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Additive genetic relationships between scrotal circumference, heifer pregnancy and stayability in Nellore cattle¹

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ABSTRACT: Scrotal circumference data from 47,605 Nellore young bulls, measured at around 18 months (SC18), were analyzed simultaneously with 27,924 heifer pregnancy (HP) and 80,831 stayability (STAY) records, in order to estimate their additive genetic relationships. Additionally, the possibility that economically relevant traits measured directly in females could replace SC18 as a selection criterion was verified. HP was defined as the observation that a heifer conceived and remained pregnant, which was assessed by rectal palpation at 60 days. Females were exposed to sires for the first time at about 14 months of age (between 11 and 16 mo). STAY was defined as whether or not a cow calved every year up to 5 yr of age, when the opportunity to breed was provided. A Bayesian linear-threshold-threshold analysis via Gibbs sampler was used to estimate the variance and covariance components of the multi-trait model. Heritability estimates were 0.42 ± 0.01 , 0.53 ± 0.03 and 0.10 ± 0.01 , for SC18, HP and STAY, respectively. The genetic correlation estimates were 0.29 ± 0.05 , 0.19 ± 0.05 and 0.64 ± 0.07 between SC18 and HP, SC18 and STAY, and HP and STAY, respectively. The residual correlation estimate between HP and STAY was -0.08 ± 0.03 . The heritability values indicate the existence of considerable genetic variance for SC18 and HP traits. However, genetic correlations between SC18 and the female reproductive traits analyzed in the present study can only be considered moderate. The low residual correlation between HP and STAY suggests that environmental effects common to both traits are not major. The high heritability estimate for HP and the high genetic correlation between HP and STAY obtained in the present study confirm that EPD for HP can be used to select bulls for the production of precocious, fertile and long-lived daughters. Moreover, SC18 could be incorporated in multi-trait analysis to improve the prediction accuracy for HP genetic merit of young bulls.

Key words: beef cattle, genetic correlation, heritability, linear-threshold model, reproductive traits

INTRODUCTION

Reproductive traits influence beef cattle breeding profitability in two main ways. First, the reproductive rates determine the amount of product that can be sent to the market. Second, herds' reproductive performance affects both the generation interval and the selection intensity that can be applied. Brazilian breeding programs, however, include in their selection indexes almost exclusively growth traits. The only exception is the scrotal circumference, included in the indexes as an indicator trait for age to puberty and fertility. More recently, however, some authors have evaluated economically relevant traits that can be measured directly on females, such as heifer pregnancy (Evans et al., 1999; Eler et al., 2002, 2004; Silva et al., 2003; Pereira et al., 2007) and stayability (Snelling et al., 1995; Doyle et al., 2000; Silva et al., 2003, 2006; Van Melis et al., 2007). Heifer pregnancy and stayability traits have several properties that confirm them as candidates for inclusion in selection objectives; firstly, recording heifer pregnancy data presents no additional costs, since they are routinely collected by producers. Moreover, pregnancy diagnosis approaches are well defined (rectal palpation or ultrasound), analytical procedures have already been developed (threshold model or survival analysis), heritability estimates for heifer pregnancy in the Brazilian Nellore herds are relatively high, and the expected progeny differences can be informed as a percentage.

Knowledge of the genetic correlation between scrotal circumference and economically relevant traits measured directly in females is essential for maximizing the potential economic profit. Moreover, an appropriate multi-trait analysis generally improves the accuracy of genetic

evaluations, as a consequence of the borrowing of the information of pleiotropic gene effects between correlated traits.

The objectives of this study were to determine the additive genetic relationships between scrotal circumference, heifer pregnancy and stayability, and verify the possibility of using those traits measured directly in females as selection criteria for the genetic improvement of fertility in Nellore cattle.

MATERIAL AND METHODS

Data

The dataset included heifer pregnancy (**HP**) and stayability (**STAY**) records from females born between 1994 and 2005 and between 1984 and 2000, respectively, and scrotal circumference (**SC18**) records from bulls born between 1984 and 2004. All animals were from Nellore breed, and were from the 15 herds owned by Agropecuaria CFM Ltda, in the states of São Paulo, Mato Grosso do Sul, and Goiás, in Brazil.

Cattle Management

Both bulls and females were maintained on pasture, with salt and mineral supplementation (11% Ca, 6% P, 1% Mg, 4% S, 16% Na, 0.15% Cu, 0.15% Mn, 0.45% Zn, 0.015% I, 0.007% Co, and 0.002% Se). Every year, the mating season began in November and ended in January, lasting 60 d for cows and 90 d for heifers. Artificial insemination and natural service mating were used in lots with one or multiple sires. The ratio of cows per bull was about 35:1. Heifers were exposed to first breeding beginning at either 2 yr of age (1986-1994), or at

14 mo of age (1995-2006). Heifers that failed to conceive at 14 mo were retained until the next breeding season when they were exposed again (2 years old). After this age, heifers and cows that failed to conceive were removed from herd, such that only potentially fertile females remained in the herd. All females were evaluated for pregnancy, by rectal palpation made by a veterinarian, approximately 60 d after the end of breeding season. Bulls were selected based on an index including EPD for weaning weight, postweaning gain, SC18 and muscle score, in a proportion of 20, 40, 20 and 20%, respectively (Eler et al., 2004). Since 2000, SC18 was replaced by HP in the index for selection purposes.

Traits

Scrotal circumference measurements were taken transversely at the greatest diameter of the scrotum, using an appropriated metal tape device, and were carried out by trained personnel when the bulls were approximately 18 mo old.

Heifer pregnancy was defined as the observation that a heifer conceived and remained pregnant by rectal palpation, when exposed at breeding time. The females were first exposed to sires at approximately 14 mo of age (between 11 and 16 mo). HP was defined as a binary trait, assuming the values 0 or 1 for heifers that failed or were successful in conceiving, respectively.

Hudson and Van Vleck (1981) defined stayability as the probability of a cow remaining in the herd until a specific age given the opportunity to reach this age. In this study, stayability was defined as whether or not a cow calved every year up to the age of 5 yr, when the opportunity to breed was provided. The data included identification of the cows, cow dams and sires, their herds, year of birth and herd of birth of each of their offspring. STAY was defined as a binary trait, with 0 indicating failure and 1 indicating success of the cow in achieving the

specified criteria. It should be mentioned the cows that fail to conceive during one mating season were culled. Almost always the unique reason for culling cows was the reproductive failure, but in some years a few cows were culled also because of poor performance of their calves at weaning.

Contemporary groups (**CG**) were defined by the combinations of farm and year of birth, weaning and 18-mo management groups, and breeding farm (farm where heifers were exposed to the bulls) for HP; farm and year of birth, and farm and year of birth of each offspring of the cow up the 5 year benchmark; and farm and year of birth, and weaning and 18-mo management groups for each bull for SC18. Data from animals with unknown parents and belonging to CG with no variability in terms of HP and STAY were eliminated, and only CG with at least five records were considered to attenuate the extreme category problem (Miszta et al., 1989). For STAY, records from cows born after 2001 were discarded, as those cows had not yet reached the specified age of 5 years when the data were collected.

The whole dataset contained 141,906 records, including 910 sires and 73,830 dams. Scrotal circumference data from 47,605 Nellore young bulls, measured at around 18 months (SC18), were analyzed simultaneously with 27,924 heifer pregnancy (HP) and 80,831 stayability (STAY) records. The pedigree file up to the tenth generation contained 179,666 animals, comprising 1,226 sires and 77,269 dams. A summary of the dataset is presented in Table 1.

Model

The model used for the multi-trait analysis was:

$$\mathbf{y} = \begin{bmatrix} \mathbf{sc} \\ \mathbf{l}_1 \\ \mathbf{l}_2 \end{bmatrix} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \mathbf{e},$$

where $\mathbf{sc}$, $\mathbf{l}_1$ and $\mathbf{l}_2$ are vectors of observations for the linear trait SC18 and of unobservable underlying liabilities for the categorical traits HP and STAY in threshold models, respectively; $\boldsymbol{\beta}$ is a vector of (fixed) CG effects; $\mathbf{u}$ is the vector of additive genetic effects; $\mathbf{e}$ is a vector of residual effects; and $\mathbf{X}$ and $\mathbf{Z}$ are known incidence matrices relating CG and genetic effects to the elements in $\mathbf{y}$. The variance-covariance matrix for $\mathbf{u}$ and $\mathbf{e}$ can be described as:

$$V \begin{bmatrix} \mathbf{u} \\ \mathbf{e} \end{bmatrix} = \begin{bmatrix} \mathbf{G} \otimes \mathbf{A} & 0 \\ 0 & \mathbf{R} \otimes \mathbf{I} \end{bmatrix},$$

where $\mathbf{A}$ is the numerator relationship matrix, $\mathbf{I}$ is an identity matrix of appropriate order, $\otimes$ is the Kronecker (direct) product, $\mathbf{G}$ is the (co)variance matrix for direct additive genetic effects, and $\mathbf{R}$ is a residual (co)variance matrix, in which the covariances between SC18 and HP and STAY liabilities were set to 0, and the variances associated with HP and STAY liabilities were set to 1 because of identifiability issues (Sorensen et al., 2005).

The traits HP or STAY were modeled using a threshold approach:

$$f(\mathbf{w}_i | \mathbf{y}_i) = \prod_{j=1}^{n_i} 1(l_{ij} < t_i)1(w_{ij} = 0) + 1(l_{ij} > t_i)1(w_{ij} = 1),$$

where, for each trait i ($i = 1$ or 2 for HP or STAY, respectively), w_{ij} and l_{ij} denote the binary variable and the underlying liability relative to observation j ; t_i is the threshold that defines the categories of the response for each trait; and n_i is the total number of data points. A probit model

was considered, such that a multivariate normal distribution was assumed for the liabilities and the SC18, i.e. $\mathbf{y} | \boldsymbol{\beta}, \mathbf{u}, \mathbf{R} \sim \text{MVN}(\mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u}, \mathbf{R} \otimes \mathbf{I})$, with $\boldsymbol{\beta}$, $\mathbf{u}$, $\mathbf{X}$, $\mathbf{Z}$, and $\mathbf{R}$ are as described above.

The age at measurement and the age of dam at calving were included in the model as linear and quadratic covariables for SC18, as well as the calving date as linear and quadratic covariables for HP.

Estimation of (co)variance components was performed using an MCMC approach with the THRGIBBS1F90 (Misztal et al., 2002), a program that implements estimation of (co)variance components and genetic parameters in threshold mixed models and allows for any combination of categorical and continuous traits. Flat prior distributions were adopted for the fixed effects $\boldsymbol{\beta}$, as well as for the variance and covariance parameters. Post-Gibbs analyses were performed using the POSTGIBBSF90 program (Misztal et al., 2002).

The analyses were run as a single chain of 550,000 cycles with a conservative burn-in period of 50,000 iterations. Starting values for (co)variance components were obtained from preliminary univariate analyses. Every 50th sample was stored for a total of 10,000 samples used for computing posterior means, medians, modes, SD, and credible regions.

RESULTS AND DISCUSSION

Estimates of Heritabilities

Posterior mean, median, mode and SD, as well as 95% highest posterior density (HPD) intervals for heritability for the multi-trait analysis of SC18, HP, and STAY in Nellore cattle are presented in Table 2. Differences between posterior mean, mode and median of heritabilities were not greater than 0.01, indicating fairly symmetric posterior distributions.

Posterior mean ($\pm$ SD) of heritability for SC18 [0.42 ± 0.01] indicates the existence of important genetic variance for this trait, similar to values described in the literature. In *Bos taurus* populations, Bourdon and Brinks (1986) estimated the heritability of age-adjusted scrotal circumference in Herefords as 0.46 ± 0.06 and Martinez-Velasquez et al. (2003) reported values of 0.41 ± 0.04 for 9 purebred and 3 composite populations. Smith et al. (1989) reported results of 0.40 ± 0.09 for several breeds. Silva et al. (2006) estimated the heritability of SC18 at 450 d in Nellore cattle and reported a value of 0.46 ± 0.02 . Some authors, however, have found higher heritability estimates for SC18 in Nellore cattle. Pereira et al. (2000), for example, reported a point estimate of 0.51.

The heritability estimate of 0.53 ± 0.03 obtained in this study for HP on the liability scale indicates the importance of genetic variance for this trait as well. Similar heritability values in Nellore cattle (0.57 ± 0.11 , 0.61 ± 0.10 , and 0.58 ± 0.13) were reported by Eler et al. (2002, 2004) and Pereira et al. (2007), respectively. Pereira et al. (2006), using survival analysis for Nellore cattle, estimated a value of 0.51 for heritability, on the logarithm scale, of age at first conception for females exposed to sires for the first time at about 14 mo of age. In *Bos taurus* populations, Evans et al. (1999) and Doyle et al. (2000) described lower heritability estimates for Hereford and Angus breeds (0.14 ± 0.18 , and 0.21 ± 0.12 , respectively). On average, the puberty in Nellore breed (*Bos indicus*) is expressed at a later age, and the genetic variability of HP seems to be much higher (Eler et al., 2004). Eler et al. (2004) and Pereira et al. (2007) suggested the use of HP as a selection criterion, with the aim of indicating early puberty in the Nellore breed.

The heritability estimated for STAY in this study [0.10 ± 0.01] can be considered low. In Nellore cattle, Silva et al. (2006) and Van Melis et al. (2007) reported greater heritability estimates (0.22 ± 0.03 , and 0.25 ± 0.02 , respectively) for STAY at 6 and 5 years-old,

respectively. However, the value obtained in this study is similar to the heritability estimates for STAY reported by Snelling et al. (1995), Doyle et al. (2000) and Silva et al. (2003) for Hereford, Angus and Nellore herds (0.11 , 0.15 ± 0.08 and 0.12 ± 0.00 , respectively). Maybe the reason for the lower heritability obtained in this study is the inclusion of correlated traits in the analysis. The cows which were allowed to reproduce in the herds (and so expressed the trait STAY) were pre-selected based on the criteria that included either SC18 or HP.

Genetic Correlation Estimates

Table 2 presents genetic correlation estimates between SC18 and HP, and between these traits and STAY. Moderate and favorable genetic correlation estimates between SC18 and HP, and between SC18 and STAY (0.29 ± 0.05 and 0.19 ± 0.05 , respectively) were obtained in the present study. This suggests that SC18 does not have a strong genetic relationship with HP and STAY, and that a selection criterion based on SC18 may not satisfactorily improve the ability of females to conceive when exposed at 14 mo-old, and to remain in the herd by producing one calf per year for a period of 5 yr. In agreement with the genetic correlation estimate found in this study between SC18 and HP, Eler et al. (2004, 2006) reported estimates of genetic correlation coefficients of 0.20 ± 0.13 and 0.27 ± 0.10 , respectively, in Nellore cattle. However, the estimate obtained in this study was higher than the value of 0.07 ± 0.03 reported by Silva et al. (2006), who also estimated the genetic correlation between SC18 and HP in Nellore cattle. Evans et al. (1999) reported an estimate close to zero for the genetic correlation between these two traits in Hereford cattle, however, additional analyses suggested a nonlinear relationship between the traits. According to Eler et al. (2004), these results indicate that the response to selection for heifer precocity based on SC18 would be much slower than previously believed for Nellore

cattle. Martínez-Velázquez et al. (2003) also concluded that the genetic response in female reproductive traits through sire selection on yearling SC was not expected to be effective in *Bos taurus* cattle.

The estimate of genetic correlation between HP and STAY found in this study (0.64 ± 0.07) can be considered as high, which suggests that using HP as a selection criterion would improve also STAY, i.e., the ability of females to remain in the herd by producing one calf per year for a specific period of time. The low value estimated for residual correlation between HP and STAY [-0.08 ± 0.03] suggests that there are not major environmental effects common to both traits. No previous genetic and residual correlation estimates between HP and STAY were found in the literature.

The high heritability estimate for HP and the high genetic correlation between HP and STAY obtained in the present study confirm that EPD for HP can be used to select bulls for the production of precocious, fertile and long-lived daughters. A selection scheme based solely on HP could be considered, however, the modest genetic correlation between HP and SC18 indicates that the indirect genetic gain on SC18 would not be satisfactory using this strategy. Moreover, SC18 can be incorporated in a multi-trait analysis to increase the prediction accuracy for HP genetic merit of young bulls.

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Table 1. Summary statistics of the dataset for the scrotal circumference at 18 mo (SC18), heifer pregnancy (HP), and stayability at five years (STAY) traits

	SC18	HP	STAY
Number of records	47,605	27,924	80,831
Number of contemporary groups	1,562	80	358
Number of sires	787	456	652
Number of dams	28,673	17,894	53,844
Number of sires in the pedigree	1,074	913	885
Number of dams in the pedigree	42,975	27,904	56,491
Number of records in the pedigree	90,931	50,065	113,329
Mean of the trait (cm)	26.89	-	-
Range of measure	541.49	-	-
Mean of age of measure (days)	541.49	-	-
Number of successful records	-	4,341	24,772
% success	-	15.55 ¹	30.65 ²

¹ % success - Heifer pregnancy was defined as successful if the heifer conceived and remained pregnant. ² Stayability was defined as successful when a cow calved every year up to the age of 5 given that she was provided the opportunity to breed.

Table 2. Posterior means, standard deviations (SD), modes, medians, and limits of the 95% highest posterior density (HPD) intervals of heritability and genetic and residual correlation coefficients in multi-trait analysis for scrotal circumference at 18 mo (SC18), heifer pregnancy (HP), and stayability (STAY) in Nellore cattle¹

Item	Mean	SD	Mode	Median	95% HPD
Heritability					
SC18	0.42	0.01	0.42	0.42	[0.39; 0.45]
HP	0.53	0.03	0.52	0.53	[0.47; 0.59]
STAY	0.10	0.01	0.10	0.10	[0.08; 0.13]
Genetic Correlation					
SC18 x HP	0.29	0.05	0.29	0.29	[0.20; 0.39]
SC18 x STAY	0.19	0.05	0.20	0.19	[0.09; 0.30]
HP x STAY	0.64	0.07	0.64	0.64	[0.50; 0.76]
Residual Correlation					
HP x STAY	-0.08	0.03	-0.08	-0.08	[-0.15; -0.02]

¹ Scrotal circumference measurements were taken transversely at the greatest diameter of the scrotum, using a metal tape device, and were carried out on the age near 18 mo; Heifer pregnancy was defined as the observation that a heifer, exposed to breeding at about 14 mo of age, conceives and remains pregnant to palpation; Stayability was defined as whether or not a cow calved every year up to the age of 5 yr given that she was provided the opportunity to breed.