^{B}	136^{C}	136^{C}	140^{B}	140^{B}	1.44	<0.001	0.452	0.835
Intake												
DMI, kg/d	10.3^{aB}	7.2^{bB}	11.0^{aB}	7.3^{bB}	12.8^{aA}	8.7^{bA}	11.3^{aB}	7.7^{bB}	0.29	<0.001	<0.001	0.445
DMI, % of BW/d	2.9^{a}	2.1^{b}	2.8^{a}	2.1^{b}	3.0^{a}	2.2^{b}	2.9^{a}	2.1^{b}	0.09	0.545	<0.001	0.923
MEI, Mcal/d	29.9^{aB}	18.8^{bB}	30.6^{aB}	18.9^{bB}	35.3^{aA}	22.6^{aA}	30.1^{aB}	20.1^{bB}	0.81	<0.001	<0.001	0.426
MEI, kcal/kg$^{0.75}$ EBW	307^{aB}	231^{bB}	312^{aB}	227^{bB}	329^{aA}	244^{aA}	295^{aB}	231^{bB}	9.21	<0.001	<0.001	0.822

[1]NL, Nellore; AN, one-half Angus + one-half Nellore; CN, one-half Canchim (five-eighths Charolais + three-eighths Zebu) + one-half Nellore; SN, one-half Simmental + one-half Nellore. The limit-fed treatment received 70% of the daily feed of the ad libitum-fed treatment of the same genetic group.
[2]GG, genetic group; NT, nutritional treatment (ad libitum-fed or limit-fed).
[a,b]Distinct lowercase letters in the same row within group differ at $P < 0.05$ by the Tukey test for diet effect.
[A,B]Distinct capital letters in the same row differ at $P < 0.05$ by by the Tukey test for genetic group effect.

but similar values were observed among CN and SN. In contrast, NL steers showed a lower EBW than the other GG tested (Table 7). Both AN and SN steers had greater EBG ($P < 0.001$) than NL and CN steers. The EBW:SBW ratio was affected by GG ($P < 0.001$), showing values between 91.4% and 92.5%, being this range in agreement with the NASEM (2016), who reported that the EBW:SBW ratio could vary from 85% to 95%.

Tedeschi et al. (2002) suggested Nellore steers' maturity at 22% of EBF represented as 365 kg in final EBW. Due to the lower values of EBF (lower than 22%) of NL, CN, and SN steers fed ad libitum, we concluded that these GG were slaughtered at an earlier stage of maturity, and consequently, the protein mass did not reach a plateau.

Several authors (Krehbiel et al., 2006; Tedeschi et al., 2017; Tedeschi, 2019) reported that MEI is responsible for affecting RE, and the proportion of fat and protein in the gain; though the efficiency of use of energy for growth needs to be computed from RE deposited as protein (Tedeschi et al., 2017, Tedeschi, 2019). As reported previously, AN steers had higher MEI (Mcal/d) in comparison of the other GG evaluated, and consequently, showed greater percentages of fat

Table 6. Least squares means and standard errors means for performance, carcass characteristics, visceral organs, and energy balance of Nellore and *B. taurus* × Nellore crosses steers fed ad libitum or limited amounts[1]

Item	NL		CN		AN		SN		SEM	*P*-value[2]		
	Ad libitum	Limit-fed	Ad libitum	Limit-fed	Ad libitum	Limit-fed	Ad libitum	Limit-fed		GG	NT	GG × T
No. of cattle	8	8	8	8	8	8	8	7	–	–	–	–
Age at slaughter, d	765	761	743	746	759	744	749	758	8.49	0.178	0.896	0.602
Initial SBW[3], kg	296^{B}	299^{B}	302^{B}	303^{B}	336^{A}	336^{A}	318^{B}	315^{B}	9.94	0.001	0.697	0.988
Final SBW, kg	450^{aC}	386^{bC}	453^{aB}	397^{bB}	508^{aA}	454^{bA}	476^{aB}	424^{bB}	11.76	<0.001	<0.001	0.917
ADG[3], kg/d	1.53^{aB}	0.86^{bB}	1.50^{aB}	0.92^{bB}	1.70^{aA}	1.17^{bA}	1.56^{aB}	1.07^{bB}	0.44	<0.001	<0.001	0.479
HCW[3], kg	249^{aB}	216^{bB}	249^{aB}	220^{bB}	273^{aA}	247^{bA}	253^{aB}	229^{bB}	7.06	<0.001	<0.001	0.927
BFT[3], mm	4.4^{aB}	2.6^{bB}	4.4^{aB}	3.0^{bB}	8.8^{aA}	5.4^{bA}	4.0^{aB}	2.8^{bB}	0.63	<0.001	<0.001	0.219
LMA[3], cm^2	59.18	53.25	60.43	61.93	57.57	59.21	61.07	54.00	2.11	0.122	0.111	0.083
Liver, kg	6.11^{aB}	4.50^{bB}	6.26^{aB}	4.68^{bB}	7.13^{aA}	5.78^{bA}	6.48^{aB}	4.90^{bB}	0.21	<0.001	<0.001	0.923
Kidney, kg	0.91	0.80	0.86	0.80	0.97	0.84	0.93	0.78	0.32	0.529	0.668	0.366
Heart, kg	1.28^{B}	1.30^{B}	1.40^{AB}	1.29^{AB}	1.46^{A}	1.43^{A}	1.53^{A}	1.34^{A}	0.06	0.045	0.094	0.390
KPIF[3], kg	5.84^{a}	3.49^{b}	6.82^{a}	3.26^{b}	7.75^{a}	4.40^{b}	9.06^{a}	4.30^{b}	1.01	0.311	<0.001	0.710

[1]NL, Nellore; AN, one-half Angus + one-half Nellore; CN, one-half Canchim (five-eighths Charolais + three-eighths Zebu) + one-half Nellore; SN, one-half Simmental + one-half Nellore. The limit-fed treatment received 70% of the daily feed of the ad libitum-fed treatment of the same genetic group.
[2]GG, genetic group; NT, nutritional treatment (ad libitum-fed or limit-fed).
[3]SBW, shrunk BW; ADG, average daily gain; HCW, hot carcass weight; BFT, back fat thickness; LMA, longissimus muscle area; KPIF, kidney, pelvic, and inguinal fat.
[a,b]Distinct lowercase letters in the same row within group differ at $P < 0.05$ by the Tukey test for diet effect.
[A,B]Distinct capital letters in the same row differ at $P < 0.05$ by by the Tukey test for genetic group effect.

Table 7. Least squares means and standard errors means for body composition and energy balance of Nellore and *B. taurus* × Nellore crosses steers fed ad libitum or limited amounts[1]

Item	NL		CN		AN		SN		SEM	*P*-value[2]		
	Ad libitum	Limit-fed	Ad libitum	Limit-fed	Ad libitum	Limit-fed	Ad libitum	Limit-fed		GG	NT	GG × T
No. of cattle	8	8	8	8	8	8	8	7	–	–	–	–
EBW[3], kg	415^{aC}	353^{bC}	418^{aB}	363^{bB}	470^{aA}	418^{bA}	435^{aB}	389^{bB}	11.26	<0.001	<0.001	0.917
EBG[3], kg/d	1.47^{aB}	0.82^{bB}	1.43^{aB}	0.88^{bB}	1.62^{aA}	1.12^{bA}	1.55^{aA}	1.02^{bA}	0.04	<0.001	<0.001	0.479
EBW:SBW, %	92.0^{aC}	91.4^{bC}	92.1^{aBC}	91.5b^{BC}	92.5^{aA}	92.1^{bA}	92.2^{aB}	91.8^{bB}	0.09	<0.001	<0.001	0.584
Fat, % of EBW	19.4^{aB}	17.4^{bB}	19.1^{aB}	16.6^{bB}	21.7^{aA}	18.1^{bA}	19.8^{aB}	17.2^{bB}	0.53	0.002	<0.001	0.546
Protein, % of EBW	18.0^{aB}	18.7^{bB}	18.0^{aB}	18.7^{bB}	17.6^{aA}	18.3^{bA}	17.9^{aB}	18.5^{bB}	0.14	0.017	<0.001	0.960
Water, % of EBW	58.0^{aB}	59.2^{bB}	58.3^{aB}	60.0^{bB}	56.4^{aA}	58.9^{bA}	57.8^{aB}	59.6^{bB}	0.41	0.004	<0.001	0.389
Ash, % of EBW	4.4^{aB}	4.6^{bB}	4.4^{aB}	4.6^{bB}	4.3^{aA}	4.5^{bA}	4.4^{aB}	4.5^{bB}	0.03	0.017	<0.001	0.960
RE[3], kcal/kg$^{0.75}$ of EBW per d	61.0^{aB}	41.0^{bB}	62.6^{aB}	42.7^{bB}	71.2^{aA}	48.0^{bA}	63.9^{aB}	43.5^{bB}	3.28	0.056	<0.001	0.952
HP[3], kcal/kg$^{0.75}$ of EBW per d	246^{aAB}	190b^{AB}	250^{aAB}	184^{bAB}	258^{aA}	196^{bA}	231^{aB}	188^{bB}	5.06	0.013	<0.001	0.147

[1]NL, Nellore; AN, one-half Angus + one-half Nellore; CN, one-half Canchim (five-eighths Charolais + three-eighths Zebu) + one-half Nellore; SN, one-half Simmental + one-half Nellore. The limit-fed treatment received 70% of the daily feed of the ad libitum-fed treatment of the same genetic group.
[2]GG, genetic group; NT, nutritional treatment (ad libitum-fed or limit-fed).
[3]EBW, empty BW; EBG, empty body gain; RE, retained energy; HP, heat production.
[a,b]Distinct lowercase letters in the same row within group differ at $P < 0.05$ by the Tukey test for diet effect.
[A,B]Distinct capital letters in the same row differ at $P < 0.05$ by by the Tukey test for genetic group effect.

(% of EBW; $P = 0.002$), protein (% of EBW; $P = 0.017$), and RE (kcal/kg$^{0.75}$ of EBW per d; $P = 0.057$) than NL, CN, and SN. In agreement with the aforementioned, NL, CN, and SN steers showed similar values of MEI, EBW, fat, protein, and RE (average of 30.22 Mcal/d, 422 kg of EBW, 19.4% of EBW, 17.9% of EBW, and 62.5 kcal/d/kg$^{0.75}$ EBW, respectively). When fed ad libitum, AN steers had higher HP ($P = 0.013$) in comparison of SN steers, but similar to NL and CN.

Steers fed ad libitum had greater EBW ($P < 0.001$), EBG ($P < 0.001$), EBW:SBW ratio ($P < 0.001$), RE ($P < 0.000$), and HP ($P < 0.001$), indicating that HP increased as MEI increased. Owens et al. (1995) mentioned that cattle's mature size could be altered genetically and nutritionally. As expected in our study, limit-fed steers showed higher values of protein (% of EBW) and lower values of fat (% of EBW), on a constant age analysis, compared with steers fed ad libitum, suggesting that restricting MEI could, theoretically, increase mature body size.

Energy requirement for maintenance and efficiency of energy utilization

Although several studies have shown that the maintenance energy expenditures vary with breeds, BW, physiological age, previous nutrition, as well as, differences in procedures and approaches (Ledger and Sayers, 1977; Geay, 1982; Ferrell and Jenkins, 1998; NASEM, 2016; Tedeschi and Fox, 2020), until now, there is no available data comparing the energy requirements of different GG of beef cattle during finishing phase raised under the same plane of nutrition from birth through slaughter and born from a single cow herd in tropical conditions.

In our study, the slope ($P = 0.600$) and intercept ($P = 0.702$) of the regression of log HP on MEI were similar among GG (Table 8). The exponential relationship between HP and MEI is shown in Figure 2. When evaluating at the same age and at the same frame size, there were no differences in NEm requirement between Nellore and AN ($P = 0.528$), CN ($P = 0.671$), and SN ($P = 0.706$). Thus, the analyses of the pooled data for NL, CN, AN, and SN resulted in a common NEm requirement of 86.86 kcal/d/kg$^{0.75}$ EBW. Assuming a 300-kg SBW steer, the NEm requirement is equivalent to 79.6 kcal/d/kg$^{0.75}$ EBW, which is very close to the 77 kcal/d/kg$^{0.75}$ EBW reported by Lofgreen and Garrett (1968). In agreement with our results, Fox and Black (1984) mentioned that beef cattle breeds with similar frame sizes are assumed to have similar net energy requirements at the same body composition.

According to the NRC (1996, 2000), the NEm was assumed to be 10% lower for *B. indicus* breeds (including Africander, Barzona, Brahman, and Sahiwal), with crossbreds being intermediate. Chizzotti et al. (2008) observed a 14% lower NEm requirement for Nellore purebreds and Nellore × *B. taurus* crossbreds, an average NEm of 75 kcal/d/kg$^{0.75}$ EBW, compared with our value of 86.8 kcal/d/kg$^{0.75}$ EBW. The meta-analysis of Marcondes et al. (2013) resulted in a NEm of 79.4 kcal/d/kg$^{0.75}$ EBW for Nellore cattle. Tedeschi and Fox (2020) reported that their 95% CI was 74.1 to 84.7 kcal/d/kg$^{0.75}$ EBW for Nellore cattle, and the average NEm of 77 kcal/d/kg$^{0.75}$ EBW reported by Lofgreen and Garrett (1968) would be about 84 kcal/d/kg$^{0.75}$ EBW, well within the CI of existing databases used for meta-analysis. This approach agrees with Frisch and Vercoe (1977), who suggested that Nellore and *B. taurus* × Nellore crosses use low-quality forage diets more efficiently than *B. taurus* cattle due to a lower maintenance requirement. They also suggested a 10% lower NEm requirement for Zebu. In contrast, when a high-quality diet is fed, *B. taurus* cattle gain weight more efficiently and at a faster rate than *B. indicus* cattle, because *B. taurus* consume more feed relative to the energy requirements for maintenance (NASEM, 2016). On the opposite, other experimental results do not support the concept of lower NEm for Nellore cattle (Ferrell and Jenkins, 1998; Tedeschi et al., 2002).

The NEm of 86.8 kcal/d/kg$^{0.75}$ EBW, reported in this study, was very similar to the NEm of 82.8 kcal/d/kg$^{0.75}$ EBW for Brahman crossbred steers reported by Ferrell and Jenkins (1998) and Tedeschi et al. (2002) who reported the NEm of 81.2 kcal/d/kg$^{0.75}$ EBW for Nellore steers. The recent publication from NASEM (2016) mentioned that the *B. indicus* cattle do not need the 10% adjustment for NEm, specifically those raised in Brazil.

The raw data presented in this article shows the exact proposal of the NRC (1996) described earlier, that crossbreds are intermediate between the European and Zebu. However, although not statistically different, the NEm values from NL and AN observed in our study were 85.53 and 90.76 kcal/d/kg$^{0.75}$, respectively, showing a decrease in NEm of 5.76% for NL in comparison with AN. Thus, our data indicate a relative difference between purebred NL and AN crossbred steers of a magnitude that is in agreement with data from NRC (1996).

There might be circumstances in which NEm requirement is reduced, but the basal metabolism is quite similar (Tedeschi and Fox, 2020). Thus, considering that the genetics of breeds and nutritional managements change over time, the

Table 8. Regression of logarithm of heat production on ME intake to describe energy utilization by Nellore and *B. taurus* × Nellore crosses steers[1]

GG[2]	Intercept[2]	Slope (× 1,000)	*N*	r^2	RMSE	NEm	MEm	km (CI)	kg (CI)
AN	1.96 ± 0.025	1.374 ± 0.086	16	0.94	0.015	90.76	142.44	63.7 (56.3,69.3)	28.4% (14.6, 42.2)
CN	1.92 ± 0.014	1.541 ± 0.052	16	0.98	0.009	82.28	130.98	62.8 (60.7, 66.2)	22.1% (8.4, 35.9)
NL	1.93 ± 0.029	1.495 ± 0.107	16	0.93	0.016	85.53	137.12	62.4 (62.8, 69.1)	24.6% (10.4, 38.8)
SN	1.95 ± 0.044	1.401 ± 0.168	14	0.85	0.024	88.80	139.11	63.8 (46.6, 73.3)	29.5% (29.5, 29.5)
All	1.94 ± 0.013	1.450 ± 0.049	62	0.93	0.016	86.86	137.53	63.2 (59.3, 66.5)	26.0% (23.3, 28.6)

[1]Values are mean ± SE. RMSE, root of the mean square error; NEm, net energy required for maintenance (kcal/kg$^{0.75}$ of EBW per d) calculated as the antilog of the intercept; MEm, metabolizable energy required for maintenance (kcal/kg$^{0.75}$ of EBW per d) calculated by iteration assuming heat produced is equal to ME intake at maintenance; km, efficiency of energy utilization for maintenance (calculated as NEm/MEm), kg, efficiency of energy utilization for growth which was calculated as the slope of the regression of RE (kcal/kg$^{0.75}$ EBW) on ME intake (kcal/kg$^{0.75}$ empty BW). CI, confidence interval for km and kg were computed by adding or subtracting one SE of the intercept and slopes for each GG, and calculating the NEm, MEm, km, and kg as described earlier.
[2]NL, Nellore; AN, one-half Angus + one-half Nellore; CN, one-half Canchim (five-eighths Charolais + three-eighths Zebu) + one-half Nellore; SN, one-half Simmental + one-half Nellore. The limit-fed treatment received 70% of the daily feed of the ad libitum-fed treatment of the same genetic group.

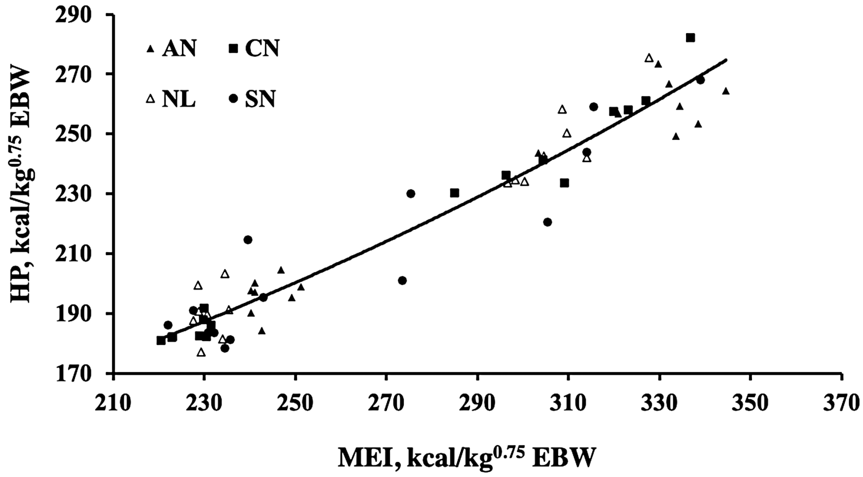

Figure 2. Exponential relationship between heat production (HP) and metabolizable energy intake (MEI) of Nellore and *B. taurus* × Nellore crosses steers from birth through slaughter. NL = Nellore; AN = one-half Angus + one-half Nellore; CN = one-half Canchim (five-eighths Charolais + three-eighths Zebu + one-half Nellore; SN = one-half Simmental + one-half Nellore. Exponential equation: HP = 86.864e$^{0.0033MEI}$, r^2 = 0.9338.

NEm of cattle deserves more attention for the research and nutritionists.

Comparisons of maintenance requirements have to account for the genetic background of the tested population. We have demonstrated (Almeida, 2005) by comparing two lines of Nellore divergently selected for growth that selection significantly increased maintenance requirements. Similiarly, Moraes et al. (2015) demonstrated very large differences in Holstein maintenance requirements over 3 decades of selection for milk production.

Because there were no differences among GG for slope and intercept when regressing HP on MEI, assuming that the maintenance requirement is the value at which HP is equal to MEI (kcal/d/kg$^{0.75}$ EBW; Table 8), we presumed the MEm was similar among GG. Thus, the MEm requirement had a common value of 137.53 kcal/d/kg$^{0.75}$ EBW. The km and kg values (Table 8) were similar among GG (P > 0.05 and P > 0.05, respectively) and were on average 63.2% and 26.0%, respectively. Similar values of km (ranging between 65% and 69%) from Brahman crossbreed steers were reported by Ferrell and Jenkins (1998). In contrast, higher values of km and kg (69.9% and 52.7%, respectively) for Nellore steers were reported by Tedeschi et al. (2002), as well as the km and kg for Nellore × Red Angus crossbreed steers mentioned by Chizzotti et al. (2007) were 70.6% and 47.0%, respectively. To calculate NEm based on comparative slaughter methods (Lofgreen and Garrett (1968), it is necessary to feed animals at two or three levels of intake (one approximating maintenance, one at libitum intake, and a third at an intermediate level). The different intake levels will result in a variation of RE in the body and HP of the animals. Our study became one of the first experiments comparing the energy requirement of different GG reared under the same management and exposed to the same feeding system throughout life. In our study, steers were assigned of two NT by GG: ad libitum and limit-fed (treatment received 70% of the daily feed of the ad libitum-fed treatment of the same GG) as supported by previous researches conducted by Old and Garret (1987) and Tedeschi et al. (2002). However, taking into account that the increased feed intake is the major component of compensatory growth when animals are placed on full feed (NASEM, 2016), a higher DMI as a % of BW for all GG fed ad libitum (average 2.90% of BW) observed in our study, suggested a compensatory growth. These higher values of DMI may be related to a very long period of feed restriction of the animals due to the lower quality and quantity of the pastures and consequently low rate of growth, especially during the 18 mo of age through the beginning of the feedlot (Table 3). According to Lofgreen and Kiesling (1985), periods of compensatory growth are usually characterized by increases in feed intake throughout the feeding period. Thus, the decision to restrict the limit-fed treatment in 70% of the daily feed of the ad libitum treatment certainly overestimated the amount of feed offered to the limited-fed steers and consequently affected the net requirement calculations in our study. Thus, our data became the first study showing how the energy requirement of the cattle could be altered when animals are influenced by compensatory gain.

Conclusion

Nellore and Nellore crossbreds reared in tropical conditions, receiving only free-choice minerals from birth through the beginning of the feedlot phase, have the potential to alter the DMI, carcass composition, mature weight, and consequently, affect the energy requirement for maintenance during the finishing period. The energy requirement of the cattle could be altered when animals are influenced by compensatory gain. Evaluating at the same age and at the same frame size, the analyses of the pooled data for NL, CN, AN, and SN resulted in a common NEm requirement of 86.86 kcal/d/kg$^{0.75}$ EBW. However, although not statistically different, the NEm values from NL showed a decrease in NEm of 5.76% when compared with AN steers. Thus, our data indicate a relative difference between purebred NL and AN crossbred.

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Conflict of Interest Statement

The authors declare no real or perceived conflicts of interest.

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