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ORIGINAL ARTICLE

Genetic associations between age at first calving and heifer body weight and scrotal circumference in Nelore cattle

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Summary

Age at first calving (AFC) measures the entry of heifers into the beef cattle production system. This trait can be used as a selection criterion for earlier reproductive performance. Using data from Nelore cattle participating in the 'Program for Genetic Improvement of the Nelore Breed' (PMGRN-Nelore Brazil), bi-trait analyses were performed using the restricted maximum likelihood method, based on an AFC animal model and the following traits: female body weight adjusted to 365 (BW365) and 450 (BW450) days of age, and male scrotal circumference adjusted to 365 (SC365), 450 (SC450), 550 (SC550) and 730 (SC730) days of age. The heritability estimates for AFC ranged from 0.02 ± 0.02 to 0.04 ± 0.02. The estimates of additive direct heritabilities (with standard error) for BW365, BW450, SC365, SC450, SC550 and SC730 were 0.36 ± 0.07, 0.38 ± 0.07, 0.48 ± 0.07, 0.65 ± 0.07, 0.64 ± 0.07 and 0.42 ± 0.07, respectively, and the genetic correlations with AFC were −0.38, −0.33, 0.10, −0.13, −0.13 and 0.06, respectively. In the herds studied, selection for SC365, SC450, SC550 or SC730 should not cause genetic changes in AFC. Selection based on BW365 or BW450 would favor smaller AFC breeding values. However, the low magnitude of direct heritability estimates for AFC in these farms indicates that changes in phenotypical expression depend mostly on non-genetic factors.

Introduction

Brazilian beef cattle production mainly consists of Zebu or Zebu-crossed bovines. These animals are already adapted to the tropical climate and to a pasture regime without supplemental feeding favoring low-cost production. The dam and heifers take up most of the financial and nutritional resources of the farm, concentrating the expenses of the production cycle on the replacement and maintenance of these females (Roberts *et al.* 2007). Animals that take a long time to begin reproduction and do not give birth regularly are unviable for the beef cattle production system. Therefore, the need for inclusion of reproductive traits in the selection index, in addition to the productive traits, becomes clear.

Age at first calving (AFC) is an easily measured reproductive trait that is usually measured early in the animals. It can be used as a selection criterion for early sexual maturity, as it measures the entry of the heifers into the beef cattle production system. Lower AFC reduces the generation interval, thus contributing towards the annual genetic gain, as well

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as providing longer lifetime production for the cows (Pelicioni *et al.* 1999).

According to Frazier *et al.* (1999), Mercadante *et al.* (2000) and Bertazzo *et al.* (2004), AFC is a trait that can respond to individual selection. However, Gressler *et al.* (2000), Pereira *et al.* (2002) and Martínez-Velázquez *et al.* (2003) found that most of the phenotypical variation observed in this trait is due to the non-additive genetic and environmental effects. In general, the reproductive traits of the females present low heritability and respond better to appropriate management than to selection. Nevertheless, Pereira *et al.* (2002) observed that the use of AFC as a selection criterion might present an efficient response in populations in which females enter the breeding season at 14 months of age.

Other traits can be used as selection criteria for early maturity in females, as long as they present favorable genetic correlations with the reproductive performance traits. The practice of selection through early body development, seeking early reproductive maturity, is very common. It is known that cattle selection based on body weight can provide larger and taller animals and these present greater nutritional demands for their maintenance. In an extensive beef cattle production system, when the nutritional and environmental conditions are unfavorable, these animals tend to be late in their reproductive performance. However, favorable negative genetic correlations have been estimated in the Nelore breed between AFC and body weight of the females at 365 (Mercadante *et al.* 2000) and 550 (Garnero *et al.* 2001) days of age.

The scrotal circumference observed during puberty is an easily obtained measurement of growth, with moderate heritability, that has been used as a selection criterion for fertility and early maturity. There is accentuated growth of the testicular mass at the beginning of puberty in males, while in females, alterations that provide phenotypical identification of puberty do not occur. For this reason, endeavors have been made to find an association of early maturity measurements that is common to both males and females. Studies have been showing that greater scrotal circumference measurements in bulls are related to earlier reproductive maturity and lower AFC for their female offspring (Toelle & Robison 1985; Moser *et al.* 1996; Vargas *et al.* 1998 and Pereira *et al.* 2001, 2002).

The present study had the aim of providing selection tools to promote early reproductive maturity in females of the Nelore breed, within the 'Program for Genetic Improvement of the Nelore Breed' (PMGRN-Nelore Brazil). Thus, the phenotypical variations of AFC and their genetic associations with heifer body weight and scrotal circumference were studied.

Materials and methods

Data from Nelore breed animals born from 1976 to 2002, on 22 farms in the state of São Paulo, Brazil, that participated in PMGRN-Nelore Brasil, coordinated by the National Association of Breeders and Researchers ('Associação Nacional de Criadores e Pesquisadores', ANCP), were analysed.

These animals were raised under a pasture regime without supplemental feeding. The calves were weaned at 6–8 months of age. The reproductive management consisted of a breeding season of 60–120 days using artificial insemination or controlled natural breeding. Body weights and male scrotal circumferences were measured at birth and every 3 months up to at least the age of 18 months.

An index called total genetic merit, developed by PMGRN-Nelore Brasil, was used for selecting genetically superior males and females in the farms. This index involves the traits of body weight, scrotal circumference and maternal ability. The traits evaluated in the cows were the AFC and body weight adjusted to 365 (BW365) and 450 (BW450) days of age. The traits evaluated in males were the scrotal circumference adjusted to 365 (SC365), 450 (SC450), 550 (SC550) and 730 (SC730) days of age.

Adjustment of body weight and scrotal circumference for age

Female body weights were adjusted to 365 and 450 days, and the scrotal circumferences were adjusted to 365, 450, 550 and 730 days. A preliminary analysis indicated that linear adjustment of these traits was inefficient. Therefore, a modified logistic non-linear function (Quirino *et al.* 1999) was used for the adjustment, considering that non-linear models are more appropriate for describing body growth than are linear adjustments (Laird 1965). This function had been studied by Grossi *et al.* (2008) and it was found to be the best out of five non-linear curves for female growth that were examined. Frizzas (2006), analysing the performance of the males from this same database, found the same modified logistic non-linear function to be the best to describe testicular growth per unit of time.

Female body weight adjusted to 210 days (BW210) was used as a covariable for AFC. It was derived from the product of observed body weight

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and a linear correction factor, i.e. the ratio between the expected body weight at 210 days and the expected body weight at each age. The expected body weight values for each age were obtained by means of quadratic regression of the body weight according to age. Thus, the body weight considered was the one closest to the body weight at 210 days, within an interval of 150–305 days of age.

Male body weights, adjusted to 365 (MBW365), 450 (MBW450), 550 (MBW550) and 730 (MBW750) days of age, and respectively used as covariates for SC365, SC450, SC550 and SC730 in the animal models, were obtained from the non-linear logistic function studied by Nelder (1961). This function was defined by Frizzas (2006) and used by Grossi *et al.* (2008) as the curve that best described male body growth, out of five non-linear curves examined in this database.

Statistical analyses

The present study was limited to offspring whose parents and birth dates were known. The general exclusion criteria were that sires with less than two offspring in each trait, contemporary groups (CG) showing less than four observations per trait and animals that died during husbandry would be disregarded. Three AFC data sets were formed for bi-trait analyses between this trait and BW365, BW450 and for analyses with scrotal circumference adjusted to four ages. In the data set used for bi-trait analyses of AFC with BW365 and BW450, only animals providing measurements of both traits were considered.

The definition of the CG was the same for all traits and comprised animals belonging to the same farm that were born during the same year and season. Two birth seasons were defined: the first for animals born from October to March (rainy season), and the second for animals born from April to September (dry season).

Least-squares analysis, using the GLM procedure available in the SAS software package (SAS 9.1, SAS Institute, Cary, NC, USA), was performed to determine the environmental factors to be considered in the mixed model. The age of the dam at calving was not included in the models because it did not significantly influence the traits studied. The normality of the residuals was verified for each trait, and records for which the standardized residual was higher than 3.5 or lower than −3.5 standard deviations were excluded from the data set for final analysis. The final data sets are described in Table 1. The total number of animals in the numerator relationship matrix, including base animals, was 42 734.

Table 1 Total number of animals and numbers of sires, dams and animals in contemporary groups (CG) considered in bi-trait analyses of age at first calving (AFC) based on female body weight adjusted to 365 (BW365) and 450 (BW450) days of age, and on scrotal circumference adjusted to 365 (SC365), 450 (SC450), 550 (SC550) and 730 (SC730) days of age

Traits	Number of animals	Sires	Dams	CG
AFC and BW365[a]	3064	256	2358	196
AFC and BW450[a]	3055	257	2353	196
AFC[b]	3318	261	2561	207
SC365	2525	199	1951	110
SC450	2538	199	1962	110
SC550	2540	199	1963	110
SC730	2536	199	1961	110

[a]Same structure data for both traits.
[b]AFC data used in the bi-trait analyses with scrotal circumference at different ages.

Maternal permanent environmental effects were not considered in the models, because they would be fragile effects. The data set structure did not allow this effect to be considered in the analyses, because the majority of the cows only had one offspring.

Animal models were defined for the following traits:

i) For AFC, in bi-trait analyses with BW365 or BW450, only the CG class was considered to be a fixed effect;

ii) For AFC, in bi-trait analyses with SC365, SC450, SC550 or SC730, the CG class was considered to be a fixed effect and, in addition, the effect of BW210 was considered to be a linear covariate of AFC, in view of its significant influence on AFC in previous least-squares analyses;

iii) For BW365 and BW450, only the CG class was considered to be a fixed effect;

iv) For SC365, SC450, SC550 and SC730, the CG class was considered to be a fixed effect, and MBW365, MBW450, MBW550 and MBW730 were considered to be linear covariates, respectively. Preliminary analyses for SC365, SC450, SC550 and SC730 that did not include MBW365, MBW450, MBW550 and MBW730, respectively, as covariates, resulted in lower heritability estimates. However, there was no change in the estimates for genetic correlations with AFC.

The genetic parameters were estimated using the Restricted Maximum Likelihood (REML) method, in bi-trait animal models. They were computed using MTDFREML (Boldman *et al.* 1995), considering

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animal and residual random effects and the previously described fixed effects for all traits. The maternal genetic effect was considered only in relation to BW365 and BW450. The initial values were taken from least-squares analyses, single-trait REML analyses and from the literature (Lôbo 1998; Borjas *et al.* 2003; Martínez-Velázquez *et al.* 2003). The environmental covariances between AFC and SC365, SC450, SC550 and SC730 were considered to be zero. After convergence was reached and stipulated at 10^{-9}, the analyses were restarted until the results found were confirmed as overall and not local maxima.

Results and discussion

The means and the minimum and maximum observed values found for AFC, the body weight of the females and the adjusted scrotal circumference can be seen in Table 2.

For AFC, the observed values are in agreement with those found by Garnero *et al.* (2001) and Pereira *et al.* (2001). However, the means were higher than those found by Mercadante *et al.* (2000) and Bertazzo *et al.* (2004). Lower means for AFC have also been reported for European cattle and crossbred cows (Frazier *et al.* 1999; Pelicioni *et al.* 1999 and Wolf *et al.* 2004). The AFC means could be reduced by appropriate management. Some authors (Pereira *et al.* 2002) found that, when the females were exposed too early (12–16 months of age) to the bull, the mean AFC was 33 months.

The means observed for BW365 and BW450 were very close to those reported by Bertazzo *et al.* (2004) for BW365 in Nelore females and by Marcondes *et al.* (2002) for BW365 and body weight adjusted to 455 days of age (BW455). Mercadante *et al.* (2000) and Siqueira *et al.* (2003), studying herds of Nelore throughout Brazil, found smaller means (187.1 ± 26.35 and 250 ± 44 kg) for BW365 and BW455, respectively. This variation in the means found in the literature was expected, as beef cattle management is extensive and the climatic and nutritional conditions of each area of the country influence the growth and weight gain of the animals.

Borjas *et al.* (2003) found means of 19.3 ± 2.19, 22.4 ± 2.83 and 25.4 ± 3.19 cm for scrotal circumference corrected respectively for 365, 456 and 548 days of age when studying 54 Nelore herds participating in PMGRN-Nelore Brazil. Means for SC550 that were similar to those observed in the present study were described by Pereira *et al.* (2001, 2002).

The heritability estimated for AFC, in bi-trait analyses with BW365, BW450, SC365, SC450, SC550 and SC730 ranged from 0.02 ± 0.02 to 0.04 ± 0.02 (standard errors of the estimates obtained from single-trait analyses). The additive genetic and phenotypical variance for AFC ranged from 0.405 to 0.688 and from 16.495 to 17.142, respectively. For this study, we only had access to the AFC of animals that calved and, therefore, there may be some bias in the heritability estimates. The estimates of direct and maternal heritability coefficients and of genetic and environmental correlations obtained for body weight of the females adjusted to BW365, BW450, SC365, SC450, SC550 and SC730, in bi-trait analyses with AFC, are shown in Table 3.

The AFC heritability indicated that direct selection for AFC might not be efficient. The great influence that the environment has on this trait had already been reported by Pereira *et al.* (2001, 2002), who reported heritability of 0.02 and 0.09, respectively, in the Nelore breed. The estimates for this parameter have ranged from 0.08 to 0.22 in different European

Table 2 Means, standard deviations (SD) and minimum (Min) and maximum (Max) values for age at first calving (AFC, months), body weight (kg) of the females adjusted to 365 (BW365) and 450 (BW450) days of age, and for scrotal circumference (cm) adjusted to 365 (SC365), 450 (SC450), 550 (SC550) and 730 (SC730) days of age

Trait	Means	SD	Min	Max
AFC	35.1	4.5	22.0	49.0
BW365	226.0	27.0	118.0	341.0
BW450	262.0	31.0	141.0	390.0
SC365	19.7	2.3	10.7	27.2
SC450	23.2	2.6	13.1	31.6
SC550	26.5	3.0	16.6	35.8
SC730	30.7	3.7	17.2	42.3

Table 3 Estimates of phenotypical (σ_P^2) and environmental (σ_e^2) variance, direct (h_d^2) and maternal (h_m^2) heritability coefficients and of genetic (r_G) and environmental (r_e) correlations obtained for body weight of the females adjusted to 365 (BW365) and 450 (BW450) days of age, and for scrotal circumference adjusted to 365 (SC365), 450 (SC450), 550 (SC550) and 730 (SC730) days of age, in bi-trait analyses with age at first calving

Trait	σ_P^2	σ_e^2	h_d^2	h_m^2	r_G	r_e
BW365	428.10	242.53	0.36 (0.07)	0.08 (0.04)	−0.38	−0.14
BW450	543.31	310.07	0.38 (0.07)	0.05 (0.03)	−0.33	−0.18
SC365	2.48	1.29	0.48 (0.07)	–	0.10	–
SC450	3.36	1.16	0.65 (0.07)	–	−0.13	–
SC550	4.45	1.58	0.64 (0.07)	–	−0.13	–
SC730	8.51	4.90	0.42 (0.07)	–	0.06	–

The values in brackets correspond to the standard errors of the estimates, obtained from single-trait analyses.

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breeds (Frazier *et al.* 1999 and Martínez-Velázquez *et al.* 2003). However, the heritability estimate reported by Bertazzo *et al.* (2004) for the Nelore breed was even greater (0.36). This variation in the estimates, obtained by reviewing the literature, reflects the diversity of genetic material found in different areas of Brazil. It is important to emphasize that the traditional beef cattle management adopted in farms, such that the beginning of reproduction for the females is defined by body weight and/or age, may make it difficult to identify heifers with early maturity, thus reducing the phenotypical variability of the trait. Pereira *et al.* (2002), studying herds in which Nelore heifers were exposed to the sire at younger ages (14–18 months), obtained greater magnitude of heritability for AFC (0.18 and 0.20, respectively), in comparison with the present study.

Estimates of additive direct and additive maternal heritabilities for BW365 of similar magnitude to those in the present study were found by Mercadante *et al.* (2000) and Gunski *et al.* (2001), in Nelore cattle. The heritabilities of direct and maternal effects on BW450 obtained in the present study were in agreement with those estimated by Marcondes *et al.* (2002) and Bittencourt *et al.* (2002), when those authors considered maternal, direct and permanent environment effects in their models.

Female growth-related traits (BW365 and BW450) presented favorable genetic correlations with AFC (−0.38 and −0.33, respectively). Thus, selection for body weight at these ages would favor smaller AFC breeding values. However, the low magnitude of direct heritability estimates for AFC in these farms indicates that changes in phenotypical expression depend mostly on non-genetic factors. Garnero *et al.* (2001), studying the relationships between AFC and female body weight adjusted to 550 days of age in a Nelore breeding herd, found a genetic correlation (−0.31) that was identical to what was estimated in the present study for AFC and BW450.

The heritability estimates for SC365, SC450, SC550 and SC730 corrected for body weight (MBW365, MBW450, MBW550 and MBW730, respectively) were greater than the estimates obtained for scrotal circumference that was not corrected for body weight (preliminary analyses: 0.36 ± 0.07 versus 0.47 ± 0.07). This greater genetic variability is concordant with the results found by Peña *et al.* (2001) and Dias *et al.* (2003), who used body weight adjusted for age as a covariable for scrotal circumference adjusted for age and indicated this trait as a selection criterion. Bourdon & Brinks (1986) did not find any differences in heritability estimates for scrotal circumference corrected for age and for age and weight.

The heritability estimates for SC365, SC450 and SC550 in the present study were greater than the heritability estimates from Gressler *et al.* (2000), Pereira *et al.* (2002) and Borjas *et al.* (2003) for scrotal circumference adjusted only for age and greater than the estimates from Pereira *et al.* (2002), Peña *et al.* (2001) and Dias *et al.* (2003) for scrotal circumference adjusted for age and body weight. Using scrotal circumference adjusted for age and body weight in the present study may have contributed towards greater magnitude of heritability estimates than in the literature. Moreover, scrotal circumference was adjusted for age using non-linear regression. These equations are more suitable for adjusting body measurements based on age, especially during phases in which growth is non-linear.

In agreement with the heritability estimates obtained in the study by Garnero *et al.* (2001), individual selection for scrotal circumference would be more efficient if it was based on 450 or 550 days of age, because at these ages the estimates were greater than those for SC365 and SC730. This indicates that the phenotypical variation observed in SC450 and SC550 was subject to less influence from the environmental and non-additive genetic effects.

The genetic correlation estimates for AFC and scrotal circumference presented low magnitudes, thus indicating that, in these herds, male selection for scrotal circumference will not cause genetic changes to the AFC. Martínez-Velázquez *et al.* (2003), studying nine different beef cattle breeds, estimated a similar genetic correlation (0.15) between AFC and scrotal circumference at approximately 1 year of age. However, favorable estimates for genetic correlations are found in the literature for AFC and scrotal circumference relating to the Nelore breed measured at several ages: −0.44 for AFC and scrotal circumference close to 20 months of age (Martins Filho & Lôbo 1991), −0.23 for AFC and SC365 (Mercadante *et al.* 2000) and between −0.23 and −0.29 for AFC and SC550 (Pereira *et al.* 2001).

Toelle & Robison (1985) observed in European cattle that a single scrotal circumference measurement, close to 365 days, would be an adequate early maturity indication for males. Measurements recorded before this age would be better related to body size, because the animal has not yet reached puberty. Therefore, in spite of the low magnitude of the estimates, the coefficients of genetic correlation lead to the assumption that the scrotal circumference of Nelore cattle, measured at 365 and 730 days of

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age, would not be under the influence of additive genes that would act on the reproductive early maturity of these animals and, for this reason, favorable associations with the female AFC were not presented.

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