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Genetic parameters and relationships of heifer pregnancy and age at first calving with weight gain, yearling and mature weight in Nelore cattle

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ABSTRACT

The objectives of the current study were to investigate the additive genetic associations between heifer pregnancy at 16 months of age (HP16) and age at first calving (AFC) with weight gain from birth to weaning (WG), yearling weight (YW) and mature weight (MW), in order to verify the possibility of using the traits measured directly in females as selection criteria for the genetic improvement of sexual precocity in Nelore cattle. (Co)variance components were estimated by Bayesian inference using a linear animal model for AFC, WG, YW and MW and a nonlinear (threshold) animal model for HP16. The posterior means of direct heritability estimates were: 0.45 ± 0.02; 0.10 ± 0.01; 0.23 ± 0.02; 0.36 ± 0.01 and 0.39 ± 0.04, for HP16, AFC, WG, YW and MW, respectively. Maternal heritability estimate for WG was 0.07 ± 0.01. Genetic correlations estimated between HP16 and WG, YW and MW were 0.19 ± 0.04; 0.25 ± 0.06 and 0.14 ± 0.05, respectively. The genetic correlations of AFC with WG, YW and MW were low to moderate and negative, with values of −0.18 ± 0.06; −0.22 ± 0.05 and −0.12 ± 0.05, respectively. The high heritability estimated for HP16 suggests that this trait seem to be a better selection criterion for females sexual precocity than AFC. Long-term selection for animals that are heavier at young ages tends to improve the heifers sexual precocity evaluated by HP16 or AFC. Predicted breeding values for HP16 can be used to select bulls and it can lead to an improvement in sexual precocity. The inclusion of HP16 in a selection index will result in small or no response for females mature weight.

1. Introduction

In tropical regions, body weight measurements at different ages and scrotal circumference have been used as selection criteria in beef cattle to improve growth and sexual precocity, whereas female reproductive traits are not included in the selection index. Recently, some authors have evaluated economically relevant traits measured directly on females for improving fertility and sexual precocity, such as heifer pregnancy (Eler et al., 2004; Silva et al., 2005; Van Melis et al., 2010) and age at first calving (Boligon et al., 2010; Buzanskas et al., 2010; Silva et al., 2005). Age at first calving is measured early and it is routinely collected, being expressed in most of the females placed in breeding. Likewise, heifer pregnancy is easy to obtain for all heifers, not requiring the use of penalties and presents moderate to high genetic variability in Nelore cattle, which justify the use of early heifer pregnancy as a selection criterion (Silva et al., 2005).

Few studies on beef cattle have investigated genetic associations of heifer pregnancy or age at first calving with body weight (Boligon et al., 2010; Grossi et al., 2009; Shiotsuki et al., 2009). Currently, in most of Brazilian cattle ranches, an increase in females mature weight is undesirable since larger animals have higher maintenance requirements and lower reproduction rates in environments where feed availability is limited and with low nutritional value (Beretta et al., 2002; Kaps et al., 1999). However, studies associating mature weight and heifers sexual precocity were not found in the literature.

Data regarding genetic correlations among productive traits extensively used as selection criteria and female sexual

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precocity is important for the development of selection index including these traits, since these relationships are little known. Therefore, the objectives of the present study were to investigate the additive genetic association of heifer pregnancy at 16 months of age and age at first calving with productive traits (weight gain from birth to weaning, yearling weight and mature weight), in order to verify the possibility of using traits measured directly in females as selection criteria for genetic improvement of sexual precocity in Nelore cattle.

2. Materials and methods

2.1. Data description

The data used in this study were obtained from a breeding company located in the northwestern region of the State of São Paulo, Brazil. This company is specialized in beef cattle using Nelore animals reared on pasture with the objective of selling young breeding stock and animals for slaughter.

Two breeding seasons are performed: an anticipated breeding season that occurs from February to March, during which all heifers (irrespective of body weight and body condition score) are exposed to reproduction at about 16 months of age in order to identify sexual precocious animals; and another breeding season, from November to January, in which all females participate. Heifers pregnancy is evaluated by rectal palpation approximately 60 days after the end of the breeding season. Heifers that do not conceive during the anticipated breeding season are again exposed in the second breeding season and, if they do not become pregnant, are discarded.

Heifer pregnancy at 16 months of age (HP16) was defined based on the conception and calving. Heifers calving before 31 months of age were considered as sexually precocious (HP16 = 1). For non-precocious females, calving occurred between 31 and 42 months of age (HP16 = 2). Another traits evaluated were: age at first calving (AFC), weight gain from birth to weaning (WG), yearling weight (YW) and females mature weight (MW). The MW was obtained from a single record taken when the animals were at least 4-years old (Table 1).

Contemporary groups (CG) included: herd and year of birth, for HP16; herd, year and season of birth and breeding season, for AFC; herd, year and season of birth, management group at weaning and sex, for WG and YW, yearling management group was also added for YW; herd, year and season (March to April and May to June) of recording and management group at weaning and at yearling, for MW.

Table 1
Number of observations, means, number of sires and dams and contemporary groups (CG) considered in the analyses for heifer pregnancy at 16 months of age (HP16), age at first calving (AFC), weight gain from birth to weaning (WG), yearling weight (YW) and mature weight (MW).

Traits	Observations	Means	Sire	Dams	CG
HP16 (%)	33,557	14.20	475	20,882	47
AFC (days)	25,594	1056.44	455	17,304	171
WG (kg)	70,295	143.45	618	28,214	1184
YW (kg)	47,608	268.09	562	22,001	1562
MW (kg)	3261	434.59	260	3,037	46

Contemporary groups with less than four animals were excluded. For AFC, WG, YW and MW, animals with measurements 3.5 standard deviations above or below the mean of the respective GC were removed. For HP16, there were no homogeneous CG (i.e. all animal with the same value for the trait, 1 or 2).

2.2. Analysis

The (co)variance components were estimated by Bayesian inference using a linear animal model for AFC, WG, YW and MW and a nonlinear (threshold) animal model for HP16. The GIBBS2F90 (analysis between AFC and WG, YW and MW) and THRGIBBSF90 (analysis between HP16 and WG, YW and MW) softwares developed by Misztal (2007) were used. Weaning weight was included in all analyses to account for the effects of sequential selection.

For all traits, the animal model included genetic additive direct and residual effects as random and the CG as fixed effect. Maternal additive genetic and permanent environmental effects were considered as random effects for WG. Covariates in the models were: age at the beginning of the breeding season (linear effect) for HP16; animal age at measurement (linear and quadratic effects) for WG, YW and MW; age of cow at calving (linear and quadratic effects) for WG and YW. The complete model can be represented in matrix notation as follows:

$$y = X\beta + Z_1 a + Z_2 m + Wc + e$$

where: y = vector of observations; β = vector of fixed effects; a = vector of direct additive genetic effects; m = vector of maternal additive genetic effects; c = vector of maternal permanent environmental effects, and e = vector of residual random errors associated with the observations. X, Z_1, Z_2 and W are incidence matrices related to β, a, m and c to y.

The vectors β, a, m and c are location parameters from the conditional distribution. It was assumed *a priori* to a uniform distribution of β, which reflects a vague prior knowledge about this vector. For other components, Inverted Wishart distributions were defined as *a priori*. Thus, the distribution of y given the parameters of location and scale was assumed (Van Tassel and Van Vleck, 1996):

$$y|\beta, a, m, c, R \sim N[X\beta + Z_1 a + Z_2 m + Wc, I_N R]$$

A threshold model was used for HP16. In this model, it is assumed that the underlying scale presents normal continuous distribution, represented as follows:

$$U|\theta \sim \mathrm{N}\left(W\theta, I\sigma_e^2\right)$$

where: U is the vector of the underlying scale of order r; $\theta' = (\beta', a', m', c')$ is the vector of the location parameters of order s with β corresponding to the set of fixed effects and a, m and c corresponding to random effects; W is the known incidence matrix of order r by s; I is the identity matrix of order r by r; and σ_e^2 is the residual variance. Since the σ_e^2 cannot be estimated (Gianola and Foulley, 1983), an arbitrary value was attributed to this parameter ($\sigma_e^2 = 1.0$).

The prior distributions for genetic and residual effects followed normal multivariate distributions:

$$P\left(a|\sigma_a^2\right) \sim N\left(0, A\sigma_a^2\right)$$

$$P\left(e|\sigma_e^2\right) \sim N\left(0, I\sigma_e^2\right)$$

where A is the relationship matrix and σ_a^2 is the additive genetic variance.

After defining the model parameters, the link between the two scales (categorical and continuous) could be established based on the contribution of the probability of an observation that fitted the first category, which is proportional to (Gianola and Foulley, 1983):

$$P(y\nu = 0|t, \theta) = P(U\nu < t|t, \theta) = \Phi((t - w'\nu\theta) / \sigma_e)$$

where: $y\nu$ = response variable for the νth observation; t = threshold value arbitrarily assigned as the true value is unobservable; $U\nu$ = value of the underlying variable for the νth observation; $\Phi()$ = cumulative distribution function of a standard normal variable; and $w'\nu$ = scalar of the incidence matrix that linked θ to the νth observation. Since the observations are conditionally independent, given θ, the likelihood function is defined by the product of contributions of each record.

A total of 800,000 samples were generated in the analyses and, a burn-in period of 100,000 samples with samples taken each 20 cycles. The convergence was verified using the POSTGIBBSF90, a program developed by S. Tsuruta (Misztal et al., 2002) and by the R program with the BOA package (Smith, 2001), which generates convergence diagnostics according to Geweke (1992) and Heidelberger and Welch (1983). Point estimates of parameters were calculated as the posterior mean of the respective variance components as the resulting distributions tended to be symmetric.

3. Results and discussion

In the data set studied, 4765 heifers (14.20%) presented a successful pregnancy at 16 months of age. This result is similar to those reported by Eler et al. (2004), Silva et al. (2005) and Van Melis et al. (2010) for Nelore heifers younger than 18 months of age, who rates ranging from 10 to 18%. In Brazil, although some farmers are anticipating Nelore heifers breeding season, in order to identify sexual precocious animals, heifers early pregnancy is not yet used as a selection criterion.

Table 2 shows the posterior density estimates of variance and heritability obtained for HP16 and AFC with WG, YW and MW. For all traits, the estimates were calculated as the means of the results obtained from three-traits analysis. Results from POSTGIBBSF90 and BOA package (Geweke and Heidelberger and Welch tests) indicated that the number of rounds, burn-in period and number of Markov chains samples considered were sufficient to reach the convergence for all parameter estimates (results not shown).

The posterior means, modes and medians for variances and heritabilities were similar (Table 2), indicating distributions close to normal. The heritability posterior mean estimate for HP16 was high, pointing out that using this trait as a selection criterion, will increase the heifers probability of conceiving at 16 months of age. For Nelore cattle, similar results were reported by Eler et al. (2004), Silva et al. (2005) and Van Melis et al. (2010). For *Bos taurus* (Angus and Hereford), Evans et al. (1999) and Doyle et al. (2000) reported lower heritability estimates for this trait than in the present study, with values of 0.14 ± 0.08 and 0.21 ± 0.12, respectively. According to Eler et al. (2004), Nelore animals (*Bos indicus*) have not been selected for fertility, showing greater genetic variability for this trait than those usually reported for *Bos taurus* populations.

Table 2
Posterior estimates of direct heritability (h_a^2), maternal heritability (h_m^2), direct additive genetic (σ_a^2), genetic maternal (σ_m^2), maternal permanent environmental (σ_{ap}^2) and residual (σ_r^2) variances for heifer pregnancy at 16 months of age (HP16), age at first calving (AFC), weight gain from birth to weaning (WG), yearling weight (YW) and mature weight (MW).

Traits	Parameters				
		Mean (SD)	Mode	Median	95% HPD
HP16	h_a^2	0.45 (0.02)	0.45	0.45	0.40 to 0.50
	σ_a^2	0.82	0.83	0.83	0.66 to 1.01
	σ_r^2	1.00	1.00	1.01	0.98 to 1.02
AFC	h_a^2	0.10 (0.01)	0.09	0.09	0.07 to 0.12
	σ_a^2	103.40	102.92	102.87	74.12 to 138.10
	σ_r^2	1,045.49	1,042.99	1,044.93	1,001.72 to 1,061,09
WG	h_a^2	0.23 (0.02)	0.23	0.23	0.21 to 0.25
	h_m^2	0.07 (0.01)	0.06	0.07	0.05 to 0.08
	σ_a^2	65.79	66.42	65.51	53.54 to 78.42
	σ_m^2	19.06	19.51	19.19	12.11 to 26.10
	σ_{ap}^2	49.99	48.74	49.91	45.84 to 53.61
	σ_r^2	151.37	151.40	151.50	145.50 to 158.81
YW	h_a^2	0.36 (0.01)	0.36	0.36	0.34 to 0.39
	σ_a^2	166.49	165.40	166.40	143.40 to 182.90
	σ_r^2	291.61	291.70	291.60	281.60 to 291.60
MW	h_a^2	0.39 (0.04)	0.38	0.39	0.34 to 0.43
	σ_a^2	705.35	673.12	699.01	469.20 to 968.50
	σ_r^2	1,083.86	1,113.00	1,086.90	876.61 to 1,282.31

95% HPD = 95% highest posterior density interval; SD = standard deviation.

The heritability estimated for AFC was low, indicating that this trait is highly influenced by the environmental components (i.e. nutritional and management conditions applied on the ranch) and thus the selection to decrease the AFC would result in a small genetic gain. This result agreed with those reported in recent studies for Nelore cattle, that range from 0.04 ± 0.01 to 0.17 ± 0.01 (Boligon et al., 2010; Buzanskas et al., 2010; Silva et al., 2005). Heritability estimates for AFC are influenced by the fact that only the females that have calved are considered in the analysis. Moreover, the short length of the breeding seasons, which in our data were 75 days for cows and 60 days for heifers, can contribute to decreasing genetic variances and heritability estimates. Considering these results, HP16 is a better selection criterion for heifer sexual precocity than AFC.

Heritability estimates for WG, YW and MW (Table 2) were within the range reported in the literature for Nelore cattle (Boligon et al., 2008; Boligon et al., 2010; Grossi et al., 2009). In Angus, Kaps et al. (1999) also reported high heritability for cows mature weight (i.e. ranging from 0.44 to 0.53) indicating that this trait can be changed by selection. The maternal heritability estimated for WG (0.07 ± 0.01) was in agreement to that estimated by Grossi et al. (2009) of 0.08 ± 0.04. In general, the posterior means of direct heritability for growth traits suggest that these traits should respond to individual selection.

The posterior means of genetic correlations between HP16 and WG, YW and MW were 0.19 ± 0.04; 0.25 ± 0.06 and 0.14 ± 0.05, respectively. The phenotypic correlations were 0.18 ± 0.07; 0.15 ± 0.04 and 0.09 ± 0.05, respectively, in the same order. Estimates of posterior density of genetic and phenotypic correlations between HP16 and WG, YW and MW are shown in Fig. 1. These results indicate that HP16 do not have a strong genetic relationship with the productive traits commonly used as selection criteria in Nelore cattle. Thus, the selection based only in WG and/or YW will not satisfactorily improve the ability of females to conceive at 16 months of age. Using another sample of the same data from the present study, Shiotsuki et al. (2009) found low and positive genetic correlations of HP16 with post-weaning gain (0.09 ± 0.05) and negative with weaning weight (−0.25 ± 0.03). However, no similar studies were found in the literature using different populations, to allow a fair comparison.

Positive and low posterior mean estimate of genetic correlation between HP16 and MW suggests that the inclusion of HP16 in the selection index is an interesting alternative in order to improve females sexual precocity with little or no genetic change in mature weight. This result is relevant for beef cattle industry because, as related by Boligon et al. (2009), long-term selection for body weight at young ages will increase mature size of cows, thus reducing the economic efficiency of some production systems with limited nutritional resources. No previous genetic correlation estimates between HP16 and MW were found in the literature.

The posterior density of genetic and phenotypic correlations between AFC and WG, YW and MW are shown in Fig. 2. The estimates of the posterior mean for the genetic correlations between AFC and WG, YW and MW were low-moderate and negative, with values of −0.18 ± 0.06; −0.22 ± 0.05 and −0.12 ± 0.05, respectively. Phenotypic correlations posterior mean estimates were: −0.21 ± 0.03 (AFC × WG); −0.14 ± 0.03 (AFC × YW) and −0.10 ± 0.04 (AFC × MW). Thus, selection criteria commonly used in beef cattle, which include productive traits (i.e. weight gains and weights measured at young ages) in a selection index, will result in a slow decrease of the AFC. However, results from literature indicate that there are positive genetic relationships between weights obtained at young ages and mature weight (Boligon et al., 2009), so using only weights at young ages as selection criteria, will increase cows feed requirements.

In agreement with the present study, Boligon et al. (2010) reported genetic associations between AFC and post-weaning gain and yearling weight of −0.29 and −0.24, respectively. These authors also found a small negative genetic correlation (−0.14) between AFC and MW, for Nelore cattle. Pereira et al. (2001) reported genetic correlation estimates between AFC of Nelore females exposed at 14 and 26 months of age and weight gain at 345 days of age close to zero, −0.08 and −0.03, respectively. For Wiltbank et al. (1966) there is a weight gain threshold above which the females will reach puberty. These authors observed that, when the post-weaning gain was small, small differences in weight gain had an important effect on age at puberty. On the other hand, when post-weaning gain was higher, differences in average daily weight gain did not affect age at puberty. Evaluating three Hereford lines selected for weaning weight, final yearling weight, and final weight plus muscling score, Wolfe et al. (1990) showed that selection for rate of weight gain did not influence the age at puberty.

Our results indicate that long-term selection for animals that are heavier at young ages tends to improve the heifers sexual precocity evaluated by HP16 or AFC. Furthermore, it is expected a greater response to selection for sexual precocity when the animals are selected considering HP16 than using AFC. Predicted breeding values for HP16 can be used to select bulls and it can lead to an improvement in sexual precocity. In addition, the inclusion of heifer pregnancy in a selection index will result in small or no response for females mature weight. Thus, it is possible to select animals simultaneously for growth and early pregnancy, in a favorable way.

4. Conclusions

Heifer pregnancy at 16 months of age has high genetic variability in Nelore cattle and can be used to improve sexual

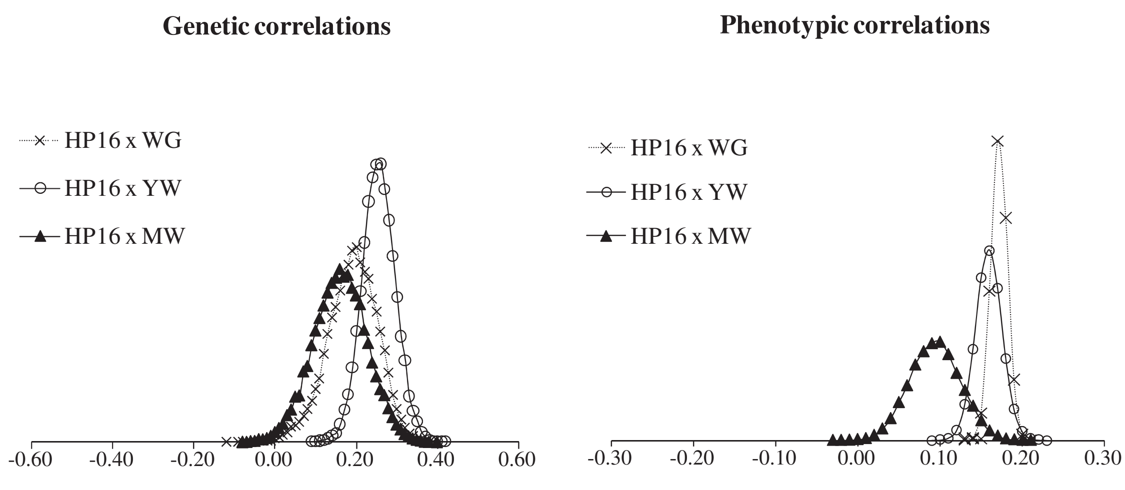

Fig. 1. Posterior density of genetic and phenotypic correlations between heifer pregnancy at 16 months of age (HP16) and weight gain from birth to weaning (WG), yearling weight (YW) and mature weight (MW).

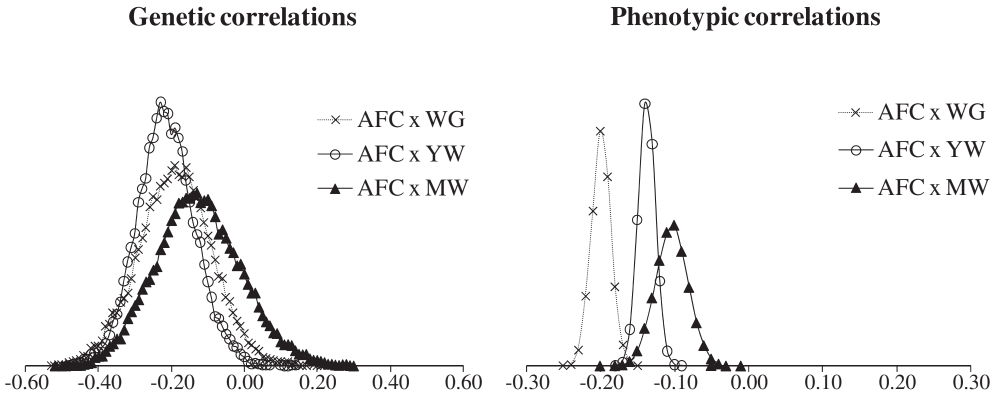

Fig. 2. Posterior density of genetic and phenotypic correlations between age at first calving (AFC) and weight gain from birth to weaning (WG), yearling weight (YW) and mature weight (MW).

precocity. Better phenotypic performance in age at first calving may be achieved by changes in management.

Long-term selection for animals with higher pre-weaning weight gain and late yearling weight will increase the rate of heifer pregnancy at 16 months of age slowly.

The inclusion of heifer pregnancy at 16 months of age in the selection index will improve sexual precocity, without important changes in females mature weight.

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