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Association of visual scores with reproductive traits in Nelore cattle using Bayesian Inference

Associação de escores visuais com características reprodutivas em bovinos Nelore utilizando Inferência Bayesiana

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Abstract
The use of morphological traits assessed using visual scores as indirect selection criteria in cattle has the advantage of evaluating young animals regarding potential productive and reproductive performance. This enables breeders to make earlier decisions compared to later measurements, such as scrotal circumference at 450 days (SC450) and stayability (STAY). The aim of this study was to estimate the genetic parameters for visual score traits and their associations with reproductive traits: scrotal circumference at 365 days of age (SC365), SC450, STAY, probability of precocious calving (PPC30) and age at first calving (AFC) in Nellore cattle. Visual score data from 4,175 Nellore cattle, with an average age of 22 months, and reproductive data from 3,075 cattle belonging to the HoRa Genetics Provada herd were used. The morphological traits were evaluated by the MERCOS methodology. The heritability estimates obtained ranged from 0.15 to 0.28 for visual scores and 0.10 to 0.54 for reproductive traits. Genetic correlations between visual scores and reproductive traits were generally low, except between: muscularity and PPC30; structure and STAY; racial and SC450; conformation and SC365, SC450, STAY, and AFC; navel and STAY and AFC; and sacrum and SC365, STAY, and AFC, which were moderate to high. The identification of animals with flat sacral bone (not protruding or sloping) can also be an efficient characteristic in the identification for early pregnancy, and together with the musculature score, they can be related to animals with lower age at the first calving.
Keywords: beef cattle; genetic association; morphological traits; sexual precocity; stayability.

Resumo
A utilização de características morfológicas de bovinos, pelo uso de escores visuais como critério de seleção indireta tem como vantagem a avaliação em animais jovens quanto ao potencial desempenho produtivo e reprodutivo, antecipando a tomada de decisão em comparação a medidas tomadas de forma tardia, como perímetro escrotal aos 450 dias (PE450) e stayability (STAY). Objetivou-se estimar os parâmetros genéticos para características de escores visuais e a associação dessas com características reprodutivas, perímetro escrotal aos 365 (PE365) dias de idade, PE450, STAY, probabilidade de parto precoce (3P) e idade ao primeiro parto (IPP) em bovinos Nelore. Foram utilizadas informações de escores visuais e de reprodução de 4.175 e 3.075 bovinos, respectivamente, com idade média de 22 meses, pertencentes a fazenda HoRa Genética Provada. As características morfológicas foram avaliadas pela metodologia MERCOS. As estimativas de herdabilidade obtidas apresentam grande amplitude, variando de 0,15 a 0,28 para escores visuais e 0,10 a 0,54 para características reprodutivas. As correlações genéticas entre característica de escores visuais e reprodução foram, de maneira geral baixas (0.03-0.66), com exceção entre a musculosidade e 3P, estrutura e STAY, racial e PE450, conformação com PE365, PE450, STAY e IPP, ônfalo com STAY e IPP, e sacro com PE365, STAY e IPP, que foram moderadas a altas. A identificação de animais com melhor osso sacro (mesmo nível das ancas), ou seja, não saliente ou inclinado pode ser uma característica eficiente na identificação para prenhez precoce, e juntamente ao escore de musculatura poderão ser relacionados a animais com menor idade ao primeiro parto.
Palavras-chave: associação genética; características morfológicas; precocidade sexual; stayability; zebuínos.

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1.Introduction

Livestock breeding programs often classify animals using selection indices composed of reproductive and growth traits, which can be combined with morphological type scores[1]. In that regard, morphological traits can complement economically important traits, since they allow the early identification and culling of animals that present some type of defect that can compromise the production system.

Selection based on morphological traits assessed using visual scores can contribute to genetic improvement of beef cattle, as the heritability estimates vary from low to high magnitude[2],[3],[4],[5],[6],[7],[8]. Moreover, the use of visual scores allows a large number of animals to be evaluated, being less costly and time-consuming compared to objective measurements, allowing the selection of animals that are better adapted to the environment in which they are raised. For example, breeders can avoid animals with larger body size and poorly developed musculature and favor those with medium size and well-developed musculature[9],[10],[4],[5],[11].

Even more important than visual scores and growth traits for the production system are the traits that indicate fertility and sexual precocity, such as age at first calving (AFC), probability of precocious calving (PPC30), stayability (STAY) and scrotal circumference (SC365 and SC450)[12],[13],[14],[11],[15]. High indices for reproductive traits enable greater selection intensity and, consequently, more rapid genetic progress and greater profitability[16]. Improvement of sexual precocity makes it possible to reduce the animals' pre-productive time and increase the number of calves produced in the cow's lifetime. On the other hand, improvement of STAY, an indicator of reproductive longevity, make it possible to reduce feeding costs with unproductive females[17],[18],[14],[16].

Evaluation through visual scores of young animals allows indirect assessment of reproductive measures obtained later in life, such as SC450 and STAY[19], leading to reduced cost of evaluation and an increased profitability of the production system [20]. In fact, Boligon and Albuquerque[21] and Paterno et al.[5],[6] report that selection for visual scores, besides allowing the selection of animals that are better balanced in terms of their morphology, can indirectly lead to a reduction in AFC of heifers. Knowledge of the genetic relationship between visual scores and fertility and sexual precocity indicator traits may enable prediction of the potential impacts of inclusion of visual scores in the selection indices on reproductive efficiency of Nellore cattle.

So far, reports of an index that includes both traits have not been related in previous studies. Visual scores are used more frequently in properties that do not select through objective measures or used as additional selection tools or for animals' disposal. However, for the simultaneous use of reproductive traits and visual scores as a selection criterion, whether through indices or not, it is important to know the genetic correlations and possible correlated responses. Given the above, the aim of this study was to estimate genetic parameters for visual scores and their associations with reproductive traits in Nellore cattle, using Bayesian inference.

2.Material e methods

2.1 General information about the data set

The research project was approved by the Ethics and Animal Experimentation Committee/CEUA of the Universidade Federal de Goiás, according to protocol Number 089/20 issued by this institution.

Visual score data from 4,175 Nellore cattle, evaluated from 2017 to 2020 and data from 3,075 cattle with reproductive information, belonging to HoRa Genetics Provada, located in the municipality of Brasilândia, Mato Grosso do Sul (MS) were used. This farm is participating of the Nelore Brasil Genetic Breeding Program, coordinated by the National Association of Breeders and Researchers (ANCP), which provided the genealogy information. Visual scores were the morphological traits of muscularity (M), physical structure (PS), racial aspects (R), conformation (C), and navel (omphalos; N), and sacrum (SAC), based in a score from 1 to 3, evaluated according to MERCOS methodology [22] based in a score from 1 to 5.

The M score is evaluated the distribution of muscle tissue in the animal body, its muscle development, volume, and length. If these muscles were prominent, the score assigned was higher (score 5). The PS score is evaluated the support of the animal, that is, the integrity and size of the hoof, and bone thickness. Score 1 was thin physic structure and five thick PS. The racial aspects are evaluated by breed profiling, considering defects such as chamfer or "crooked face" deviation and jaw articulation. If the animal fits the breed standard, the score assigned was higher. The conformation score is evaluated considering body length, thoracic amplitude, rib arching, depth, rump width and length, and the distance between the top of the spine and the bottom of the body at the start of the last rib – at the deepest point of the body. For this score, the dorsal and ventral lines should be parallel or open slightly towards the rump. A very deep conformation is given a score of 5, while a shallow one gets a score of 1. The N score trait is evaluated by the navel length. A score of one is given to animals with a short navel, and five to a very large navel. The sacrum is evaluated by the rump length, the distance between the ilium and ischium bone, and the slope of the rump. The sacral bone should not be protruding, but flat or at the same level as the hips. Reproductive traits included adjusted scrotal circumference at 365 (SC365) and 450

(SC450) days of age, age at first calving (AFC), probability of precocious calving (PPC30) and stayability (STAY). Scrotal circumference was measured every 90 days using a tape measure specific to this purpose, from 9 months to 18 months of age. For PPC30, females that had confirmed pregnancy and calved for the first time by 30 months of age received category 2 (success) and females that did not present calving until that age received category 1 (failure). For STAY, females that produced at least three calves by 76 months received category 2 (success) and animals that did not reach three births by this age received category 1 (failure).

2.2 Statistical analysis and estimation of (co)variance components and genetic parameters

Editing, consistency and descriptive analysis of the data were performed using software R [28]. The contemporary groups (CG) and the covariates included in the models were defined after analysis using mixed models to identify the non-genetic factors that influenced ($P<0.05$) the evaluated traits. For the reproductive traits, the CG was composed of animals of the same sex, from the same herd, born in the same year and season, and same management group at the time of measurement of each trait. The animals' birth season was grouped into two classes, the dry season, from April to September, and the rainy season, from October to March. To ensure greater variability within the CG for the visual score traits, the CG was composed only of animals from the same herd and year of birth, with the other significant factors (sex, birth season and management group) included separately in the model as fixed effects. For categorical traits, it is necessary that the CG have observations in all classes of the evaluated variable. This action was also necessary to guarantee the convergence of the Bayesian analyses.

Phenotypic data more than 3.5 standard deviations above or below the mean of their CG, CG with fewer than four animals, and sires with fewer than five progeny were removed. In addition, for muscularity and structure traits, animals that presented a score equal to one were excluded, due to the low frequency of this class for these traits. The visual score distributions and the ideal score are presented in table 1. The numbers of observations and descriptive statistics of the evaluated traits are presented in Table 2. The sires and cows columns' represent the fathers and dams of the evaluated animals. Initial values of the (co)variance components were obtained from preliminary analyses with linear models and a restricted maximum likelihood approach, using programs REMLF90 and AIREMLF90[23].

The covariance components, heritability estimates, and genetic, residual and phenotypic correlations, were estimated using a linear animal model for traits SC365, SC450 and AFC, threshold animal model for visual scores, PPC30 and STAY traits, and linear-threshold for the combination of linear and categorical traits (two-trait analyses). These analyses were performed under a Bayesian approach, with the program THRGIBBS1F90[24] .

Table 1. Distribution (%) for the visual scores traits in Nellore cattle, from the farm HoRa Genética Provada, Brasilândia (MS).

Traits	Visual Scores				
	1	2	3*1	4	5*2
Muscularity	0.00	12.81	40.12	43.55	3.53
Physical structure	0.00	8.98	55.13	35.00	0.89
Racial aspects	3.26	31.57	48.77	16.02	0.38
Conformation	0.72	20.17	48.60	29.58	0.93
Navel	1.44	25.65	64.43	7.95	0.53
Sacrum	11.71	79.90	8.38	---	---

*1 Ideal score for omphalos (navel) and sacrum; *2 Ideal score for muscularity, physical structure, racial aspects and conformation.

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Table 2. Descriptive statistics of reproduction and visual scores traits in Nellore cattle from HoRa Genética Provada, Brasilândia (MS).

Traits	N°	Sires	Cows	Min.	Max.	Median	Mode	SD	CV (%)	N° CG	Average of CG
SC365 (cm)	1065	55	930	18	29	22.37	21.00	1.90	8.51	9	57
SC450 (cm)	1053	55	898	19	35	26.40	25.60	2.58	9.79	7	69
STAY	932	58	781	1	2	1.45	2.00	0.50	34.32	12	29
PPC30 (meses)	2102	74	1601	1	2	1.19	1.00	0.39	32.97	18	53
AFC (meses)	3075	103	2380	21	39	33.59	34.00	3.72	11.06	22	60
M	4170	101	3066	2	5	2.38	4.00	0.75	31.52	23	182
PS	4154	101	3055	2	5	2.28	3.00	0.63	27.70	23	182
R	4175	101	3069	1	5	2.79	3.00	0.76	27.24	23	182
C	4175	101	3069	1	5	3.10	3.00	0.74	24.02	23	182
N	4175	101	3069	1	5	2.80	3.00	0.61	21.88	23	182
SAC	4175	101	3069	1	3	1.97	2.00	0.45	22.73	23	182

Nº: number of observations; Min.: minimum values; Max.: maximum values; SD: standard deviation; CV: coefficient of variation; Nº. CG: number contemporary groups; Average of CG: average of animals per GC; SC365: adjusted scrotal circumference at 365 days of age; SC450: adjusted scrotal circumference at 450 days of age; STAY: stayability; AFC: age at first calving; PPC30: probability of precocious calving; M: muscularity; PS: physical structure; R: racial aspects; C: conformation; N: navel; SAC: sacrum.

In matrix terms the general model can be described $y = \boldsymbol{X}\beta + \boldsymbol{Z}a + e$, where: y is the vector of observations; β is the vector of fixed effects; is the vector of direct additive genetic effects; $\boldsymbol{X}$ and $\boldsymbol{Z}$ are the incidence matrices that relate β and a to y, respectively; and e is the vector of residual effects associated with each observation. The GCs were included as fixed effects for the reproduction traits. For the visual score traits, the CG were considered as fixed effects, in addition to sex, birth season and management group, and the age of the animal at the time of evaluation as covariate (linear and quadratic effects). The model that included age as linear and quadratic covariates presented the least prediction errors, therefore was considered as the most suitable. Considering that a single technician did the visual evaluations, there was no need to include this effect in the model. Maternal and permanent environment effects were not used, because analysis of variance showed that the contributions of these effects on the phenotypic variances were less than 3%.

The visual scores were analyzed adopting the following threshold model:

$$f(w_i|y_i) = \prod_{j=1}^{n_i} 1(l_{ij} < t_1)1(w_{ij} = 1) + 1(t_1 < l_{ij} < t_2)1(w_{ij} = 2)$$
$$+1(t_2 < l_{ij} < t_3)1(w_{ij} = 3) + 1(t_3 < l_{ij} < t_4)1(w_{ij} = 4)$$
$$+1(t_4 < l_{ij} < t_5)1(w_{ij} = 5)$$

where for each trait i (i = 1, 2, 3, 4 or 5), w_{ij} and l_{ij} are categorical variables and underlying scale observation j, respectively, t_1 and t_4 are the thresholds that define the categorical response for each trait, and n_i represents the total data number for each evaluated trait. A uniform prior distribution was defined for the thresholds. For the M and PS traits it was assumed that $t_1 = 0$, so that the vector of estimable thresholds was defined as $t = t_2; t_3; t_4$ and t_5 .

Uniform and inverted Wishart distributions were assumed *a priori* for the systematic effects and (co)variance components, respectively. Chains from 63,000 to 2,000,000 iterations were generated, with a burn-in of 50,000 to 1,000,000 cycles and sampling every 10 to 500 cycles. This variation was used to ensure convergence for each categorical trait or combination of two traits. *A posteriori* estimates were obtained using the POSTGBBSF90 program[23].

Convergence was verified through graphical inspection (trace and *a posteriori* density graphics) of genetic and residual variances vs. the iterations. Furthermore, convergence of the chains was evaluated by the criterion proposed by Geweke[25] and by the autocorrelation between the samples. These analyses were performed using the Boa[26] and EasyGEN[27] package from the R[28] software program, and was used to calculate the mean, mode, median, SD, and 95% high posterior density (HPD) interval for all parameters from the individual marginal posteriors. The HPD region provides the interval that includes 95% of samples and is a measure of reliability.

3. Results

Table 3 presents posterior estimates of direct heritability (h^2d) coefficients for the reproductive and visual score traits in Nelore cattle. In general, the heritability estimates for the reproductive traits were of high magnitude (SC365, 0.50±0.01; SC450, 0.53±0.01; STAY, 0.38±0.02; and PPC30, 0.54±0.02), with the exception of AFC (0.10±0.01). In contrast, the heritability estimates of visual scores were of low to moderate magnitude (0.15±0.01 to 0.28±0.01), with the highest values obtained for the physical structure score.

Table 4 shows the estimates of genetic, residual and phenotypic correlations between scores and reproductive traits. Due to the symmetry and the low magnitude of the standard deviations of the heritability estimates (Table 3) and genetic correlations (Tables 4) estimates, the means are used in this discussion as measures of the posterior distributions of the genetic parameters.

There was a favorable, moderate genetic correlation between SC365 and the conformation visual score (0.25±0.22) and an unfavorable, negative and moderate genetic correlation between SC450 and racial score (-0.25±0.17).

The other estimates obtained between scrotal circumferences and visual scores were low. Stayability showed moderate to high genetic associations with visual scores, with the highest values observed with conformation and sacral bone scores (0.36±0.25 and 0.66±0.31, respectively), and the lowest for M and R. The PPC30 also showed a high correlation with SAC (-0.55±0.23) and moderate with M (-0.22±0.22), however these estimates were negative. The correlations between PPC30 and the other visual scores (E, R, C and N) were low (-0.19 to -0.06±0.29). For AFC, low genetic correlations were observed with visual scores, ranging from -0.09±0.25 to -0.20±0.28, with the exception between N and AFC, whose value was -0.24±0.27.

The phenotypic correlation between SC365 and M was favorable and moderate. Favorable and moderate residual correlations between SC365 and M as well as SAC, and between SC450 and M, R, and SAC. Residual correlations between PP30 and M as well as PS were favorable, positive and moderate and between PPC30 and O were moderate and negative. STAY presented unfavorable and moderate residual correlations with the M, C, and SAC scores (-0.22, -0.28 and -0.35, respectively), but these estimates were negative. AFC also showed a favorable, moderate and negative phenotypic correlation with SAC (-0.21).

Table 3. Posteriori estimates of variance components for reproduction and visual scores traits in Nellore cattle

Parameter	Mean ± SD	Mode	Median	CI (95%)
σ^2a SC365	1.24±0.01	1.11	1.20	0.67-1.99
σ^2e SC365	1.71±0.01	1.76	1.73	1.15-2.17
σ^2p SC365	2.58±0.02	2.51	2.56	1.60-3.64
h^2d SC365	0.50±0.01	0.47	0.49	0.46-0.55
σ^2a SC450	3.01±0.01	2.87	2.96	1.76-4.59
σ^2e SC450	2.69±0.01	2.77	2.72	1.55-3.65
σ^2p SC450	5.70±0.01	5.64	5.67	3.32-8.24
h^2d SC45	0.53±0.01	0.51	0.52	0.53-0.55
σ^2a STAY	0.63±0.14	0.38	0.51	0.13-1.80
σ^2e STAY	1.00±0.01	1.00	1.00	0.94-1.06
σ^2p STAY	1.63±0.07	1.38	1.52	1.07-2.87
h^2d STAY	0.38±0.02	0.27	0.34	0.12-0.61
σ^2a PPC30	1.23±0.20	0.81	1.07	0.39-2.93
σ^2e PPC30	1.00±0.01	1.00	1.00	0.94-1.07
σ^2p PPC30	2.23±0.10	1.81	2.07	1.33-4.00
h^2d PPC30	0.54±0.02	0.44	0.51	0.29-0.73
σ^2a AFC	0.71±0.01	0.64	0.69	0.30-1.22
σ^2e AFC	6.70±0.01	6.68	6.70	6.16-7.22
σ^2p AFC	7.41±0.01	7.32	7.39	6.45-8.44
h^2d AFC	0.10±0.01	0.09	0.09	0.05-0.14
σ^2a M	0.06±0.01	0.06	0.06	0.03-0.09
σ^2e M	0.23±0.01	0.20	0.22	0.15-0.35
σ^2p M	0.29±0.02	0.26	0.28	0.19-0.45
h^2d M	0.21±0.01	0.23	0.22	0.19-0.20
σ^2a PS	0.05±0.01	0.05	0.05	0.03-0.07
σ^2e PS	0.14±0.01	0.13	0.13	0.10-0.18
σ^2p PS	0.19±0.02	0.18	0.19	0.13-0.26
h^2d PS	0.28±0.01	0.28	0.28	0.24-0.27
σ^2a R	0.02±0.01	0.02	0.02	0.01-0.03
σ^2e R	0.06±0.01	0.05	0.06	0.04-0.12
σ^2p R	0.08±0.02	0.08	0.08	0.06-0.16
h^2d R	0.25±0.01	0,29	0.27	0.25-0.21
σ^2a C	0.02±0.01	0.02	0.02	0.00-0.02
σ^2e C	0.06±0.01	0.06	0.06	0.05-0.08
σ^2p C	0.08±0.02	0.01	0.02	0.01-0.03
h^2d C	0.25±0.01	0.29	0.27	0.24-0.22
σ^2a N	0.004±0.01	0.004	0.004	0.00-0.05
σ^2e N	0.02±0.01	0.02	0.02	0.01-0.03
σ^2p N	0.03±0.02	0.02	0.02	0.02-0.04
h^2d N	0.15±0.01	0.16	0.16	0.12-0.14
σ^2a SAC	0.03±0.01	0.02	0.03	0.01-0.04
σ^2e SAC	0.12±0.01	0.12	0.12	0.10-0.13
σ^2p SAC	0.15±0.02	0.15	0.15	0.12-0.18
h^2d SAC	0.18±0.01	0.17	0.18	0.11-0.24

σ^2a: direct additive genetic variance; σ^2 maternal variance; σ^2pe: permanent environmental genetic variance; σ^2e: residual variance; σ^2p: phenotypic variance; h^2d: direct heritability; SC365: adjusted scrotal circumference at 365 days of age; SC450: adjusted scrotal circumference at 450 days of age; STAY: stayability; AFC: age at first calving; PPC30: probability of precocious calving; M: muscularity; PS: physical structure; R: racial aspects; C: conformation; N: navel; SAC: sacrum.

4. Discussion

The high heritability estimates obtained for SC365 and SC450 are within the range reported in the literature for Nellore cattle, whose values range from 0.29 to 0.58 and 0.33 and 0.57, respectively[12,13,15,16,29,30,15], in analyses using Bayesian Inference and Maximum Restricted Likelihood. In general, the heritability for SC is higher than the other reproductive traits used as selection criteria, a fact attributed to the lower environmental influence on expression of this trait.

The close heritability values obtained for SC365 and SC450 indicate similar genetic variability between them, demonstrating that genetic selection can be performed for either of the traits, obtaining similar genetic gains[16]. However, use of SC365 enables earlier selection of animals for sexual precocity, due to the association between factors related to early ovarian development in females and testicular development in males[29]. On the other hand, selection for SC450 is indicative of sexual fertility, being related to libido, quantitative and qualitative aspects of semen [31].

Table 4. A posteriori estimates of genetic, residual, and phenotypic correlations between visual score and reproduction traits in Nellore cattle.

Parameters	Genetic Correlations				Residual	Phenotypic Correlations
	Mean ± SD	Mode	Median	CI (95%)	Correlations	
M x SC365	0.15±0.18	0.18	0.16	(-0.21)-0.48	0.20	0.21
M x SC450	0.03±0.18	-0.04	0.00	(-0.33)-0.35	0.27	0.09
M x STAY	-0.06±0.24	-0.03	-0.05	(-0.52)-0.43	-0.22	-0.08
M x PPC30	-0.22±0.22	-0.25	-0.23	(-0.62)-0.22	0.23	-0.02
M x AFC	0.14±0.20	0.18	0.16	(-0.27)-0.53	-0.09	-0.01
PS x SC365	0.13±0.19	0.13	0.14	(-0.23)-0.49	0.11	0.12
PS x SC450	0.14±0.18	0.14	0.15	(-0.23)-0.47	0.16	0.08
PS x STAY	0.21±0.29	0.26	0.24	(-0.46)-0.68	-0.18	-0.08
PS x PPC30	0.17±0.32	0.18	0.16	(-0.39)-0.91	0.26	0
PS x AFC	-0.09±0.25	-0.09	-0.09	(-0.58)-0.42	-0.07	0.01
R x SC365	-0.16±0.19	-0.15	-0.16	(-0.51)-0.22	0.13	0.03
R x SC450	-0.25±0.17	-0.24	-0.26	(-0.55)-0.08	0.29	0.07
R x STAY	-0.16±0.28	-0.22	-0.17	(-0.64)-0.45	-0.06	0.06
R x PPC30	-0.14±0.21	-0.19	-0.15	(-0.55)-0.26	0.19	0.02
R x AFC	-0.18±0.23	-0.16	-0.17	(-0.61)-0.23	-0.04	-0.03
C x SC365	0.25±0.22	0.26	0.26	(-0.23)-0.64	-0.03	0.14
C x SC450	0.04±0.19	0.03	0.04	(-0.32)-0.42	0.13	0.18
C x STAY	0.36±0.25	0.66	0.37	(-0.12)-0.74	-0.28	0.11
C x PPC30	0.19±0.22	0.26	0.20	(-0.23)-0.60	-0.17	0.11
C x AFC	-0.20±0.28	-0.17	-0.19	(-0.72)-0.31	0.05	-0.10
N x SC365	0.08±0.21	0.06	0.08	(-0.32)-0.49	0.15	0.09
N x SC450	-0.06±0.18	-0.10	-0.06	(-0.41)-0.32	0.15	0.00
N x STAY	-0.25±0.29	-0.22	-0.26	(-0.78)-0.35	0.09	0.01
N x PPC30	-0.06±0.29	0.01	-0.05	(-0.59)-0.47	-0.36	0.03
N x AFC	-0.24±0.27	-0.29	-0.25	(-0.72)-0.26	0.05	-0.04
SAC x SC365	-0.10±0.22	-0.12	-0.10	(-0.54)-0.32	0.22	0.10
SAC x SC450	-0.25±0.19	-0.22	-0.24	(-0.60)-0.11	0.31	0.03
SAC x STAY	0.66±0.31	0.94	0.75	(-0.08)-0.99	-0.35	0.20
SAC x PPC30	-0.55±0.23	-0.46	-0.54	(-0.91)-(-0.07)	0.07	0.17
SAC x AFC	0.08±0.28	0.04	0.07	(-0.46)-0.63	0.03	-0.21

SC365: adjusted scrotal circumference at 365 days of age; SC450: adjusted scrotal circumference at 450 days of age; STAY: stayability; AFC: age at first calving; PPC30: probability of precocious calving; M: muscularity; PS: physical structure; R: racial aspects; C: conformation; N: navel; SAC: sacrum.

The heritability estimate for STAY found in the present study was higher than those reported in the literature for Nellore cattle, whose estimates range from low to moderate magnitude (0.09 to 0.25)[(32),(13),(14),(15)]. However, Queiroz et al.[(33)] reported a higher heritability estimate (0.59) in Caracu cattle. The high heritability for STAY in this study is not surprising, since, like the other evaluated traits, the animals belonged to a single herd and were submitted to the same rearing and handling conditions, reducing environmental variance.

Furthermore, reproductive performance has been used in this herd as a selection criterion, so that all animals that presented reproductive problems were discarded. Only those that had their first calving early and/or that calved regularly and weaned heavy calves remained in the herd. Thus, selection for reproductive performance was carried out prioritizing longer-lived, more fertile females with shorter calving intervals, resulting in lower environmental variance and, consequently, greater heritability for STAY. This resulted in a proportion of 45% of the cows with the capacity to remain in the herd and producing, compared to the ANCP breeding program average, which is 31% (Lôbo *et al.* unpublished data).

The wide variation in heritability estimates for this trait can be attributed to the different models used to define the trait, as well as to possible genetic differences in the evaluated populations[33),(32]. The heritability estimate obtained demonstrates that the selection of females based on stayability is feasible. In addition, the use of this trait as a selection criterion is advantageous, since it is possible to obtain significant genetic gains that will result in the reduction of costs spent on the replacement of females. Since the females remained productive in the herd for a longer time, there is an the increase in the number of animals for commercialization and decrease of the maintenance costs of the cow herd, due to the greater number of calves born and the increased proportion of productive adult animals in the herd [34].

The high heritability estimate obtained for PPC30 (0.54±0.02) indicates a high response to genetic selection. Moreover, the estimate obtained is close to the values presented in the literature for Nellore cattle, whose values estimated under Bayesian inference range from 0.36[6] to 0.55[35]. The result obtained in the present study confirms that the PPC30 trait can be included in beef cattle selection programs as an effective criterion for selection for sexual precocity[13]. The high heritability for PPC30 can be attributed to selection for precocity and reproductive efficiency that the evaluated herd has been submitted, as mentioned for STAY.

A direct indicator of sexual precocity in females, AFC presented an estimate of heritability close to those found in Nellore cattle by Claus et al. [19] and Costa et al. [15], whose estimates ranged from 0.08 to 0.13. This result suggesting that selection focused on this trait will bring a slower genetic progress compared to PP30, due to the low estimate of heritability (0.10±0.01). However, considering the economic importance of traits that indicate sexual precocity for production systems and the greater ease of evaluation of AFC compared to PP30, which is a categorical trait, its use as a selection criterion is justified[16),(36].

Additionally, the lower heritability estimate for AFC can be attributed to the greater influence that reproductive management has on this trait, compared to PP30. For this reason, although young heifers have genetic potential for sexual precocity, they are not exposed to reproduction due to their body weight, even if they are physiologically mature. So the difference within the population can be attributed not to the genetic component, but to the age at which heifers are exposed to mating[16),(36].

According to Forni et al.[37], morphological traits suffer highest environmental influence, due to this, responses to selection of lowest magnitude can be expected, in agreement with the estimates obtained in the present study. There are several methodologies for visual evaluation, however few studies have been found using the MERCOS evaluation methodology[22]. However, Faria et al.[38] using this same evaluation method, reported heritability coefficients close to those found in this study, whose values were 0.21; 0.27; 0.20 and 0.29 for M, PS, R and C, respectively, in Nellore cattle evaluated at 22 months of age and with a number of observations similar to that used in the present study. However, studies using other visual assessment methodologies reported higher values ranging from 0.33 to 0.40 for PS; 0.40 to 0.44 for P and 0.35 to 0.37 for M[5),(6),(11]. In this sense, the estimates found in the present study, together with those reported in the literature, show that morphological traits can respond to individual selection and promote genetic gains, especially scores for structure, racial aspects and conformation. Thus, selection based on these visual scores should lead to changes in the progeny's body conformation.

Boligon and Albuquerque[21] also reported moderate genetic correlations between scrotal circumference obtained at different ages and visual conformation scores. Accordingly, Faria et al.[2] outlined values ranging from 0.24 to 0.65 between SC365 and SC450 on one hand, and conformation scores assessed at different ages. From this perspective, the favorable and moderate genetic correlation between SC365 and the C score, along with the results found in the literature, indicate that the selection for animals with better conformation should lead to more fertile animals. However, the unfavorable, negative and moderate genetic correlation obtained between racial score and SC450 indicates that simultaneous selection should be carried out for both traits to obtain greater genetic gains and a more harmonious selection.

The low estimates of genetic correlations between scrotal circumference (SC) and M, PS, N indicate that most genes that influence SC do not affect these visual scores. Likewise, Duitama et al.[39] found low genetic correlations in Nellore cattle between PS, P and M scores and scrotal circumference (-0.04; -0.05 and -0.03). The low estimates found by Duitama et al.[39] can be ascribed to the smaller number of animals evaluated for SC when compared to the number of visual scores registered, which can also be observed in the present study (Table 2), since most animals with phenotypic information for the morphological traits were females. In contrast, Faria et al.[2] reported higher genetic correlation estimates than the present study between scores of M and PS with SC365 and SC450 (0.46 and 0.50; 0.59 and 0.49, respectively) measured at 22 months of age in Nellore cattle. According to the authors, although this age is considered late, the results obtained enable identification of more fertile animals. In addition, these results reflect most common Brazilian beef cattle production systems, which in the vast majority are extensive. Using a different assessment method, Boligon and Albuquerque[21] also reported estimates of high genetic correlations between SC and P and M scores (0.31 and 0.29, respectively).

Despite the low genetic correlations between most visual scores and SC, favorable and moderate phenotypic correlations between SC365 and M and residual correlations between SC365 and M and SAC, and SC450 and M, R and SAC indicate that environmental changes that lead to improvements in scrotal circumference can result in higher scores for M, R, and SAC. In addition, phenotypic selection for animals with greater muscularity, sacral bone and better racial characterization can lead to animals with higher scrotal circumference. Residual correlation includes associations arising from environmental effects that are not considered in the statistical model and non-additive genetic effects [40].

The favorable and moderate genetic association between STAY and C can be partially attributed to the relationship that stayability has with sexual precocity, indirectly indicated by conformation and greater muscularity. This is especially true in young heifers, since the lower heifer's age at first calving, the greater the chance of her having three births up to 76 months of age. Even so, factors other than conformation may be related to sexual precocity, since the genetic correlation between C and PPC30 was low (0.19±0.22). In that regard, the genetic association between STAY and C may also be related to lower rates of dystocia in heifers with better body conformation, resulting in greater reproductive longevity and corroborating the results obtained between STAY and SAC.

The favorable and high estimate of genetic correlation between STAY and SAC (0.66±0.31) can be attributed to the fact that the sacral bone is an indirect indicator of reproductive efficiency, as it is associated with easier calving and a lower incidence of reproductive problems[41]. This may also be related to the greater ability of the female to avoid culling and remain in the herd, because in the evaluated herd, only animals with the best rump angle or sacral bone are retained. On the other hand, STAY showed a lower genetic association with the scores of musculature, physical structure, racial aspects and navel. However, the estimates obtained indicate that animals with better body structure, greater conformation, precocious, reduced navel size and flat sacral bones (not protruding or sloping) are those that have a greater capacity to remain productive in the herd.

The unfavorable, moderate and high estimates of genetic correlation obtained between the probability of precocious calving and M and SAC indicate greater genetic gains and greater genetic influence of muscularity and sacral bone in the occurrence of early pregnancy, compared with genetic correlations obtained between PPC30 and other visual scores. However, this correlation was unfavorable, indicating that it is important to include both traits so that the gain for both is in the same desired direction for improved reproductive performance.

Working with Nelore cattle, Brunes et al.[42] identified tail insertion as an effective trait for the identification of females that will present early pregnancy, and the animals that presented the desired scores for tail insertion also presented a lower age at first calving. This fact may explain the moderate correlation obtained between PPC30 and SAC. The authors also reported that the results could be attributed to the association of tail insertion with muscularity score, which is also used to identify precocious heifers. Tail insertion is a point to identify the degree of muscularity in the animal's body, a fact that can also be observed in the high correlation obtained in the study by Soares et al.[43] between sacrum and musculature (0.44).

The favorable, moderate and positive residual correlations obtained between PPC30 with M and PS, and negative and moderate between PPC30 and O indicate that the phenotypic selection for animals with greater muscularity and body structure, can result in earlier-calving heifers, due to the relationship between muscle mass and reproductive performance.

In general, the low genetic association between some visual score traits, with the exception of sacral bone and traits indicative of sexual precocity and reproductive longevity, can be attributed to selection for precocity and reproductive regularity to which the herd was subjected, leading to lower variability for PPC30, AFC and STAY, which may have influenced the genetic association estimates. This herd was initially established with older dams that were not subjected to the breeding challenge for sexual precocity, therefore could not have presented lower AFC. In this way, the manifestation of age at first calving may have been delayed due to factors other than genetics, while there was rigorous culling of females with reproductive failure, so the females were long-lived but later-maturing. After the first year, as the selection program was initiated, the heifers began to be challenged for sexual precocity. Heifers are required to become pregnant, on average, at 23 months and to present a short calving interval, but without being selected for PPC30.

Paterno et al.[6] reported positive and favorable genetic correlations between PPC30 and STAY with visual scores of PS, finishing precocity and M (0.06 and 0.18; 0.52 and 0.26 and 0.44 and 0.24, respectively). Tramonte[44] reported moderate magnitude genetic correlations between visual + scores (conformation, muscularity, physical structure) with PPC30 and STAY (0.22 and 0.29, respectively). Faria et a.[2] using the same visual assessment methodology as that used in this study reported moderate to high magnitude favorable genetic correlations between visual scores of M, PS, C and SAC (-0.46; -0.33; -0.49, and -0.50, respectively), obtained at 22 months of age, with AFC.

Paterno et al.[6] found negative and low to high genetic correlations between PS, finishing precocity and M scores with AFC of -0.06, -0.47, and -0.37, respectively. On the other hand, Boligon and Albuquerque[21] observed higher genetic associations between AFC and visual scores evaluated in yearlings, in relation to visual scores obtained at weaning, probably because the traits evaluated in yearlings are obtained closer to the age at first calving. Thus, the assessment age would also influence the association between visual scores and sexual precocity, as well as the management and selection process to which the animals are subjected. These results, together with those obtained in the present study, indicate that the response to selection for animals with higher visual scores and precocity traits are antagonistic. However, phenotypic changes to the SAC score can lead to the selection of earlier-calving heifers.

5. Conclusion

The estimates of genetic correlations between the score for sacral bone and STAY show that the selection of animals with the best rump score may result in a greater ability of the female to remain in the herd. The identification of animals with flat sacral bone can also be an efficient characteristic in the identification for early pregnancy, and together with the musculature score, they can be related to animals with lower age at the first calving. As such, traits measured through visual scores can be used as auxiliary tools along with the selection of objective measures.

In addition, the use of visual scores as selection criteria allows the anticipation of decision-making, such as the animals disposal with some morphological defect that may compromise the production system, thus helping to identify functional, balanced and adequate animals for the production sustém, in line with market requirements. In addition, it allows each farm to build its own visual identity for the herd.

Declaration of Competing of Interest

No conflicts of interest were declared by the authors.

Author contributions

Conceptualization: L.B. Brunes and C. Magnabosco. *Data curation*: L.B. Brunes. *Formal analysis*: L.B. Brunes and B.B. Soares. *Methodology*: C. Magnabosco. *Investigation*: B.B. Soares and C. Magnabosco. *Project management*: C. Magnabosco. *Resources*: M.G. Narciso. *Writing (original draft)*: B.B. Soares, V.S. Magnabosco and R. D. Sainz. *Writing (review and editing)*: B.B. Soares, L.B. Brunes, F. Baldi, A.S. Carmo and R. D. Sainz

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