

## Morphometric measurements of calves of beef cattle from different genetic groups up to one year of age

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Edited by: Gerson Barreto Mourão

Received November 27, 2020

Accepted June 01, 2021

**ABSTRACT:** Heterosis plays an important role on yield and profitability of beef production systems. This study evaluates the morphometrics of purebred Nellore (N) and Charolais (C) animals and of the second (G2) and third (G3) generations of their alternating crosses, regarding the effects of genetic group and heterosis from birth to 365 days of age. The experiment comprised 159 calves (C = 29, N = 22, G2 - 3/4C 1/4N = 21, 3/4N 1/4C = 9, G3-5/8C 3/8N = 44 and 5/8N 3/8C = 34). The foreshank girth (FG), thoracic girth (TG), body length (BL), and hip height (HH) were measured after birth, and at 63, 210, and 365 days of age, and the total increases were calculated. The Charolais animals had greater FG, TG, and BL values than Nellore, while the latter had greater HH. For the offspring generations, the predominance of Charolais genes in the genotypes resulted in greater measurements for FG and TG in G2, whereas the predominance of Nellore genes resulted in higher HH values in both generations. The crossbred animals had greater values for all measurements than the purebreds, with more significant differences in FG, TG, and BL compared to Nellore purebreds and in HH compared to Charolais. Charolais animals show higher values for muscularity; while, Nellore animals are taller. Crossbred animals show greater development compared to purebreds, indicating a significant effect of heterosis.

**Keywords:** biometry, cattle breeding, cattle growth, genetic variation, mating

### Introduction

Studies on growth performance in animals are based on the assessment of body weight, which is more susceptible to the nutritional fluctuations experienced by animals over time than linear morphometrics (Northcutt et al., 1992). Due to the lower variation, along with the easiness to make large-scale measurements, morphometrics is viewed with great interest in animal selection programs (Hagger and Hoffer, 1991).

Morphometrics describes an individual or a population more completely than weight alone does (Salako, 2006). It is also useful for understanding animal growth (Choy et al., 2017) and used as selection criteria based on growth (Van Marle-Köster et al., 2000). Since morphometric traits of size and shape are indicators of development of an animal body over time (Fernandes et al., 2010), they can be used as good predictors of performance and longevity of animals (Lee and Kim, 2010).

Objective evaluation of body conformation traits using an animal morphometrics, along with the weight and age, allows the efficient use of morphometrics to identify high-yielding animals (Vaz et al., 2016). Furthermore, measurements are less costly with relatively high accuracy and consistency (Ige et al., 2015). Therefore, determining different animal biotypes and heterosis behavior in measurements is fundamental for cattle crossbreeding and selection programs.

This study aimed to determine the effects of genetic group and heterosis on the morphometric measurements from birth to 365 days of age of Nellore and Charolais purebred animals and their second and third crossbred generations.

### Materials and Methods

The experiment was conducted in Santa Maria, Rio Grande do Sul State, Brazil, in a region known as the Central Depression (29°43'25" S, 53°42'19" W, altitude 95 m). The climate of the region is humid subtropical. The Institutional Committee on Animal Use (CEEA No. 8250-2015) approved all procedures.

In the experiment, we used 159 calves from continuous alternating crossbreeding of Charolais and Nellore breeds. The animals were purebred Charolais (C = 29) and Nellore (N = 22), second generation crossbreeds (G2 - 3/4C 1/4N = 21 and 3/4N 1/4C = 9), and third generation crossbreeds (G3 - 5/8C 3/8N = 44 and 5/8N 3/8C = 34). The animals were born during the same season and were kept under similar conditions of nutrition and health management. The same bulls sired the Charolais and Nellore calves and the crossbreeds. The breeding season consisted of 45 days of artificial insemination followed by 45 days of natural mating. The calves were generated with the semen of six bulls from each breed during insemination and two clean-up bulls of each breed in separate areas when transferred to the field for mating.

The calves, from birth to early weaning at 63 days  $\pm$  3 days, remained with their dams in natural pastures as a single management group, at a stocking rate of 0.9 AU ha<sup>-1</sup> (AU = animal unit = 450 kg body weight). After weaning, all the calves were submitted to the same management, receiving the same feed. For the first five days after weaning, the calves remained in a corral, receiving commercial feed containing 22 % crude protein (CP). Then, they received corn silage in addition to the concentrate containing 18 % CP at an amount equal to 1 % of live weight for more 30 days. Afterward, the calves were kept in a pasture of millet (*Penisetum americanum* Leeke), supplemented with the same concentrate in the same proportion until five months of age. From 5 to 12 months of age, the calves were kept in natural pastures, receiving corn silage and a concentrate containing 18 % CP.

The cows and calves were weighed after calving and again after weaning at 63 days. The calves continued to be weighed up to at seven months (210 days) and twelve months (365 days) of age. On these occasions, body morphometrics were taken, in addition to the total gains, including foreshank girth (FG), thoracic girth (TG), body length (BL), and hip height (HH). HH was measured with a setsquare, while the chest and FG, along with BL, were measured with a tape. HH corresponded to the distance from the sacrum to the ground. TG was equal to the girth of the animal, measured just behind the front limbs. BL corresponded to the distance between the humeroscapular joint and the hip joint. FG was measured at the medial portion of the arm, between the radiocarpal joint and the end of the olecranon.

We evaluated the effects of heterosis and the genetic group on the morphometric traits of body growth in the animals. Heterosis of each generation (G2 and G3) and retained heterosis for each trait was obtained through the equations described by Pacheco et al. (2010):

Heterosis (%) = [(overall crossbred mean value/overall purebred mean value) - 1]\*100;

Retained heterosis = [(overall crossbred mean/overall straightbred mean) - 1]\*100;

The experimental design was completely randomized, with a different number of replications per genetic group. The data obtained for the different intervals were subjected to the analysis of variance and the mean values compared by the t-test of the SAS 9.4 statistical software (2013), using the following mathematical model:

$$Y_{ijklm} = \mu + MS_i + GG_j(MS_i) + DGG_k + ID_l + CO_m + E_{ijklm}$$

where:  $Y_{ijklm}$  are the dependent variables (body measurements);  $\mu$  is the mean value for all observations of the trait;  $MS_i$  is the effect of the  $i$ -th mating system: 1 (purebreeds), 2 (G2 crossbreeds), 3 (G3 crossbreeds);  $GG_j(MS_i)$  corresponds to the effect of the genetic group

of index  $j$ , where 1 corresponds to the Charolais breed and 2 to the Nellore breed within  $MS_i$ , 1 corresponds to genetic group 3/4C 1/4N and 2 to the 3/4N 1/4C within  $MS_i$ ; 2; 1 corresponds to the 5/8C 3/8N animals, and 2 to the 5/8N 3/8C animals, within  $MS_i$ ; 3;  $DGG_k$  maternal effects (at birth) and maternal heterosis effect;  $ID_l$  is the covariable of age for the dam of the animals of index 1 ( $\beta$ 's are regression coefficients associated to age of mother in years (AM,  $3 \leq AM \leq 12$ ));  $CO_m$  is the covariable of calving order for calves  $m$ ; and  $E_{ijklm}$  is the residual random effect NID (0,  $\sigma^2$ ).

The same mathematical model was used for measurements at 210 and 365 days; however, the  $DDG_k$  was excluded.

## Results

The morphometric characteristics of the steers, regardless of genetic group or mating system, showed growth from birth to 365 days, according to data descriptive statistics (Table 1).

### Effects of genetic groups within mating systems (purebred and crossbred)

Differences ( $p > 0.05$ ) in FG (Table 2) occurred between purebred animals at all ages evaluated and were higher in Charolais animals. Charolais animals showed similar FG gains (10.49 cm) to Nellore (9.48 cm,  $p < 0.05$ ), from birth to 365 days of age. Within each generation, FG only presented a difference at 365 days with superiority for the offspring of Charolais bulls in G2, and for the offspring of Nellore bulls in G3. The increase in FG from birth to 365 days in the crossing generations was higher for the offspring of Charolais bulls than that of Nellore bulls in G2 (11.88 vs. 9.33 cm, respectively), but not differing in G3 (11.79 vs. 12.14 cm, respectively).

Charolais animals had greater TG than Nellore ( $p < 0.05$ ) at 365 days of age only, with total absolute increases of 64.46 and 58.08 cm from birth to one year of age respectively (Table 3). Within the crossbred generations, TG presented similar behavior in G2 and was greater at 365 days of age ( $p < 0.05$ ) in animals with a predominance of Charolais, but with no difference ( $p > 0.05$ ) in G3 at the other ages under evaluation. The total increase from birth to 365 days of age was greater ( $p < 0.05$ ) for offspring of Charolais bulls than of Nellore bulls (66.72 vs. 58.62 cm) in G2, but with no difference ( $p > 0.05$ ) in G3 (67.71 vs. 65.88 cm).

Among the purebreeds, BL differed ( $p < 0.05$ ) only at 365 days of age and was greater in Charolais than in Nellore animals with total absolute gains of 49.82 and 44.64 cm from birth to 365 days of age, respectively (Table 4). Within each generation, BL did not differ ( $p > 0.05$ ) at any age with a total increase from birth to 365 days of 51.32 and 49.63 cm in G2, and with values of 51.68 and 50.61 cm in G3, respectively, for offspring of Charolais bulls and Nellore bulls.

**Table 1** – Means and standard derivations, coefficient of variation, and minimum and maximum values for morphometric traits at different ages for growing beef cattle.

Traits	Means	SD	CV	Mi V	Ma V
Foreshank girth at birth	18.72	1.51	7.37	14.0	23.0
Thoracic girth at birth	72.81	4.23	5.49	63.0	83.0
Body length at birth	61.18	5.20	8.16	50.0	88.0
Hip height at birth	71.57	4.53	5.11	57.0	84.0
Foreshank girth at 63 days	22.64	1.56	6.45	18.0	27.0
Thoracic girth at 63 days	93.77	5.59	6.42	78.0	111.0
Body length at 63 days	79.13	5.59	6.42	65.0	101.0
Hip height at 63 days	82.83	5.18	4.76	65.0	93.0
Foreshank girth at 210 days	27.57	2.43	7.37	22.0	34.0
Thoracic girth at 210 days	117.6	9.29	5.13	93.0	141.0
Body length at 210 days	99.23	7.31	5.08	79.0	117.0
Hip height at 210 days	96.67	6.79	4.17	78.0	112.0
Foreshank girth at 365 days	29.91	3.05	8.15	22.0	36.0
Thoracic girth at 365 days	137.6	11.23	6.24	106.0	161.0
Body length at 365 days	111.1	8.92	6.01	88.0	132.0
Hip height at 365 days	1.08	7.11	4.64	91.0	124.0
Foreshank girth gain from birth to 365 days	11.18	3.14	25.23	4.0	20.0
Thoracic girth gain from birth to 365 days	64.75	11.48	14.60	35.0	88.0
Body length gain from birth to 365 days	49.97	9.13	15.46	19.0	72.0
Hip height gain from birth to 365 days	36.22	6.41	14.51	15.0	49.0

SD = standard deviation; CV = Coefficient of variation; Mi V = Minimum Values; Ma V = Maximum Values.

**Table 2** – Mean values, standard errors, and heterosis for foreshank girth (cm) in males at different developmental stages, according to the genetic group.

Genetic Composition			Animal age (days)				Increase	
Bull	Cow	Calf	Birth	63	210	365		
C	C	C	19.47 <sup>a</sup>	23.27 <sup>a</sup>	27.67 <sup>a</sup>	29.88 <sup>a</sup>	10.49 <sup>a</sup>	
N	N	N	17.31 <sup>b</sup>	21.46 <sup>b</sup>	25.70 <sup>b</sup>	26.83 <sup>b</sup>	9.48 <sup>a</sup>	
Mean values purebred			18.39 <sup>A</sup>	22.37 <sup>A</sup>	26.69 <sup>B</sup>	28.36 <sup>B</sup>	9.99 <sup>B</sup>	
C	½ N ½ C	¾ C ¼ N	18.78 <sup>a</sup>	22.35 <sup>a</sup>	27.57 <sup>a</sup>	30.71 <sup>a</sup>	11.88 <sup>a</sup>	
N	½ C ½ N	¾ N ¼ C	19.41 <sup>a</sup>	23.83 <sup>a</sup>	27.99 <sup>a</sup>	28.67 <sup>b</sup>	9.33 <sup>b</sup>	
Mean values G2			19.10 <sup>A</sup>	23.09 <sup>A</sup>	27.78 <sup>A</sup>	29.69 <sup>A</sup>	10.61 <sup>A</sup>	
C	¾ N ¼ C	5/8 C 3/8 N	18.40 <sup>a</sup>	22.51 <sup>a</sup>	27.88 <sup>a</sup>	30.28 <sup>b</sup>	11.79 <sup>a</sup>	
N	¾ C ¼ N	5/8 N 3/8 C	19.19 <sup>a</sup>	22.87 <sup>a</sup>	28.17 <sup>a</sup>	31.26 <sup>a</sup>	12.14 <sup>a</sup>	
Mean values G3			18.80 <sup>A</sup>	22.69 <sup>A</sup>	28.02 <sup>A</sup>	30.77 <sup>A</sup>	11.97 <sup>A</sup>	
Heterosis <sup>1</sup> , %								
			G2	3.86	3.22	4.08*	4.69*	6.21*
			G3	2.22	1.43	4.98*	8.50*	19.82*
Retained heterosis <sup>2</sup>			3.05	2.32	4.53	6.59	13.01	
Difference crossbred vs <sup>3</sup>								
			C (%)	-2.67	-1.63	0.08	1.17	7.62
			N (%)	9.47	6.67	8.56	12.67	19.09

C = Charolais; N = Nellore; G2 = Generation two; G3 = Generation three; <sup>1</sup>[(overall crossbred mean value/overall purebred mean value) - 1] \* 100; <sup>2</sup>[(overall crossbred mean/overall straightbred mean) - 1] \* 100; <sup>3</sup>[(overall crossbred mean/individual straightbred mean) - 1] \* 100; <sup>a,b</sup>in the same column differ within the mating system ( $p < 0.05$ ) by t-test; <sup>A,B</sup>in the same column differ between the mating systems ( $p < 0.05$ ) by t-test; \*Statistical difference ( $p < 0.05$ ) when comparing crossbreds vs. purebreds.

HH differed ( $p < 0.05$ ) at all ages among the purebreds and the Nellore animals were taller than the Charolais, with total absolute gains of 35.68 and 30.50

cm from birth to 365 days of age (Table 5). Within each crossbred generation, HH differed ( $p < 0.05$ ) at all ages, and offspring of Nellore bulls were taller in each generation.

**Table 3** – Mean values, standard errors, and heterosis for thoracic girth (cm) in males at different developmental stages, according to the genetic group.

Genetic Composition			Animal age (days)				Increase
Bull	Cow	Calf	Birth	63	210	365	
C	C	C	72.02 <sup>a</sup>	91.44 <sup>a</sup>	113.91 <sup>a</sup>	136.98 <sup>a</sup>	64.46 <sup>a</sup>
N	N	N	70.38 <sup>a</sup>	92.38 <sup>a</sup>	113.56 <sup>a</sup>	128.21 <sup>b</sup>	58.08 <sup>b</sup>
Mean values purebred			71.20 <sup>B</sup>	91.91 <sup>B</sup>	113.74 <sup>B</sup>	132.60 <sup>B</sup>	61.27 <sup>B</sup>
C	½ N ½ C	¾ C ¼ N	73.05 <sup>a</sup>	95.16 <sup>a</sup>	118.63 <sup>a</sup>	139.51 <sup>a</sup>	66.72 <sup>a</sup>
N	½ C ½ N	¾ N ¼ C	74.02 <sup>a</sup>	98.22 <sup>a</sup>	120.12 <sup>a</sup>	133.11 <sup>b</sup>	58.62 <sup>b</sup>
Mean values G2			73.54 <sup>A</sup>	96.69 <sup>A</sup>	119.38 <sup>A</sup>	136.31 <sup>AB</sup>	62.67 <sup>AB</sup>
C	¾ N ¼ C	5/8 C 3/8 N	72.89 <sup>a</sup>	93.41 <sup>a</sup>	118.85 <sup>a</sup>	140.04 <sup>a</sup>	67.71 <sup>a</sup>
N	¾ C ¼ N	5/8 N 3/8 C	74.48 <sup>a</sup>	95.06 <sup>a</sup>	120.45 <sup>a</sup>	140.87 <sup>a</sup>	65.88 <sup>a</sup>
Mean values G3			73.69 <sup>A</sup>	94.24 <sup>A</sup>	119.66 <sup>A</sup>	140.46 <sup>A</sup>	66.80 <sup>A</sup>
Heterosis <sup>1</sup> , %							
G2			3.29	5.20*	4.96*	2.80	2.28
G3			3.49	2.54*	5.20*	5.93*	9.03*
Retained heterosis <sup>2</sup>			3.39	3.87	5.08	4.36	5.66
Difference crossbred vs <sup>3</sup>							
C (%)			2.21	4.40	4.92	1.03	0.04
N (%)			4.60	3.34	5.25	7.94	11.46

C = Charolais; N = Nellore; G2 = Generation two; G3 = Generation three; <sup>1</sup>[(overall crossbred mean value/overall purebred mean value) – 1]\*100; <sup>2</sup>[(overall crossbred mean/overall straightbred mean) – 1]\*100; <sup>3</sup>[(overall crossbred mean/individual straightbred mean) – 1]\*100; <sup>a,b</sup>in the same column differ within the mating system ( $p < 0.05$ ) by t-test; <sup>A,B</sup>in the same column differ between the mating systems ( $p < 0.05$ ) by t-test; \*Statistical difference ( $p < 0.05$ ) when comparing crossbreds vs. purebreds.

**Table 4** – Mean values, standard errors, and heterosis for body length (cm) in males at different developmental stages, according to the genetic group.

Genetic Composition			Animal age (days)				Increase
Bull	Cow	Calf	Birth	63	210	365	
C	C	C	61.05 <sup>a</sup>	77.86 <sup>a</sup>	97.46 <sup>a</sup>	111.09 <sup>a</sup>	49.82 <sup>a</sup>
N	N	N	58.59 <sup>a</sup>	76.37 <sup>a</sup>	95.19 <sup>a</sup>	103.12 <sup>b</sup>	44.64 <sup>b</sup>
Mean values purebred			59.82 <sup>B</sup>	77.11 <sup>B</sup>	96.32 <sup>B</sup>	107.11 <sup>B</sup>	47.23 <sup>B</sup>
C	½ N ½ C	¾ C ¼ N	60.60 <sup>a</sup>	81.32 <sup>a</sup>	101.08 <sup>a</sup>	113.00 <sup>a</sup>	51.32 <sup>a</sup>
N	½ C ½ N	¾ N ¼ C	59.93 <sup>a</sup>	80.88 <sup>a</sup>	100.32 <sup>a</sup>	109.56 <sup>a</sup>	49.63 <sup>a</sup>
Mean values G2			60.75 <sup>AB</sup>	81.10 <sup>A</sup>	100.70 <sup>A</sup>	111.28 <sup>A</sup>	50.48 <sup>AB</sup>
C	¾ N ¼ C	5/8 C 3/8 N	61.02 <sup>a</sup>	78.59 <sup>a</sup>	100.30 <sup>a</sup>	112.85 <sup>a</sup>	51.68 <sup>a</sup>
N	¾ C ¼ N	5/8 N 3/8 C	63.34 <sup>a</sup>	80.90 <sup>a</sup>	100.55 <sup>a</sup>	113.48 <sup>a</sup>	50.61 <sup>b</sup>
Mean values G3			62.04 <sup>A</sup>	79.74 <sup>A</sup>	100.43 <sup>A</sup>	113.16 <sup>A</sup>	51.14 <sup>A</sup>
Heterosis <sup>1</sup> , %							
G2			1.55	5.19*	4.55*	3.89*	6.88*
G3			3.71	3.42*	4.27*	5.65*	8.28*
Retained heterosis <sup>2</sup>			2.63	4.29	4.41	4.77	7.79
Difference crossbred vs <sup>3</sup>							
C (%)			0.06	3.28	3.19	1.01	2.19
N (%)			4.79	5.32	5.65	8.82	14.04

C = Charolais; N = Nellore; G2 = Generation two; G3 = Generation three; <sup>1</sup>[(overall crossbred mean value/overall purebred mean value) – 1]\*100; <sup>2</sup>[(overall crossbred mean/overall straightbred mean) – 1]\*100; <sup>3</sup>[(overall crossbred mean/individual straightbred mean) – 1]\*100; <sup>a,b</sup>in the same column differ within the mating system ( $p < 0.05$ ) by t-test; <sup>A,B</sup>in the same column differ between the mating systems ( $p < 0.05$ ) by t-test; \*Statistical difference ( $p < 0.05$ ) when comparing crossbreds vs. purebreds.

### Effects of heterosis and complementarity on morphometric measurements

Comparing the generations, the FG of the purebred and crossbred animals did not differ ( $p > 0.05$ ) until weaning at 63 days of age. After this period, measurements at 210 and 365 days showed that crossbreds had greater FG than purebreds, with heterosis of 4.1 and 5.0 %

( $p < 0.05$ ) at 210 days and 4.7 and 8.5 % ( $p < 0.05$ ) at 365 days in G2 and G3, respectively. The growth of crossbred animals was greater when compared to Nellore and Charolais purebreds, with total increases of 19.1 and 7.6 %, respectively.

In different generations, crossbred animals had greater TG than purebreds, with heterosis ~ 5 and ~ 3 % ( $p < 0.05$ ) at 63 days, ~ 5 and ~ 5 % ( $p < 0.05$ ) at

**Table 5** – Mean values, standard errors, and heterosis for hip height (cm) in males at different developmental stages, according to the genetic group.

Genetic Composition			Animal age (days)				Increase
Bull	Cow	Calf	Birth	63	210	365	
C	C	C	69.36 <sup>b</sup>	77.44 <sup>b</sup>	90.24 <sup>b</sup>	100.49 <sup>b</sup>	30.50 <sup>b</sup>
N	N	N	73.87 <sup>a</sup>	86.23 <sup>a</sup>	99.52 <sup>a</sup>	109.26 <sup>a</sup>	35.68 <sup>a</sup>
Mean values purebred			71.62 <sup>A</sup>	81.84 <sup>B</sup>	94.88 <sup>B</sup>	104.88 <sup>B</sup>	33.09 <sup>B</sup>
C	½ N ½ C	¾ C ¼ N	68.72 <sup>b</sup>	81.80 <sup>b</sup>	95.79 <sup>b</sup>	106.30 <sup>b</sup>	37.91 <sup>a</sup>
N	½ C ½ N	¾ N ¼ C	75.23 <sup>a</sup>	86.98 <sup>a</sup>	102.29 <sup>a</sup>	110.46 <sup>a</sup>	34.64 <sup>a</sup>
Mean values G2			71.98 <sup>A</sup>	84.39 <sup>A</sup>	98.54 <sup>A</sup>	108.37 <sup>A</sup>	36.27 <sup>A</sup>
C	¾ N ¼ C	5/8 C 3/8 N	69.46 <sup>b</sup>	81.99 <sup>b</sup>	96.49 <sup>b</sup>	108.03 <sup>b</sup>	39.28 <sup>a</sup>
N	¾ C ¼ N	5/8 N 3/8 C	75.49 <sup>a</sup>	85.85 <sup>a</sup>	100.20 <sup>a</sup>	113.00 <sup>a</sup>	36.90 <sup>a</sup>
Mean values G3			72.47 <sup>A</sup>	83.92 <sup>A</sup>	98.34 <sup>A</sup>	110.52 <sup>A</sup>	38.09 <sup>A</sup>
Heterosis <sup>1</sup> , %							
G2			0.05	3.11*	3.86*	3.33*	9.61*
G3			1.19	2.54*	3.65*	5.41*	15.11*
Retained heterosis <sup>2</sup>			0.84	2.83	3.75	4.35	12.36
Difference crossbred vs <sup>3</sup>							
C (%)			4.13	8.67	9.09	8.91	21.90
N (%)			-2.22	-2.41	-1.09	0.02	4.20

C = Charolais; N = Nellore; G2 = Generation two; G3 = Generation three; <sup>1</sup>[(overall crossbred mean value/overall purebred mean value) - 1]\*100; <sup>2</sup>[(overall crossbred mean/overall straightbred mean) - 1]\*100; <sup>3</sup>[(overall crossbred mean/individual straightbred mean) - 1]\*100; <sup>a,b</sup>in the same column differ within the mating system ( $p < 0.05$ ) by t-test; <sup>A,B</sup>in the same column differ between mating systems ( $p < 0.05$ ) by t-test. \*Statistical difference ( $p < 0.05$ ) when comparing crossbreds vs. purebreds.

210 days, and ~ 3 and ~ 6 % ( $p < 0.05$ ) at 365 days in G2 and G3, respectively. The TG growth of crossbreds was greater when compared to the Nellore purebreds.

Purebreds and crossbreds differed ( $p < 0.05$ ) from birth in BL. BL of crossbreds was greater than of purebreds up to 365 days, with heterosis of ~ 1 and ~ 4 % ( $p < 0.05$ ) at birth, ~ 5 and ~ 3 % ( $p < 0.05$ ) at 63 days, ~ 4 and ~ 4 % ( $p < 0.05$ ) at 210 days, and ~ 4 and ~ 6 % ( $p < 0.05$ ) at 365 days in G2 and G3, respectively. The BL growth of crossbreds was greater in Nellore than in Charolais purebreds, with increases of 14 and 2 %.

Purebreds and crossbreds differed ( $p < 0.05$ ) from weaning at 63 days of age in HH. Crossbreds were taller than purebreds up to 365 days, with heterosis ~ 3 and ~ 2 % ( $p < 0.05$ ) at 63 days, ~ 4 and ~ 4 % ( $p < 0.05$ ) at 210 days, and ~ 3 and ~ 5 % ( $p < 0.05$ ) at 365 days in G2 and G3, respectively. The HH growth of crossbreds was greater in Charolais than in Nellore purebreds, with total increases of 21.9 and 4.2 %, respectively.

Both generations had higher HH mean values compared to purebreds. Unlike muscularity, the inclusion of Nellore genes into the genotype increased HH differences in individuals of the advanced crossbred generations in relation to purebred animals. The HH increase was more pronounced in purebred Charolais.

## Discussion

### Effects of genetic groups within mating systems (purebred and crossbred)

The greater values of Charolais animals at 365 days of age for FG, TG, and BL (Tables 1, 2, and 3, respectively)

may be due to differences in selection and in their respective aptitudes. Continental European breeds, such as Charolais, were selected based on their aptitude to produce meat and traction, resulting in animals with greater muscling than other European breeds, especially of British origin, which were selected based on quantitative and qualitative carcass and meat traits (Gregory and Cundiff, 1980). In Zebu breeds, such as Nellore, due to their tolerance to warm climates, natural selection resulted in animals with a thinner (Randhawa et al., 2014), lighter structure, with low muscle and bone mass, and better fat deposition than the Charolais breed (Restle et al., 2002).

Body measurements of BL, and FG and TG in cattle are important, since these measurements correlate positively with carcasses of greater size, better conformation (Pacheco et al., 2014), and greater retail cut yield (Pascoal et al., 2010; Cardoso et al., 2020). The selection of animals with greater muscling adds value at slaughter, as their carcasses have greater dressing percentages and yields of retail cuts (Cardoso et al., 2020).

Crossbred animals, mainly Charolais, irrespective of the generation, were similar to Charolais purebreds for FG, TG and BL at 365 days of age. The inclusion of Charolais genes favored these traits in crossbreds compared to purebred Nellore (Pacheco et al., 2010; Vaz et al., 2016), since differences in mean values for FG, TG, and BL in crossbreds were more pronounced in Nellore than in Charolais purebreds (Fernandes et al., 2020).

Vaz et al. (2016) evaluated the morphometrics of Charolais and Nellore calves and their first and second generation crosses up to 24 months of age. The authors

found no difference between the genetic groups within each mating system for the crossbred generations, except for TG at eight months of age in G2 animals, which was greater in animals with Charolais genetic. This is because Charolais animals are selected for greater muscle development, weight gain, and adult weight (Fernandes et al., 2020), and lower stress at weaning (Willians and Randle, 2017). Similar results at different ages can be explained by the earlier fat deposition in Nellore compensating for greater growth of Charolais animals, and the region of the thorax and ribs with high fat deposition. The greater fat deposition in carcasses of Nellore compared to Charolais for different generations of their crosses is an additive genetic effect (Restle et al., 2002).

HH at the different ages was greater in Nellore (purebreds and crossbreds) than in Charolais animals. Higher HH of Nellore animals is due to the evolutionary process of natural selection. Nellore originated in India, where temperatures are commonly high (Randhawa et al., 2014; Sivakumar et al., 2017) and the greater distance between the ground surface and the animal body ensure body temperature, especially on warmer days (Vaz et al., 2016).

#### Effects of heterosis and complementarity on morphometric measurements

Heterosis was pronounced at all the ages under evaluation, regardless of the trait. However, heterosis was not significant in body measurements at birth, regardless of the generation studied. This shows that, in the intrauterine environment, a larger body size cannot be explained by the determinant factors of heterosis and additive genetic (Falconer and Mackay, 1996) or even that the environment in the current study was not limiting thus allowing heterosis to be pronounced (Rauw and Gomez-Raya, 2015). In addition, measurements at birth reflect the dam nutrition status and its adaptation to the environment (Fordyce et al., 2013), that is, offspring nutrition demands more from the dam.

For the other ages, at 63 (weaning), 210, and 365 days, heterosis was positive and significant for all measurements. This effect was possibly due to individual heterosis (Yadav et al., 2018; Wakchaure et al., 2015) also because animals belonged to the two advanced crossbred generations and benefited from maternal heterosis, since the dams belonged to the first and second crossbred generations.

Heterotic response showed similarity in all measurements that up to 63 days, with animals of G2 showing greater absolute values for heterosis than animals of G3. Until weaning at 63 days of age, measured heterosis followed the degree of maternal (100 and 50 %) and individual (75 and ~ 62 %) heterozygosity in the generations, providing larger measurements for G2 offspring of F1 cows. Calf performance until weaning depends greatly on its dam (Prayaga, 2003),

where F1 females produce more milk with a higher level of total solids than purebred females (Rodrigues et al., 2014), allowing for greater energy intake by the calves (Mendonça et al., 2019). This is due to maternal heterosis, since the dams were F1 and F2 generations, respectively, determining a better environment for calves due to maternal heterozygosity compared to purebreds (Leal et al., 2018). Following weaning, around 210 days, for FG and TG measurements, individual heterosis becomes a determinant of higher values, with these traits no longer undergoing the influence of the maternal effect for their development.

Body measurements of animal length and HH showed complementarity results, where the values show optimization of the additive genetic feature of the Charolais and Nellore breeds, harmonizing these measurements in the crossbred animals when compared to purebreds (Schiermiester et al., 2015). Pacheco et al. (2010) and Pacheco et al. (2014) studied carcass data of Charolais and Nellore animals and their crosses and found complementarity effects between breeds, mostly due to their genetic distance.

The fact that complementarity was not more pronounced in FG and TG is because these measurements are highly susceptible to environmental effects, such as the nutritional level (Northcutt et al., 1992; Schiermiester et al., 2015).

## Conclusions

Charolais animals are more muscular than the Nellore; however, the latter are taller.

In the crossbred animals, an increase in the predominance of Charolais in the genotypes does not increase muscularity in relation to genotypes with Nellore predominance, except in second-generation animals at 365 days of age. However, predominance of Nellore genes produces taller animals at all ages, regardless of generation.

Crossbred animals are more developed in body measurements compared to purebreds, indicating a significant effect of heterosis up to 365 days.

## Acknowledgments

This work was supported by the Coordination for the Improvement of Higher Level Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Brasil - CAPES) for the partial financing by-Finance Code 001.

## Authors' Contributions

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