Livestock Science 154 (2013) 13–18

Contents lists available at SciVerse ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Genetic associations between hip height, body conformation scores, and pregnancy probability at 14 months in Nelore cattle

M.L. Santana Jr.[a,*], J.P. Eler[b], D.C. Cucco[c], A.B. Bignardi[a], J.B.S. Ferraz[b]

[a] *Grupo de Melhoramento Animal de Mato Grosso (GMAT), Instituto de Ciências Agrárias e Tecnológicas, Campus Universitário de Rondonópolis, Universidade Federal de Mato Grosso, MT-270, Km 06, CEP 78735-001, Rondonópolis, MT, Brazil*

[b] *Grupo de Melhoramento Animal e Biotecnologia (GMAB), Faculdade de Zootecnia e Engenharia de Alimentos, Departamento de Medicina Veterinária, Universidade de São Paulo, C. Postal 23, CEP 13635-970, Pirassununga, SP, Brazil*

[c] *Departamento de Zootecnia, Centro de Educação Superior do Oeste, Universidade do Estado de Santa Catarina, CEP: 89815-630, Chapecó, SC, Brazil*

ARTICLE INFO

Article history:
Received 25 October 2012
Received in revised form
17 February 2013
Accepted 19 February 2013

Keywords:
Bone
Genetic correlation
Growth
Visual score
Threshold model
Zebu

ABSTRACT

Genetic parameters for hip height (HH), finishing precocity score (PRE), muscling score (MUS), bone score (BONE), and probability of pregnancy at 14 months (HP) were estimated using records of 121,086 Nelore animals born between 1984 and 2008 on 12 farms from three Brazilian states. The Bayesian linear-threshold analysis via the Gibbs sampler was used to estimate the (co)variance components applying a multi-trait animal model. Posterior mean estimates of heritability for HH, PRE, MUS, BONE, and HP were 0.36, 0.26, 0.26, 0.26, and 0.50, respectively. Therefore, the genetic improvement of these traits is possible. The genetic correlations between all traits studied were of low to high magnitude. High genetic correlations were observed between visual scores (0.85 and 0.99). Therefore, the simultaneous inclusion of PRE, MUS and BONE in a selection index does not seem to be necessary for the present population. The genetic correlation of HP with HH and visual scores ranged from −0.06 to 0.25, indicating that selection for traits related to body structure and conformation has little or no effect on HP.

1. Introduction

Intensive selection for growth traits has been used in different beef cattle breeding programs. As a consequence of the growing market requirements for high-quality meat, traits related to body conformation of the animals have received increasing attention on the part of breeders. Body conformation scores are used as selection criteria to infer carcass quality (Shiotsuki et al., 2009). The most widely used body conformation scores are finishing precocity, conformation, and muscling. These scores are easily obtained by trained examiners. In addition, they show moderate heritability and should therefore respond satisfactorily to selection (Van Melis et al., 2003).

In Brazil, beef cattle farming systems are based mainly on extensive pastures. As a consequence, the animals need to possess an adequate bone structure with sufficiently strong legs that guarantee support of their own weight. In this respect, evaluation of the bone structure of beef cattle may have benefits for the production system since it permits to obtain by selection animals that move around easily and can get their food efficiently.

Reproductive traits are also important for the production system, especially for Zebu animals reared in a tropical area (Eler et al., 2002). One reproductive trait commonly used as a selection criterion is the probability

* Corresponding author. Tel.: +55 6634104000 × 4110.
E-mail address: 10mario@gmail.com (M.L. Santana Jr.).

1871-1413/$ - see front matter
http://dx.doi.org/10.1016/j.livsci.2013.02.018

of pregnancy at 14 months. This trait presents high heritability, is favorably related to growth traits, and is easily measured (Silva et al., 2003; Eler et al., 2004). Formigoni et al. (2005) evaluating the economic value of the probability of pregnancy at 14 months, found that selection for this trait will contribute to reduce production costs.

The current scenario of beef production requires efficient improvement of both reproductive traits and body structure- and carcass-related traits. Studies investigating the genetic association between body structure and reproductive traits in Nelore cattle are scarce. Therefore, the objective of the present investigation was to estimate genetic associations between hip height (HH), finishing precocity score (PRE), muscling score (MUS), bone score (BONE), and probability of pregnancy at 14 months (HP) in Nelore cattle.

2. Material and methods

2.1. Data and cattle management

Data from the Genetic Breeding Program of Agro-Pecuária CFM Ltda. that have been stored and analyzed since 1994 by the Animal Breeding and Biotechnology Group, College of Animal Science and Food Engineering, Pirassununga, State of São Paulo, were used in this study.

The complete pedigree included 167,854 animals (up to eight generations) born between 1984 and 2008 on 12 farms located in the states of Mato Grosso do Sul, São Paulo, and Bahia. The farms included in this study belong to the same company, which uses standard basic procedures of data collection and storage. The animals were kept on high quality pasture (40% *Brachiaria brizantha*, 50% *Panicum maximum*, and 10% others) and received only salt and mineral supplementation. Calves born between the end of August and December remained with their dams on high-quality pasture up to 7 months of age. The breeding season ranged from November to January for cows and from October to January for heifers. The females were placed randomly in lots with a group of bulls or in some cases in lots with a single bull. The cow-to-bull ratio was about 35:1. About 60 days after the end of the breeding season, heifers (approximately 14 months of age) were evaluated by rectal palpation or ultrasound for the diagnosis of pregnancy. The heifer pregnancy/probability of pregnancy at 14 months (HP) was analyzed as a categorical trait, with a value of 1 (success) assigned to heifers that were diagnosed pregnant and a value of 0 (failure) assigned to those that were not pregnant at that time.

The HH was measured using a metric tape and corresponds to the distance (in cm) from the ground to hip. The PRE is a measure of the ability of the animal to store fat reserves and is used to identify animals that will deposit finishing fat earlier. This variable was obtained by attributing visual scores ranging from 1 to 6, with a score of 6 indicating animals with greater fat reserves. The MUS takes into account the muscle mass of the animal. This variable was also measured by attributing scores from 1 to 6, with animals with more muscle mass receiving a score of 6. The BONE was attributed to each animal using the following visual scores: 1 = light, 2 = intermediate, and 3 = heavy. The variable was evaluated based on the bone structure of the legs and hocks. All scores were attributed to observations made within the contemporary groups by three trained examiners. All observations of HH, PRE, MUS and BONE were made at yearling age (around 18 months of age). A general description of the data set used in this study is shown in Table 1. For all traits studied, records of animals in contemporary groups with fewer than 20 animals were excluded. In addition, data exceeding 3.5 standard deviations above or below the overall mean for HH were eliminated. As proposed by Harville and Mee (1984), records for the categorical traits HP and BONE of contemporary groups in which all scores were the same, i.e., groups without variability, were also eliminated.

Table 1
Description of the data set for hip height (HH), finishing precocity score (PRE), muscling score (MUS), bone score (BONE), and heifer pregnancy (HP) in Nelore cattle.

Item	Trait				
	HH (cm)	PRE (1–6)	MUS (1–6)	BONE (1–3)	HP (1 or 0)
Number of animals in the pedigree	137,769	161,842	165,191	78,337	55,430
Number of sires with progeny record	852	1032	1034	537	468
Number of dams with progeny record	41,393	50,367	52,060	21,244	18,367
Sires with more than 50 progeny	242	299	303	107	67
Animals with records	96,876	114,013	117,846	40,844	28,887
Mean of the trait	135.29	3.66	3.57	–	–
Standard deviation	6.91	0.93	0.94	–	–
Number of contemporary group	476	615	642	125	83
% Success	–	–	–	–	16.1
% Category 1	–	0.8	1.4	48.1	–
% Category 2	–	9.3	10.1	48.7	–
% Category 3	–	34.9	37.6	3.2	–
% Category 4	–	33.8	32.4	–	–
% Category 5	–	19.5	17.1	–	–
% Category 6	–	1.7	1.4	–	–

BONE: 1 = light, 2 = intermediate, 3 = heavy; PRE: a score of 6 indicating animals with greater fat reserves; MUS: a score of 6 indicating animals with more muscle mass.

2.2. Models and genetic analysis

The statistical models for all traits included the fixed effect of contemporary group, formed by farm, year of birth, sex (except HP), and management group. The age at measurement (linear covariate) and age of dam at calving (linear and quadratic covariate) were also included. The direct additive genetic and residual effects were considered to be random. The (co)variance components were obtained by multi-trait linear-threshold animal model using a Bayesian approach. The general model can be written in matrix form as

$$y = Xb + Za + e$$

where **y** is the vector of observations and liabilities for categorical traits; **b** is the vector of systematic effects [contemporary group, linear effect of age at measurement, linear and quadratic effects of age of dam at calving;]; **a** is the vector of random additive genetic effects; **e** is the random residual effects, and **X** and **Z** are incidence matrices corresponding to the observations for systematic effects and random additive genetic effects, respectively. Faria et al. (2008) showed no differences in genetic parameters for finishing precocity and muscling using threshold or linear models for a similar scale of variables in Nelore cattle. Therefore, the following assumptions were made:

$$y|b,a,R \sim NMV(Xb+Za,R), \mathrm{Var}\begin{bmatrix} a \\ e \end{bmatrix} = \begin{bmatrix} \Lambda_A \otimes A & 0 \\ 0 & R \otimes I \end{bmatrix}$$

where Λ_A and **R** are the additive genetic and residual (co)variance matrices for the traits, respectively; **A** is the numerator matrix of the coefficients of relationship between animals; **I** is an identity matrix, and $\otimes$ is the Kronecker product. Regarding the structure of **R**, the residual variance was set to 1 for the binary trait (HP) because this parameter is not identifiable. Prior distributions for the parameters of the model were

b $\propto$ constant,

$$a|\Lambda_A \sim NMV(0, \Lambda_A \otimes A),$$

$$\Lambda_A|\nu_a, \sigma_a^2 \sim WI(\nu_a, \nu_a\sigma_a^2),$$

$$R|\nu_e, \sigma_e^2 \sim WI(\nu_e, \nu_e\sigma_e^2),$$

where *NMV* and *WI* indicate multivariate normal and inverse Wishart distributions, respectively, and ν_a, σ_a^2 and ν_e, σ_e^2 correspond to the degree of confidence and *a priori* values for additive genetic and residual (co)variances, respectively.

The traits HP and BONE were analyzed using a threshold sampling model. The model for BONE (y_i) assumed an underlying distribution (l_i):

$$f(y_i|l_i) = \prod_{i=1}^{n} 1(l_i < t_1)1(y_i = 1) + 1(t_1 < l_i < t_2)1(y_i = 2) + 1(t_2 < l_i)1(y_i = 3)],$$

where t_1 and $t_2$are thresholds that define the three categories of response and 1(.) is an indicator function that takes value 1 if the condition specified is true, otherwise the value is 0.

Analysis was performed with the THRGIBBS1F90 program (Misztal et al., 2002). Analysis consisted of a single chain of 550,000 cycles, with a conservative burn-in period of 50,000 cycles and a thinning interval of 50 cycles. Thus, 10,000 samples were effectively used to estimate the parameters. The Bayesian Output Analysis (BOA) package (Smith, 2005) was used to calculate the posterior mean, and 95% highest posterior density.

3. Results and discussion

3.1. Heritability estimates

The estimates of variance components and coefficients of heritability shown in Table 2 indicate that all traits studied should respond to selection. The heritability for HH obtained in the present study (0.36) was similar to that reported by Pedrosa et al. (2010) (0.35) who evaluated animals of the same population. Silva et al. (2003) and Shiotsuki et al. (2009) obtained a heritability of 0.30 for HH in Nelore cattle. In contrast, Pereira et al. (2010) found a heritability of 0.62 also for Nelore animals, but this value was based on a much smaller number of observations for this trait. Height monitoring of cattle is important because larger animals are associated with higher maintenance costs.

The heritability estimates for PRE and MUS were of moderate magnitude (0.26). Similarly, Cardoso et al. (2004) reported heritability coefficients of 0.25 and 0.26, respectively, for PRE and MUS in Angus cattle. Regatieri et al. (2011) found estimates of 0.27 and 0.26 for PRE and MUS in Nelore cattle. Shiotsuki et al. (2009) observed lower heritabilities (0.21 and 0.23) for these traits also in Nelore animals. In contrast, higher heritabilities for PRE and MUS (0.33 and 0.32) than those obtained in the present study were reported by Boligon and Albuquerque (2010) for Nelore animals. According to Cardoso et al. (2004), differences in the magnitude of heritability coefficients of visual scores are due to differences in the evaluation systems and models used. In this respect, the number of records for visual scores used in this investigation was much higher than that employed in the studies cited above.

The heritability for HP (0.50) was similar to those reported in the literature for Nelore cattle. Eler et al. (2002) found a heritability of 0.57 for HP and suggested that this trait can be used as a selection criterion. Shiotsuki et al. (2009) obtained an estimate of 0.49 for HP at 16

Table 2
Posterior means (95% highest posterior density) of variance components and heritability obtained for hip height (HH), finishing precocity score (PRE), muscling score (MUS), bone score (BONE), and heifer pregnancy (HP) in Nelore cattle by multi-trait analysis.

Trait	Additive genetic variance	Residual variance	Heritability
HH	5.57 (5.29–5.86)	9.62 (9.39–9.84)	0.36 (0.35–0.38)
PRE	0.16 (0.15–0.17)	0.44 (0.43–0.44)	0.26 (0.25–0.28)
MUS	0.16 (0.15–0.17)	0.45 (0.44–0.45)	0.26 (0.25–0.28)
BONE	0.04 (0.04–0.05)	0.13 (0.12–0.13)	0.26 (0.23–0.29)
HP	1.02 (0.82–1.26)	1.00	0.50 (0.45–0.56)

months. Van Melis et al. (2010) reported a heritability of 0.53 for HP and suggested that the expected progeny difference for this trait can be used to select sires that produce more precocious and fertile daughters. The heritability estimates of HP obtained for Nelore animals are higher than those reported for *Bos taurus* animals, which range from 0.13 to 0.27 (Evans and Golden, 1999; Doyle et al., 2000). According to Eler et al. (2002), HP shows greater variability in *Bos indicus* animals because of recent selection for this trait. Thus, the genetic variability of *B. indicus* seems to be more preserved than *B. taurus*.

The heritability for BONE was 0.26. A lower estimate (0.22) has been reported by Miglior et al. (1994) for Limousin bulls. In addition to being an important factor for carcass composition, the bone structure of beef cattle is especially relevant for pasture-based production systems that require good locomotion ability of the animal. Many studies on bone structure have been conducted on dairy cattle. Jamrozik et al. (1991) reported a heritability of 0.22 for bone quality of Canadian Holstein cattle. Using the same breed, Fatehi et al. (2003) obtained heritability estimates for bone quality ranging from 0.24 to 0.29 depending on the farming system. In a study on Danish Holsteins, Laursen et al. (2009) found a heritability of 0.27 for apparent bone structure, indicating that this trait will respond to selection.

3.2. Correlations

The genetic correlations between all traits studied were of low to high magnitude (Table 3). The genetic correlation of HH with PRE, MUS, HP and BONE was low, indicating that selection for HH would result in little or no response in the other traits. The genetic correlations between HH-PRE and HH-MUS (0.25 and 0.21) differed from those reported by Koury Filho et al. (2009) for yearling Nelore animals (−0.29 and −0.33). Faria et al. (2009a) found genetic correlations close to zero between HH and MUS measured at 15 and 22 months of age in Nelore animals (0.08 and −0.08). It should be noted that the number of records of visual scores and HH used in this study was higher than that evaluated by Koury Filho et al. (2009) and Faria et al. (2009a). As discussed for the heritability estimates of visual scores, the use of different models and a subjective scoring system may explain the differences between the genetic correlations found here and the literature.

The genetic correlation between HH and HP was negative, but close to zero (−0.06), indicating that selection for HH has little or no effect on HP. Silva et al. (2003) reported a genetic correlation of 0.10 in Nelore animals. In a study involving three Nelore lines (two selected for higher yearling weight and one control selected for mean yearling weight), Mercadante et al. (2003) showed that selection for weight promoted a significant increase in HH without compromising the reproductive performance of cows in terms of days to calving and calving success. However, unfavorable genetic correlations between HH and reproductive traits have also been reported. Shiotsuki et al. (2009), using data from Nelore animals, reported a genetic correlation of −0.24 between HH and HP at 16 months of age, indicating that long-term selection for HH may compromise HP. In a study on Brahman cattle, Vargas et al. (1998) obtained a genetic correlation of 0.25 between HH and age at puberty of heifers. Vargas et al. (1999) concluded that larger framed Brahman females reach puberty later and also calve later than females with small or medium frame size. Although there is no strong evidence that an increase of HH compromises female reproductive performance of the Nelore population, particularly HP, Vargas et al. (1999) emphasized that an increased height of the animals may increase nutritional requirements and, consequently, the costs of animal maintenance.

The correlation between HH and BONE (0.38) indicates that selection for HH may result in a long-term increase of BONE. Studies investigating the genetic correlation between HH and BONE in beef cattle are scarce. For Limousin bulls, Miglior et al. (1994) reported a genetic correlation of zero between BONE and height at hooks. Nephawe et al. (2004) obtained a genetic correlation of 0.48 between percentage of bone in carcass and mature HH for beef cattle (GPE-USMARC, Clay Center), indicating that these traits are moderately correlated. In a study on Brown Swiss cows, Samoré et al. (2010) found a genetic correlation of 0.33 between height and hock quality.

The genetic correlation between PRE and MUS was of high magnitude (0.99), indicating that the two traits can be considered the same. The similarity between these traits is also demonstrated by the correlations with the other traits studied. A high genetic correlation between PRE and MUS has also been reported by Regatieri et al. (2011) and by Koury Filho et al. (2010) for Nelore cattle (0.85 and 0.95, respectively). According to the latter authors, selection for one of the visual scores studied will imply a positive correlated response in the other. Thus, the simultaneous inclusion of PRE and MUS in a selection index does not seem to be necessary for the present population.

The genetic correlations between PRE and HP and MUS and HP (0.25 and 0.24, respectively) suggest little improvement in reproductive precocity when animals are selected for higher visual scores of PRE and MUS. Similarly, Shiotsuki

Table 3
Posterior means (95% highest posterior density) of genetic (above the diagonal) and residual (below the diagonal) correlations between hip height (HH), finishing precocity score (PRE), muscling score (MUS), bone score (BONE), and heifer pregnancy (HP) in Nelore cattle by multi-trait analysis.

Trait	HH	PRE	MUS	BONE	HP
HH	–	0.25 (0.21–0.29)	0.21 (0.17–0.25)	0.38 (0.32–0.44)	−0.06 (−0.14–0.01)
PRE	0.18 (0.16–0.19)	–	0.99 (0.99–0.99)	0.85 (0.82–0.89)	0.25 (0.18–0.32)
MUS	0.18 (0.17–0.19)	0.76 (0.76–0.77)	–	0.85 (0.82–0.89)	0.24 (0.21–0.32)
BONE	0.06 (0.05–0.07)	0.30 (0.29–0.32)	0.26 (0.25–0.27)	–	0.03 (−0.06–0.13)
HP	0.01 (0.00–0.02)	0.09 (0.06–0.12)	0.07 (0.05–0.09)	0.03 (0.02–0.04)	–

et al. (2009) reported genetic correlations of 0.18 and 0.16 between PRE-HP at 16 months and MUS-HP at 16 months, respectively, for Nelore animals. On the basis of favorable genetic correlations between PRE and age at first calving (−0.26) and between MUS and age at first calving (−0.18), Boligon and Albuquerque (2010) concluded that selection for visual scores should improve the reproductive performance of Nelore cows. Santana et al. (2012) reported a genetic correlation of 0.23 between PRE and HP of Nelore cattle. Using data from Brahman cattle, Vargas et al. (1999) found no significant effect of body condition score on age at puberty. However, females with a higher body condition score at 18 months of age calved earlier than those with a lower score. In contrast, Faria et al. (2009b) observed a low genetic correlation (−0.24) between MUS and age at first calving in Nelore cattle.

The visual scores of PRE and MUS were strongly correlated with BONE (0.85), indicating that greater muscle mass and earlier finishing are associated with a heavier bone structure. Therefore, selection for higher PRE and MUS in this population should lead to animals with higher BONE. This genetic association needs to be taken into account during selection in this population because animals with higher BONE values are undesired. Most studies in the literature reported a low genetic association between skeletal and carcass measures. Miglior et al. (1994) obtained a genetic correlation of 0.38 between muscle development and BONE and of zero between fat thickness and BONE in Limousin bulls. A genetic correlation coefficient close to zero between frame size and longissimus muscle area at yearling led Johnson et al. (1993) to conclude that muscling and skeletal size are weakly correlated in Brangus cattle. In contrast, Nephawe et al. (2004), studying beef cattle (GPE-USMARC, Clay Center), reported a genetic correlation of −0.38 between bone percentage in carcass and body condition score. The divergence in the correlation between carcass components might be attributed to differences between breeds, which were highlighted by Berg and Butterfield (1968). In addition, these authors showed that the proportion of bone, muscle and fat in the carcass is influenced by age, weight, and nutrition of the animals.

The genetic correlation between BONE and HP was close to zero (0.03), indicating that in the present population selection for any of these traits would not lead to changes in the other trait. Faria et al. (2009a) obtained a favorable, although weak (−0.17), genetic correlation between physical structure at 15 months of age (hoof integrity and size, strength and width of bones, ligaments) and age at first calving in Nelore animals. Studies reporting genetic correlations between BONE and reproductive performance of beef cattle are scarce. In a study on Holstein–Friesian cows, Onyiro et al. (2008) obtained genetic correlations of 0.07 between bone quality and calving interval and of 0.36 between bone quality and 56-day non-return rate, indicating that selection for bone quality would contribute little to improve reproductive performance. Gutiérrez et al. (2002) studied Asturiana de los Valles cattle, a breed that is reared mainly in mountain areas and under semi-extensive conditions, and observed that cows with better skeletal development (body size and depth) presented a shorter calving interval and earlier calving date.

The residual correlations between the traits studied were usually positive and of low magnitude, except for the residual correlation between PRE and MUS which was of high magnitude (0.76). Therefore, in the present population, correlated environmental effects are small for most of the traits studied. According to Shiotsuki et al. (2009), improvement in the animal rearing environment of the population studied would probably act on all traits in the same direction. Similar residual correlations have been reported by Miglior et al. (1994) for body structure and conformation of Limousin bulls (0.00–0.43). Koury Filho et al. (2009) obtained residual correlations of 0.22–0.56 between PRE, MUS and HH. As observed in the present study, Koury Filho et al. (2010) found a high residual correlation between PRE and MUS in Nelore cattle (0.82). The authors suggested the existence of correlations between non-additive genetic and environmental effects that affect the expression of these traits.

4. Conclusion

All traits studied present important additive genetic variation and can be used as selection criteria in Nelore cattle. The simultaneous inclusion of all visual scores studied here in a selection index does not seem to be necessary for the present population because the genetic correlations between them were close to unity. The genetic correlations of HP with HH and visual scores were of low magnitude, indicating that selection for the traits related to body structure and conformation has little or no effect on HP.

Conflict of interest statement

The authors warrant that there are no any conflicts of interests among authors and between authors and other people, institutions or organizations.

References

Berg, R.T., Butterfield, R.M., 1968. Growth patterns of bovine muscle, fat and bone. J. Anim. Sci. 27, 611–619.

Boligon, A.A., Albuquerque, L.G., 2010. Genetic correlations between visual scores and reproductive traits in Nelore cattle using Bayesian inference. Pesqui. Agropecu. Bras. 45, 1412–1418.

Cardoso, F.F., Cardellino, R.A., Campos, L.T., 2004. (Co)variance components and genetic parameters of post-weaning traits in Angus cattle. R. Bras. Zootec. 33, 313–319.

Doyle, S.P., Golden, B.L., Green, R.D., Brinks, J.S., 2000. Additive genetic parameter estimates for heifer pregnancy and subsequent reproduction in Angus females. J. Anim. Sci. 78, 2091–2098.

Eler, J.P., Silva II, J.A., Ferraz, V., Dias, J.B., Oliveira, F., Evans, H.N., Golden, B.L., J.L., 2002. Genetic evaluation of the probability of pregnancy at 14 months for Nellore heifers. J. Anim. Sci. 80, 951–954.

Eler, J.P., Silva II, J.A., Evans, V., Ferraz, J.L., Dias, J.B.S., Golden, B.L., F., 2004. Additive genetic relationship between heifer pregnancy and scrotal circumference in Nellore cattle. J. Anim. Sci. 82, 2519–2527.

Evans, J.L., Golden, B.L., Bourdon, R.M., Long, K.L., 1999. Additive genetic relationships between heifer pregnancy and scrotal circumference in Hereford cattle. J. Anim. Sci. 77, 2621–2628.

Faria, C.U., Magnabosco, C.U., Albuquerque, L.G., Reyes, A. de los, Bezerra, L.A.F., Lobo, R.B., 2008. Genetic analysis for visual scores of bovines with the linear and threshold Bayesian models 43, 835–841.

Faria, C.U., Magnabosco, C.U., Albuquerque, L.G., Bezerra, L.A.F., Lobo, R.B., 2009a. Genetic correlation estimates between visual scores and carcass traits measured by ultrasound in Nelore cattle using linear-threshold Bayesian models. R. Bras. Zootec. 38, 2144–2151.

Faria, C.U., Magnabosco, C.U., Albuquerque, L.G., Reyes, A., de los, Bezerra, L.A.F., Lobo, R.B., 2009b. Bayesian analysis in the estimation of genetic correlations between visual scores and reproductive traits in Nelore cattle using linear-threshold models. Arq. Bras. Med. Vet. Zootec. 61, 949–958.

Fatehi, J., Stella, A., Shannon, J.J., Boettcher, P.J., 2003. Genetic parameters for feet and leg traits evaluated in different environments. J. Dairy Sci. 86, 661–666.

Formigoni, I.B., Ferraz, J.B.S., Silva, J.A., II., V., Eler, J.P., Brumatti, R.C., 2005. Economic value for stayability and heifer pregnancy at 14 months in beef cattle herds. Arq. Bras. Med. Vet. Zootec. 57, 220–226 .

Gutiérrez, J.P., Alvarez, I., Fernández, I., Royo, L.J., Díez, J., Goyache, F., 2002. Genetic relationships between calving date, calving interval, age at first calving and type traits in beef cattle. Livest. Prod. Sci. 78, 215–222.

Harville, D.A., Mee, R.W., 1984. A mixed-model procedure for analyzing ordered categorical data. Biometrics 40, 393–408.

Jamrozik, J., Schaeffer, L.R., Burnside, E.B., Sullivan, B.P., 1991. Estimates of heritabilities of Canadian Holstein conformation traits by threshold model. Can. J. Anim. Sci. 71, 629–632.

Johnson, M.Z., Schalles, R.R., Dikeman, M.E., Golden, B.L., 1993. Genetic parameter estimates of ultrasound-measured longissimus muscle area and 12th rib fat thickness in Brangus cattle. J. Anim. Sci. 71, 2623–2630.

Koury Filho, W., Albuquerque, L.G., Alencar, M.M., Forni, S., Silva, J.A.I.I.V., Lôbo, R.B., 2009. Estimates of heritabilities and correlations for visual scores, weight and height at 550 days of age in Nelore cattle herds. R. Bras. Zootec. 38, 2362–2367.

Koury Filho, W., Albuquerque, L.G., Forni, S., Silva, J.A.I.I.V., Yokoo, M.J., Alencar, M.M., 2010. Genetic parameters estimates for visual scores and their association with body weight in beef cattle. R. Bras. Zootec. 39, 1015–1022.

Laursen, M.V., Boelling, D., Mark, T., 2009. Genetic parameters for claw and leg health, foot and leg conformation, and locomotion in Danish Holsteins. J. Dairy Sci. 92, 1770–1777.

Mercadante, M.E.Z., Packer, I.U., Razook, A.G., Cyrillo, J.N.S.G., Figueiredo, L.A., 2003. Direct and correlated responses to selection for yearling weight on reproductive performance of Nelore cows. J. Anim. Sci. 81, 376–384.

Miglior, F., Kemp, R.A., Burnside, E.B., 1994. Genetic parameter estimates of conformation and performance traits in station-tested Limousin bulls. Can. J. Anim. Sci. 74, 379–381.

Misztal, I., Tsuruta, S., Strable, T., Auvray, B., Druet, T., Lee,D.,2002. BLUPF90 and related programs (BGF90). CD-ROM communication 28:07. In: Proceedings of the 7th World Congress on Genetics Applied to Livestock Production, Montpellier, France.

Nephawe, K.A., Cundiff, L.V., Dikeman, M.E., Crouse, J.D., Van Vleck, L.D., 2004. Genetic relationships between sex-specific traits in beef cattle: mature weight, weight adjusted for body condition score, height and body condition score of cows, and carcass traits of their steer relatives. J. Anim. Sci. 82, 647–653.

Onyiro, O.M., Andrews, L.J., Brotherstone, S., 2008. Genetic parameters for digital dermatitis and correlations with locomotion, production, fertility traits, and longevity in Holstein–Friesian dairy cows. J. Dairy Sci. 91, 4037–4046.

Pedrosa, V.B., Eler, J.P., Ferraz, J.B.S., Silva, Silva, J.A.I.I.V., Ribeiro, S., Silva, M.R., Pinto, L.F.B., 2010. Genetic parameters for mature weight and growth traits in Nelore cattle. Rev. Bras. Saúde Prod. Anim. 11, 104–113.

Pereira, M.C., Yokoo, M.J., Bignardi, A.B., Sezana, J.C., Albuquerque, L.G., 2010. Hip height and its relationships with reproductive and growth traits in Nelore cattle. Pesqui. Agropecu. Bras. 45, 613–620.

Regatieri, I.C., Boligon, A.A., Albuquerque, L.G., 2011. Genetic analysis of visual scores and their relationships to mature female weight in Nellore breed. R. Bras. Zootec. 40, 100–105.

Samoré, A.B., Rizzi, R., Rossoni, A., Bagnato, A., 2010. Genetic parameters for functional longevity, type traits, somatic cell scores, milk flow and production in the Italian Brown Swiss. Ital. J. Anim. Sci. 9, 145–152.

Santana, Jr., Eler, J.P., Ferraz, J.B.S., Mattos, E.C., 2012. Genetic relationship between growth and reproductive traits in Nellore cattle. Animal 6, 565–570.

Shiotsuki, L., Silva J.A.II V., Tonhati, H., Albuquerque, L.G., 2009. Genetic associations of sexual precocity with growth traits and visual scores of conformation, finishing, and muscling in Nelore cattle. J. Anim. Sci. 87, 1591–1597.

Silva J.A.II V., Van Melis, M.H., Eler, J.P., Ferraz, J.B.S., 2003. Estimation of genetic parameters for probability of pregnancy at 14 months and hip height in Nelore beef cattle. R. Bras. Zootec 32, 1141–1146.

Smith, B.J., 2005. Bayesian Output Analysis Program (BOA) for MCMC 〈http://www.public-health.uiowa.edu/boa/〉 (acessed May 10).

Vargas, C.A., Elzo, M.A., Chase Jr, C.C., Chenoweth, P.J., Olson, T.A., 1998. Estimation of genetic parameters for scrotal circumference, age at puberty in heifers, and hip height in Brahman cattle. J. Anim. Sci. 76, 2536–2541.

Vargas, C.A., Olson, T.A., Chase Jr, C.C., Hammond, A.C., Elzo, M.A., 1999. Influence of frame size and body condition score on performance of Brahman cattle. J. Anim. Sci. 77, 3140–3149.

Van Melis, M.H., Eler, J.P., Silva J.A.II V., Ferraz, J.B.S., 2003. Estimate of genetic parameters in beef cattle using restricted maximum likelihood and method. R. R. Bras. Zootec. 32, 1624–1632.