

Genetic parameters, genetic trends, and principal component analysis for productive and reproductive traits of Guzera beef cattle

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ABSTRACT - The objectives of this study were to estimate genetic parameters and genetic trends and perform principal component analysis for the following traits: body weight adjusted at 210 days of age (W210), one year (W365), and yearling or 450 days of age (W450); weight gain from birth to weaning or 210 days of age (WGBW), from weaning to 365 days of age (WGW365), and from one year to yearling (WGY); and scrotal circumference adjusted at 365 (SC365) and 450 (SC450) days of age of Guzera beef cattle. Variance components were estimated under a two-trait animal model using the restricted maximum likelihood method. The fixed effects included in the model were birth season, contemporary group, and covariable age of dam at calving as linear and quadratic effects. Heritability estimates ranged from 0.10 (WGY) to 0.41 (W450 and SC450). The studied traits could be used as selection criteria because of their sufficient additive genetic variability to respond to the selection process. However, lower selection efficiency is expected for WGBW and WGY. Genetic trends studied were significant for all traits, except WGY. The W365 and W450 traits belonged to the “Genetic Merit Total” index and responded to selection with favorable genetic gain per year. The traits that were not included in the selection index showed favorable positive genetic correlations attributed to the indirect selection processes. The principal component analysis identified two groups of traits. The first group related to body weight and weight gain and the second related to the scrotal circumference, indicating that selection could be applied to one group of traits within each observed group. The genetic gains were attributed in the same direction for the other traits belonging to the groups. Thus, we recommend selecting animals for W365 based on first group, and SC365 based on second.

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Keywords: animal breeding, *Bos taurus indicus*, genetic correlation, heritability

Introduction

In the genetic constitution of Brazilian cattle, it is estimated that *Bos taurus indicus* DNA is present in more than 80% of the herds either as purebreds or crossbreds (IBGE, 2015). The Guzera is considered a dual-purpose breed and has been widely used in both purebred and crossbreeding schemes to produce

efficient dairy cows and beef calves since they have precocity, adaptability, resistance to parasites, heat tolerance, and good performance (Peixoto et al., 2016).

Productive performance traits, such as body growth and reproductive efficiency, affect the profitability of beef cattle (Laureano et al., 2011), because they decrease the generation interval, accelerate the genetic progress, and result in precocious animals with better performance. Thus, the antagonism that has been observed between the direct and maternal genetic effect estimates and their correlation with growth traits in beef cattle is important for breeding programs, since they allow more accurate heritability estimates (Campêlo et al., 2004).

Animal performance can be evaluated by body weight and weight gain adjusted to different ages, because these traits are easy to measure and present moderate to high magnitudes of heritability estimates, which generally respond satisfactorily to the selection process (Bologon et al., 2010a). Thus, the present investigation aimed to estimate genetic parameters and trends for traits related to productive and reproductive performance of Guzera beef cattle and explore relationships among animal estimated breeding values for these traits using the principal component analysis (PCA) method to provide subsidies for the genetic evaluation program of this economically important breed.

Material and Methods

A total of 18,491 records from Guzera males and females born between 1987 and 2009 were used in this study. These animals participated in the Programa Guzerá Brasil, coordinated by the Associação Nacional de Criadores e Pesquisadores (ANCP, Brazil). The individuals were managed under an extensive production system based on pasture. Weaning occurred between six and eight months of age. The reproductive management consisted of a mating season lasting 60 to 120 days, using artificial insemination or controlled natural mating.

The performance traits studied were: weaning body weight adjusted to 210 days (W210), at 365 (W365) and 450 (W450) days old; weight gain from birth to weaning (210 days of age; WGBW), from weaning to 365 days of age (WGW365), and from one year to yearling (450 days of age; WGY). The scrotal circumference adjusted at 365 (SC365) and 450 (SC450) days of age were the studied traits related to reproductive performance.

An index, termed "Total Genetic Merit" (TGM), developed by ANCP, Brazil, was employed to select genetically superior males and females since 1999 (Lôbo et al., 2000). This index includes breeding values estimated for the following weighted traits: maternal ability (0.20), weight at 365 (0.20) and 450 (0.20) days of age, scrotal circumference at 365 (0.10) and 450 days of age (0.10), age at first calving (0.15), and gestation period (0.05).

Preliminary analyses were performed for all traits to eliminate inconsistent data. For analysis of fixed effects, animals with no phenotypic data and with no record of sire, dam, and date of birth were excluded. The fixed effects considered in the model were defined by a least square analysis, using the GLM procedure in the SAS software (Statistical Analysis System, version 9.3). Birth season was defined as rainy season for animals born between October and March and dry season for animals born between April and September. The contemporary group consisted of animals having the same sex and from the same farm, year, and birth season. Contemporary groups with less than four records were excluded from the data file. The linear and quadratic effects of the covariate age of dam at calving were considered in the analyses for all traits studied, except for WGW365 and WGY. The analysis of variance was performed using the SAS (v. 9.1) GLM procedure to ascertain the distribution of the residues for each variable. Records with standardized residuals greater than 3.5 or lower than -3.5 standard deviations were excluded. The relationship matrix contained 26,160 animals.

Genetic parameters were estimated by the Restricted Maximum Likelihood Method (REML) for two-trait animal models using the WOMBAT software (Meyer, 2007). The maternal genetic effect was considered in the model for WGBW, W210, WGW365, W365, and W450 traits.

The statistical models proposed for the traits studied are described below:

$$y = X\beta + Za + e \quad (1)$$

$$y = X\beta + Za + Wm + e, \quad (2)$$

in which y is the vector of records for each trait, X is the incidence matrix for fixed effects, β is the fixed effects vector (contemporary group), Z is the incidence matrix relating records to animal additive direct genetic effects, W is the incidence matrix for maternal genetic effects, a is the vector for animal additive direct genetic effects, m is the vector for maternal genetic effects, and e is the random residual effects vector.

The variance and covariance structure of random effects in the multitrait animal model, such as the expected values for y_1 to y_n are X_1b_1 to X_nb_n , respectively, and are presented as follows:

$$\text{Var} \begin{bmatrix} a_1 \\ a_2 \\ a_n \\ \vdots \\ e_1 \\ e_2 \\ \vdots \\ e_n \end{bmatrix} = \begin{bmatrix} A\sigma_{a_1}^2 & \sigma_{a_1a_n} & \dots & \sigma_{a_1a_n} & 0 & 0 & 0 & 0 \\ \sigma_{a_1a_2} & A\sigma_{a_2}^2 & \dots & \sigma_{a_2a_n} & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & 0 & 0 & 0 & 0 \\ \sigma_{a_1a_n} & \sigma_{a_2a_n} & \dots & A\sigma_{a_n}^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & I\sigma_{e_1}^2 & \sigma_{e_1e_n} & \dots & \sigma_{e_1e_n} \\ 0 & 0 & 0 & 0 & \sigma_{e_1e_2} & I\sigma_{e_2}^2 & \dots & \sigma_{e_2e_n} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & \sigma_{e_1e_n} & \sigma_{e_2e_n} & \dots & I\sigma_{e_n}^2 \end{bmatrix} \quad (3)$$

in which $\sigma_{a_1}^2$ to $\sigma_{a_n}^2$ are the direct additive genetic effects variances, $\sigma_{e_1}^2$ to $\sigma_{e_n}^2$ are the residual variances, $\sigma_{a_1a_2}$ to $\sigma_{a_na_{n-1}}$ are the additive genetic covariances between traits, $\sigma_{e_1e_2}$ to $\sigma_{e_ne_{n-1}}$ are the residual covariances between traits, and A and I are the relationship matrix and identity matrix, respectively.

Genetic trends for performance traits studied were obtained from the linear regression analysis of mean breeding values according to birth year (1984 to 2009). The t statistic was used to verify the null hypothesis that the regression coefficient was zero, at the 5% significance level. Genetic trends for SC365 and SC450 were described by Grupioni et al. (2015).

The additive genetic values predicted for the studied traits were used to perform the PCC using the STATISTICA8 software (Statistica 8.0, Statsoft, Inc., Oklahoma, USA). The main purpose of this analysis was to reduce the dimension of the genetic correlation matrix to indicate which traits should be used as selection criteria.

The principal components are orthogonal latent variables consisting of linear combinations of variables (in this case, breeding values for the traits studied). By definition, the first principal component explained most of the total genetic variance, the second principal component explained the second largest portion of the total genetic variability not correlated with the first principal component, and so on, until all the variance has been explained. In a dataset with p variables, the principal component i (PC $_i$) is given by:

$$PC_i = a_{i1}X_1 + a_{i2}X_2 + \dots + a_{ij}X_j \quad (4)$$

in which $i = 1, 2, \dots, p$ and $j = 1, 2, \dots, p$, a_{ij} is the j -th standardized coefficient in the i -th principal component; and X_j is the j -th value of the original variable. The standardized coefficients were calculated by:

$$a_{ij} = \frac{\text{eigenvector}_{ij}}{\sqrt{\text{eigenvalue}_j}} \quad (5)$$

in which a_{ij} is the standardized coefficient of genetic values of the i -th variable in the j -th principal component.

The number of principal components was chosen based on the Kaiser (1960) criteria, in which only the principal components with eigenvalues greater than 1 explained the most important part of the additive genetic covariance matrix.

Results

The descriptive statistics for performance and reproductive traits obtained in this study are presented in Table 1. The heritability estimates obtained in this work from the two-trait analysis (Table 2) ranged from 0.10 (WGY) to 0.41 (W450 and SC450). Maternal heritability estimates were 0.01 (0.02) for WGBW, 0.06 (0.02) for W210, 0.06 (0.03) for WGW365, 0.04 (0.02) for W365, and 0.02 (0.02) for W450. Genetic correlations among W210, W365, and W450 were positive and high, ranging from 0.91 to 0.97 (Table 2). Weight gains at different ages were positively genetically correlated, ranging from 0.34 to 0.65. The maternal heritability estimates found for W210, W365, W450, WGBW, and WGW365 were of low magnitude, ranging from 0.01 (0.02) to 0.06 (0.02) (Table 2).

The genetic correlation between SC365 and SC450 was positive and favorable (Table 2). Body weights and scrotal circumferences measured at different ages showed positive and favorable genetic correlation

Table 1 - Number of animals (N), mean (M), coefficient of variation (CV%), and minimum (Min) and maximum (Max) values observed for productive and reproductive traits in Guzera beef cattle

Trait	N	M	CV (%)	Min	Max
W210 (kg)	9,047	120.92	19.05	47	203
W365 (kg)	4,865	241.21	23.16	104	497
W450 (kg)	6,718	278.78	64.03	130	559
WGBW (kg)	5,044	146.89	23.59	51	290
WGW365 (kg)	6,437	62.49	56.74	-66	209
WGY (kg)	6,907	36.53	58.74	-50	117
SC365 (cm)	1,773	20.82	12.38	144	299
SC450 (cm)	2,091	23.26	15.07	142	360

Weight at 210 days old (W210), year (W365), and yearling (W450); weight gain from birth to weaning (WGBW), from weaning to 365 days old (WGW365), and from one year to yearling (WGY); and scrotal circumference at 365 (SC365) and 450 (SC450) days old.

Table 2 - Direct heritability estimates (diagonal) and maternal (*), standard errors (within parenthesis), genetic (above diagonal), and environmental (below diagonal) correlations observed in final data from two-trait analyses for productive and reproductive traits studied in Guzera beef cattle

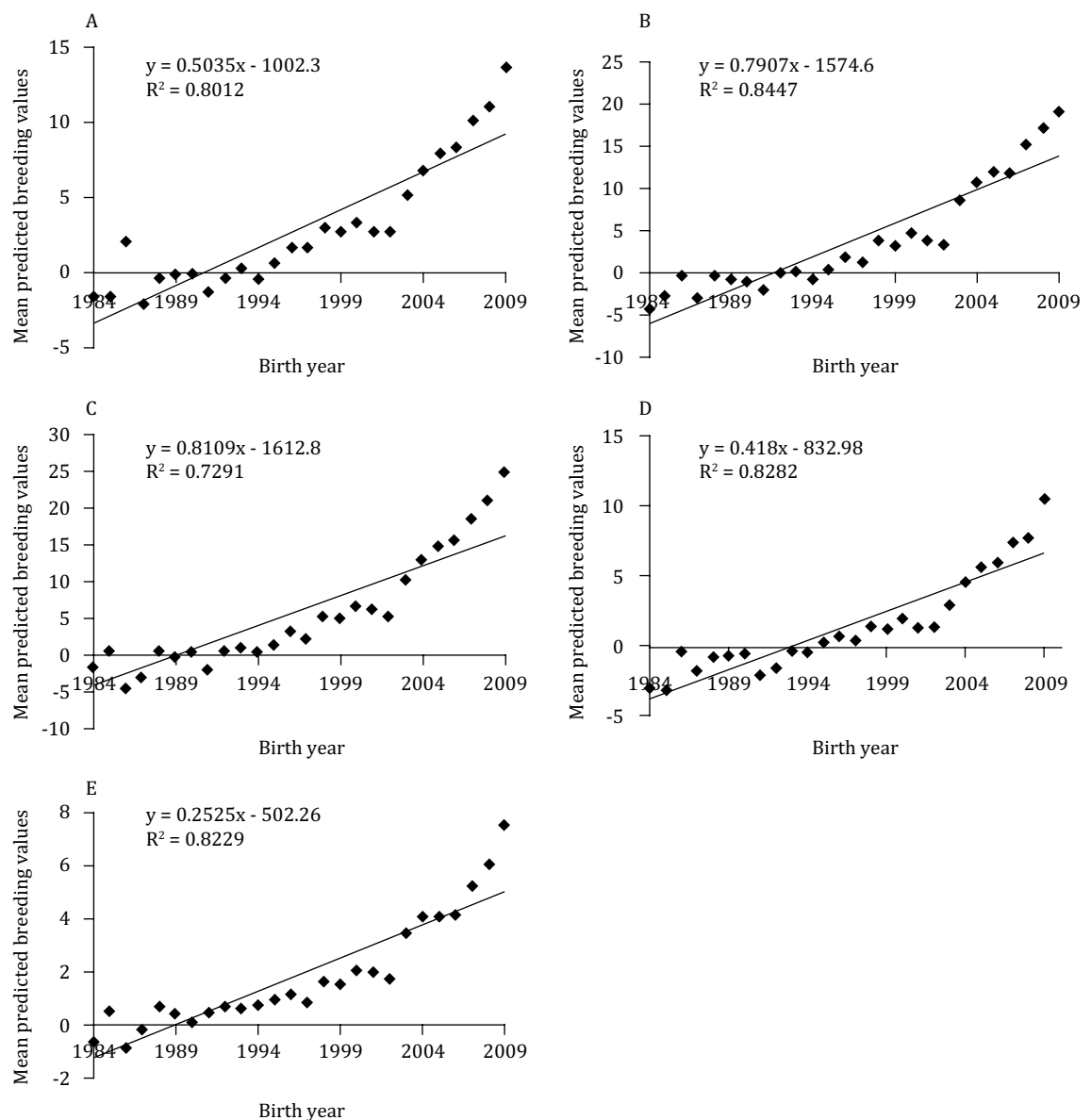
Trait	W210	W365	W450	WGBW	WGW365	WGY	SC365	SC450
W210 (kg)	0.30 (0.05) 0.06 (0.02)*	0.95 (0.03)	0.91 (0.04)	0.63 (0.12)	0.98 (0.00)	0.28 (0.15)	0.78 (0.08)	0.65 (0.09)
W365 (kg)	0.59 (0.02)	0.40 (0.05) 0.04 (0.02)*	0.97 (0.01)	0.91 (0.04)	0.91 (0.04)	0.34 (0.12)	0.72 (0.09)	0.51 (0.09)
W450 (kg)	0.54 (0.03)	0.89 (0.01)	0.41 (0.05) 0.02 (0.02)*	0.86 (0.05)	0.94 (0.03)	0.66 (0.09)	0.74 (0.08)	0.66 (0.08)
WGBW (kg)	0.14 (0.04)	0.68 (0.02)	0.57 (0.03)	0.19 (0.04) 0.01 (0.02)*	0.65 (0.13)	0.34 (0.15)	0.64 (0.13)	0.60 (0.12)
WGW365 (kg)	0.10 (0.00)	0.55 (0.03)	0.52 (0.03)	0.13 (0.05)	0.33 (0.06) 0.06 (0.03)*	0.57 (0.14)	0.86 (0.08)	0.79 (0.08)
WGY (kg)	0.05 (0.03)	0.03 (0.03)	0.44 (0.02)	0.01 (0.03)	0.03 (0.04)	0.10 (0.02)	0.14 (0.18)	0.06 (0.17)
SC365 (cm)	0.36 (0.05)	0.51 (0.05)	0.57 (0.04)	0.28 (0.05)	0.29 (0.07)	-0.05 (0.04)	0.33 (0.07)	0.90 (0.04)
SC450 (cm)	0.36 (0.05)	0.55 (0.05)	0.58 (0.05)	0.18 (0.05)	0.32 (0.06)	0.20 (0.04)	0.70 (0.03)	0.41 (0.07)

Weight at 210 days old (W210), year (W365), and yearling (W450); weight gain from birth to weaning (WGBW), from weaning to 365 days old (WGW365), and from one year to yearling (WGY); and scrotal circumference at 365 (SC365) and 450 (SC450) days old.

ranging from 0.51 to 0.78 (Table 2). Genetic correlations between scrotal circumferences and weight gains measured at different ages ranged from 0.06 (SC450 with WGY) to 0.86 (SC365 with WGW365). Genetic correlations between weights and weight gains measured at different ages ranged from 0.28 (W210 with WGY) to 0.98 (W210 with WGW365).

The regression coefficients obtained from the linear regression analysis of mean predicted breeding values based on animal birth year were significant ($P < 0.0001$) for all traits studied (Figures 1A to 1E), except for WGY. Genetic trends for WGBW, W210, WGW365, W365, and W450 indicated significant linear increases ($P < 0.001$) in additive direct breeding values equal to 0.42, 0.50, 0.25, 0.79, and 0.81 kg per birth year, respectively, from 1984 to 2009.

According to Kaiser (1960) criteria, the two principal components that explained 55.15 and 13.07% of the breeding value variance were chosen from the eight evaluated traits, totaling 68.22% of the total genetic additive variance (Table 3).



The regression coefficient was significantly ($P < 0.001$) different from zero at t test.

R^2 - coefficient of determination; weight at 210 days old (W210), year (W365), and yearling (W450); weight gain from birth to weaning (WGBW), and from weaning to 365 days old (WGW365).

Figure 1 - Mean predicted breeding values variation for the traits W210 (A), W365 (B), W450 (C), WGBW (D), and WGW365 (E) from 1984 to 2009.

Table 3 - Eigenvalues, total variance percentage explained in each principal component (PC1 and PC2), and correlation of the variables in each principal component

Principal component	Eigenvalue	Total variance (%)	Acumulated variance (%)
PC1	4.4120	55.15	55.15
PC2	1.0459	13.07	68.22

Discussion

Weaning weight adjusted to 210 days of age presented a lower mean (120.92 kg) than that found by Mucari and Oliveira (2003) in Guzera cattle. Several authors observed means higher than those obtained in this study (Table 1) for weaning weight adjusted to 205, 240, or 270 days of age (Pereira et al., 2001; Yokoo et al., 2007; Boligon et al., 2010a; 2011).

The mean found in this study (241.21 kg) for W365 was higher than values reported by Mucari and Oliveira (2003) for Guzera beef cattle and the one reported by Boligon et al. (2010a) for Nelore cattle. The mean for W450 obtained in this work for Guzera was similar to values reported by Pelicioni et al. (2003), Yokoo et al. (2007), and Boligon et al. (2011) in Nelore cattle. Mucari and Oliveira (2003) found lower means for Guzera cattle. Results observed for the Nelore breed can be considered in comparison with those obtained for Guzera, considering the same Indian origin of both breeds.

The mean obtained for WGBW was similar to the results found in Nelore beef cattle (Sarmiento et al., 2003; Boligon et al., 2010b). Weight gain from weaning to 365 days of age had a higher mean (62.49 kg) than those found in the literature (Sarmiento et al., 2003; Boligon et al., 2010a). Weight gain from one year to yearling had a lower mean (36.53 kg) compared with those obtained by Sarmiento et al. (2003) and Boligon et al. (2010a) in Nelore cattle. However, the same authors worked with weight gain from one year to 550 days of age. Most of the mentioned authors performed studies in Nelore and adjusted the weight gain for different days of what was considered for this study, which could lead to this change. It could also be due to the origin of the data or even the amount of animals for this trait.

The mean for SC365 was similar (20.82 cm) to those found in Nelore by Yokoo et al. (2007) and Boligon et al. (2010b, 2011) and higher than those observed in Guzera cattle by Torres-Júnior and Henry (2005) and the one observed by Frizzas et al. (2009) in Nelore beef cattle. For SC450, the mean estimated in this study was higher (23.26 cm) than that presented by Torres-Júnior and Henry (2005) and Frizzas et al. (2009) and lower than that measured by Yokoo et al. (2007) and Boligon et al. (2010b) in Nelore cattle.

The large variation of the mean (Table 1) observed in this study for productive and scrotal circumference traits was expected. Beef cattle management is extensive, and different nutrition and environmental conditions in each region of the country affect growth and weight gain from animals, as related by Grossi et al. (2009). The minimum values observed for weight gain from weaning to one year and from one year to yearling were negative, indicating there was loss of weight for some animals during these periods. These results indicate that the definition of a breeding season based on nutritional requirements of cows to nutrient availability according to the season of the year may not have been successfully performed in some herds, resulting in animal births outside the favorable season (second half of the year), damaging beef production.

Genetic evaluations of beef cattle in Brazil usually contemplate productive traits, since they are easy to measure and interpret and present heritability estimates from moderate to high magnitudes, indicating that selection may result in genetic progress (Boligon et al., 2009). The heritability estimates found in this study were low for W210 and WGW365, moderate for W210 and WGW365, and high for W365 and W450. Therefore, selection based on body weights (W365 and W450) may be more effective compared with selection based on weight gain, because they presented highest heritability estimates and positive and favorable genetic correlations with the other traits studied (Table 2). The genetic correlations among weight gains at different ages in Nelore cattle reported by Boligon et al. (2009, 2010b) were

similar to those observed in this study. Mucari and Oliveira (2003) estimated genetic correlations of similar magnitudes for the performance traits in Guzera cattle.

The heritability estimates reported in literature for performance traits have ranged from 0.14 to 0.35 for W210 (Pimenta Filho et al., 2001), from 0.08 to 0.45 for W365 (Mucari and Oliveira et al., 2003; Souza et al., 2004), and from 0.13 to 0.46 for W550 (Pimenta Filho et al., 2001; Mucari and Oliveira et al., 2003) in Guzera beef cattle. Malhado et al. (2002) estimated genetic correlations of 0.75 between weaning weight adjusted to 205 days of age (W205) and W365, 0.61 between W205 and W550, and 0.65 between W365 and W550 in Guzera beef cattle.

The lower magnitude from WGY and WGBW heritability estimates (Table 2) indicated that a large part of the expression of these traits was caused by non-additive genetic and environmental effects. Selection based on these traits might not be very efficient, because they may respond only slowly to the direct selection process. Among weight gain traits, WGW365 should be the most appropriate trait to be used as selection criteria. A higher proportion of phenotypic variance attributed to additive effects of genes for WGW365 compared with WGBW and WGY results in a higher improvement in genetic gain for WGW365.

Paneto et al. (2002), Sarmiento et al. (2003), and Boligon et al. (2010b) found heritability estimates for WGY ranging from 0.21 to 0.25 in Nelore cattle, higher than that estimated in this study (0.10). Yokoo (2007) observed a heritability coefficient estimate of 0.40 for W450 in Nelore beef cattle, similar to the estimate of this study (Table 2).

According to Meyer et al. (1993), traits measured until weaning are influenced by maternal effects. In this study, it was evidenced that the traits measured until weaning, as well as the measures after weaning, were little influenced by maternal effects. Thus, little or no genetic progress is expected due to selection for maternal ability in Guzera beef cattle.

Scrotal circumference is one of the most important reproductive traits used to compose selection indexes in Brazil. Scrotal circumference is an easy trait to measure and has moderate to the high magnitude of heritability estimates (Gressler et al., 2000; Fridrich et al., 2005; Eler et al., 2006; Boligon et al., 2010b). Thus, scrotal circumference presents favorable genetic correlations between semen quantity and quality (Latif et al., 2009), age at puberty in females (Santana et al., 2015), and ponderal development (Ortiz Peña et al., 2001; Brito et al., 2003).

Heritability estimates for SC365 and SC450 were described by Frizzas et al. (2009), Boligon et al. (2010b), and Boligon et al. (2011) and ranged from 0.29 to 0.41 for SC365 and from 0.42 to 0.44 for SC450 in Nelore cattle. Torres-Júnior and Henry (2005) stated that SC presents favorable genetic correlation with body weight in Guzera animals. Positive genetic correlations among SC, weights, and weight gains at different ages have been described in different studies (Frizzas et al., 2009; Boligon et al., 2010b; Raidan et al., 2017), indicating that these traits are determined, in large proportion, by the action of the same additive genes. The selection for higher scrotal circumferences would lead to increased performance traits.

The heritability coefficient for SC450 was higher than that observed for SC365 (Table 2). Yokoo et al. (2007) observed similar results for SC365 and SC450 and suggested that heritability estimates for SC365 were lower than SC450, because few animals entered puberty at 365 days of age.

Frizzas et al. (2009) and Boligon et al. (2010a, 2011) also found positive and favorable genetic correlations between scrotal circumferences measured at different ages in Nelore beef cattle. The favorable and positive genetic correlation between SC365 and SC450 (0.90 ± 0.04) indicated that animals with a higher scrotal circumference at one year also had a higher scrotal circumference as a yearling. This result suggests that the use of SC365 as a selection criterion could increase genetic improvement, because it becomes possible to select younger animals. However, Grupioni et al. (2015) reported negative and favorable genetic correlations between SC365 and SC450 with age at first calving in the same population of Guzera cattle studied in this work, indicating that selection for scrotal circumferences could result in sexual precocity in females. Yokoo et al. (2007) and Boligon et al.

(2010a) worked with Nelore cattle and observed genetic correlations similar to those reported in this study. Frizzas et al. (2009) found a positive genetic correlation for these traits, but lower than those reported in this work.

According to Guidolin (2013), it is important to perform measurements of the scrotal circumference at correct ages, because males have a significant growth period of their testicles in early puberty under the action of gonadotropic hormones. Silveira et al. (2004) suggested that the selection of animals with larger scrotal circumference at 12 months of age was associated with the choice of animals with higher levels of gonadotropic hormones in Nelore, and selection at 18 months was related to higher weights and possibly the lower variation in puberty, recommending the selection at 12 months of age. However, Boligon et al. (2010a) evaluated the scrotal circumference at 12 and 18 months of age and concluded that the latter showed higher heritability estimates and, therefore, would present better selection results. The genetic correlation among body weights and scrotal circumference traits found in this work (Table 2) indicated that selection based on scrotal circumference will result in a correlated response in the same direction for growth traits and increase the productivity of herds.

Irano et al. (2016) performed GWAS for indicators of sexual precocity in Nelore cattle and found that windows with great effects for scrotal perimeter and sexual precocity traits were not superimposed, although there is a moderate genetic correlation between these traits in Nelore cattle (Santana et al., 2015). Camargo et al. (2015), studying causal mutations, showed that highly significant SNP for andrological traits were not significant for female reproductive traits. Irano et al. (2016) elaborated three hypotheses to try to explain the association between these traits. The first suggests that the genetic correlation between male and female reproductive traits is due to genes of small effect that affect both traits; the second, that genes can act with a greater effect for one trait and with a smaller effect for another trait; and the third that both previous hypotheses could be occurring.

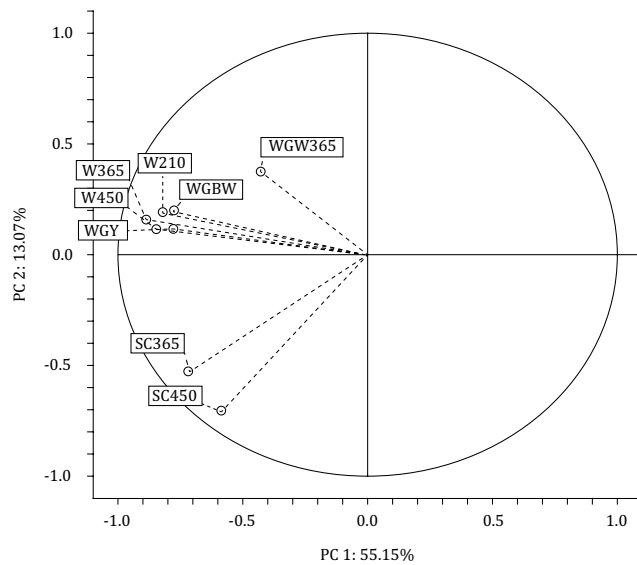
The genetic gains observed for W365 and W450 traits could be attributed to the direct selection of animals, because these traits are included in the TGM index. The additive direct breeding values observed for W365 and W450 from 1999 to 2009 indicated that the selection process brought significant ($P < 0.05$) genetic gains over the years for productive performance traits. The positive genetic correlations for WGBW, W210, WGW365, and WGY traits, which are not in the TGM index, allow us to attribute the annual genetic gains to the indirect selection process.

Although the mean genetic value of WGY has not improved over time, a linear increase of WGY mean breeding values is expected in the next generations by selecting for the TGM index, as a result of genetic correlations between WGY and other studied traits included in the TGM index that is undergoing genetic progress.

Two groups of traits are shown in Table 3. The first group is related to body weight and weight gain (Figure 2). The second is related to scrotal circumferences (SC365 and SC450). Body weight and weight gain were strongly associated with principal component 1 (PC1). The SC365 and SC450 were associated with principal component 2 (Figure 2).

The groups of traits studied were not orthogonal to each other. All traits were considerably genetically correlated, and this fact can explain why the two groups of traits were not completely separated. These results suggest that the selection of animals could be made based on two traits (one for each group) instead of all traits. Thus, the genetic gains of the other traits within each group would be in the same direction of the trait chosen as a selection criterion.

Thus, we recommend selecting animals for W365 based on PC1, and SC365 based on PC2. Another implication about the non-orthogonality between the groups of traits is that they could result in correlated responses for all traits, regardless of that chosen as a selection criterion, which is in accordance with the estimates of genetic correlations (Table 2).



Weight at 210 days old (W210), year (W365), and yearling (W450); weight gain from birth to weaning (WGBW), from weaning to 365 days old (WGW365), and from one year to yearling (WGY); and scrotal circumference at 365 (SC365) and 450 (SC450) days old.

Figure 2 - Two-dimensional graphs from principal component 1 (PC 1) versus 2 (PC 2).

Conclusions

Body weight at one year of age, yearling weight, and scrotal circumferences traits could be used as selection criteria for improvement of performance and reproduction traits, because they have enough additive genetic components to respond to the selection and belong to the Total Genetic Merit index. Their genetic gains from the selection process will be attributed in the same way in the other studied traits.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

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