Genetic parameters for growth reproductive, carcass and meat quality in Polled Nellore Cattle

Mariana Márcia dos Santos Mamede
UFG: Universidade Federal de Goias
Guilherme Jordão de Magalhães Rosa
UW-Madison Graduate School: University of Wisconsin-Madison Graduate School
Eduardo da Costa Eifert
Embrapa Cerrados: Empresa Brasileira de Pesquisa Agropecuaria Cerrados
Fernando Brito Lopes
UFG: Universidade Federal de Goias
Fernando Baldi
UNESP: Universidade Estadual Paulista Julio de Mesquita Filho
Marcos Fernando Oliveira Costa
Embrapa Cerrados: Empresa Brasileira de Pesquisa Agropecuaria Cerrados
Roberto Daniel Sainz
University of California Davis
Adriana Santana do Carmo (adrianacarmo@ufg.br)
UFG: Universidade Federal de Goias https://orcid.org/0000-0002-2712-4789
Arthur dos Santos Mascioli
UFG: Universidade Federal de Goias
Claudio Ulhoa Magnabosco
Embrapa Cerrados: Empresa Brasileira de Pesquisa Agropecuaria Cerrados

Research Article

Keywords: scrotal circumference, age at first calving, accumulated productivity, shear force, ultrasound analysis

Posted Date: May 5th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1558612/v1

Version of Record: A version of this preprint was published at Tropical Animal Health and Production on March 17th, 2023. See the published version at https://doi.org/10.1007/s11250-023-03541-3.

Abstract

Genetic parameters were estimated for scrotal circumference adjusted to 365 (SC365) and 450 (SC450) days of age, age at first calving (AFC), accumulated productivity (AP), stayability (STAY), loin eye area (LMA), thickness of subcutaneous fat over the 12^{th}-13^{th} ribs (BF), thickness of subcutaneous fat over the rump (RF), and shear force measured by Warner-Bratzler shear force (WBSF) of polled Nellore cattle. Bayesian analysis bi characteristics were performed by adopting linear animal model, whereas STAY analyzes used the linear threshold model. Heritability estimates were equal to 0.31 (SC365), 0.37 (SC450), 0.16 (AFC), 0.25 (AP), 0.16 (STAY), 0.30 (LMA), 0.13 (BF), 0.24 (RF), and 0.15 (WBSF), indicating moderate response to selection. Genetic and residual correlations between SC365 and SC450 were high and positive (0.91 and 0.74, respectively), as well as the genetic correlations of AP with SC365, SC450, AFC, and STAY (0.61, 0.62, -0.69, and 0.83, respectively). Genetic and residual correlations of WBSF with reproductive and carcass characteristics exhibited high standard deviations, however favorable.

Introduction

The biological and economic sustainability of the beef production system is directly related to animal growth and reproductive efficiencies, as well as to the carcass yield and the quality of the meat produced. However, reproductive traits have much greater economic importance than growth traits (Brumatti et al., 2011). High-fertility herds produce more animals for both sale and breeding, allowing the greater intensity of selection and, consequently, faster genetic gains. Therefore, beef cattle breeding programs generally include different reproductive traits as selection criteria, such as early puberty, fertility, and lifetime accumulated production.

Brazilian beef production, predominantly Nellore cattle raised on pasture, tends to have low reproductive efficiency, with only 10% of cows calving by 30 months of age (De Vasconcelos Silva et al., 2005). Due to the ease of measurement and favorable genetic correlations, Nellore breeding programs evaluate scrotal circumference in males and age at first calving in females to identify animals with superior sexual precocity (Short et al., 1994). Additionally, to combine reproductive and productive efficiencies, the accumulated productivity and stayability are evaluated to allow identification of females with greater potential in terms of the total production of the weaned calf.

Considering the economic and commercial efficiency of the beef production chain, the yield, and quality of the meat produced must also be included in the breeding programs of the Nellore breed. Despite the limitations and difficulties of measurement, criteria such as carcass yield, subcutaneous fat thickness, and meat quality present large quantitative and qualitative variation within and among Nellore herds (De Castro et al., 2014). Also, it is important to know their genetic relationships with the other characteristics of economic interest.

The use of naturally polled breeds, such as polled Nellore, in beef production, is advantageous because it does not burden the productive system with the dehorning costs, besides, facilitates handling, transportation and avoids damage to the carcass due to bruising. In general, the genetic parameters of reproductive and meat quality traits of the common Nellore are used in the polled herd, without considering the particularities of this population. Therefore, studies that re-estimate genetic parameters and understand the covariance structure are necessary for the genetic development of the polled herd in Brazil. (Lopes et al., 2013; Amaral et al., 2014).

The objective of this study was to estimate the heritabilities and genetic correlations for traits related to reproductive efficiency and carcass and meat quality in Polled Nellore cattle.

Material And Methods

Data from the present study were obtained from Nellore animals belonging to Embrapa Cerrados (BRGN) and Guaporé Agropecuária SA (OB), born from 2001 to 2014 and, from 1998 to 2014, respectively. The traits analyzed included reproductive efficiency criteria, such as the scrotal circumference at 365 and 450 days of age (SC365 and SC450, respectively), age at first calving (AFC), accumulated productivity (AP), stayability (STAY); in addition to carcass yield and meat quality criteria, including longissimus muscle area (LMA) subcutaneous fat thickness over the 12th-13th ribs and the rump (BF and RF, respectively), and meat shear force (Warner-Bratzler shear force, WBSF). Except for WBSF, all measures and genealogy information were provided by the Nellore Brazil Program of the National Association of Breeders and Researchers (ANCP).

The calculation of the AP reflects the contribution of the female during her stay in the herd, in terms of the total production of weaned calves and the total time of production (kg/year). The AP value was estimated by the following equation:

$$\mathrm{AP} = \frac{\mathrm{WW} \cdot \mathrm{n_{calves}} \cdot \mathrm{C_a}}{\mathrm{ALC\ \text{-}\ C_i}},$$

where WW = mean calf weaning weight (kg); ncalves = total number of calves weaned; Ca = constant equal to 365 days, to express fertility on an annual basis; ALC = age of cow at last calving (days); Ci = constant equal to 550 days, reflecting the expectation that first calving will occur at 30 months of age.

STAY was defined as a binary trait, assuming the value 1 for cows that remained in the herd up to 76 months of age, calving at least three times, and the value 0 for those who did not meet those criteria.

Live animal carcass traits were measured using real-time ultrasound, using procedures, equipment, and personnel certified by the Ultrasound Guidelines Council (http://www.ultrasoundbeef.com) and the Nellore Brazil Program. Images of LMA and BF were collected between the 12th and 13th ribs, while RF was taken over the intersection of the *gluteus medius* and *biceps femoris* muscles, located between the ileum and the ischium of the animal.

To obtain the WBSF, 490 Nellore animals belonging to OB were slaughtered (297 males and 193 females). Carcasses were chilled for 24 hours at 1 to 4°C, then a portion of the *Longissimus* muscle was removed between the 9th and 12th ribs, according to Wheeler et al. (1998). Steaks were cut to 2.54 cm thickness, vacuum-packed, and stored at 4°C for seven days before being frozen pending evaluation for WBSF (AMSA, 2016).

The kinship matrix for the estimation of variance components and genetic parameters was composed by 57,951 animals, constituting 11 generations. The contemporary groups (CG) for SC365 and SC450 considered the effects of herd, year, and season of birth and management group, whereas for WBSF it did not consider the herd effect but also included sex and slaughter date. For AFC and AP, CG included effects of herd, year, and season of birth, while STAY included only the first two. However, for LMA, BF, and RF, CG included the effects of herd, year of birth, month of birth, sex, management type, management group, field technician, and ultrasound image laboratory. CG with less than four animals, bulls with offspring in less than three CG and records 3.5 standard deviations above or below of CG mean were removed from the dataset. The number of animals evaluated, the means, standard deviations, ranges, and variation coefficients for each trait are presented in Table 1.

Table 1
Descriptive statistics of the reproductive traits, carcass and tenderness of Polled Nellore cattle included in this study.

Trait[A]	Number of animals	Mean	Standard Deviation	Minimum	Maximum	Variation Coefficient
SC365 (cm)	5570	19,73	1,96	15	32,5	9,94
SC450 (cm)	9405	21,68	2,27	15	34	10,48
AFC (month)	12610	37,98	4,21	24	49	11,08
AP (kg/cow/year)	7490	130	22,57	54	202	17,36
LMA (cm^2)	11302	47,2	8,77	20,45	98,24	18,57
BF (mm)	11269	2,05	0,88	0,09	12,54	42,99
RF (mm)	11242	2,53	1,12	0,13	13,89	44,37
WBSF (kg)	454	3,83	1,28	1,07	8,87	33,53

[A]SC365 and SC450: scrotal circumference at 365 and 450 days of age respectively; AFC: age at first calving, AP: accumulated productivity, STAY: stayability; LMA: loin eye area; BF: thickness of subcutaneous fat over the 12th -13th ribs; RF: thickness of subcutaneous fat over the rump; WBSF: Warner-Bratzler shear force.

For the estimation of the (co)variance components, bi-trait quantitative analyses were performed under a linear animal model using the GIBBS2F90 computer program (Misztal et al., 2014). For the analyses involving STAY, the linear-threshold animal model, and the THRGIBBS1F90 program were adopted (Misztal et al., 2014). Both programs use Bayesian inference by the Gibbs sampling algorithm. For the

LMA, BF, and RF characteristics, the age of the animal was considered as covariate (linear and quadratic effect).

Results

The SC at 365 and 450 days of age presented substantial absolute and relative variability, constituting important selection criteria for sexual precocity and fertility in male Polled Nellore cattle (Table 1). Most carcass and meat quality traits presented high variation coefficients.

Posterior estimates of heritability for the reproductive, carcass, and meat traits are described in Table 2. Estimates of genetic and residual correlations between reproductive, carcass, reproductive/carcass, and reproductive/meat quality are presented in Tables 3, 4, 5, and 6, respectively.

Table 2
Estimated posterior means, modes, medians, standard deviations, and 95% credible intervals for heritability coefficients for reproductive, carcass and meat quality traits in Polled Nellore cattle.

Trait[A]	Mean	Mode	Median	Standard Deviation	CI[B] 2.5%	CI 97.5%
SC365	0,3078	0,3007	0,3059	0,1041	0,2285	0,3960
SC450	0,3671	0,3630	0,3659	0,1013	0,2903	0,4497
AFC	0,1639	0,1617	0,1633	0,0800	0,1290	0,2011
AP	0,2519	0,2512	0,2515	0,0773	0,2055	0,3000
STAY	0,1572	0,1547	0,1564	0,0832	0,1145	0,2033
LMA	0,3020	0,3016	0,3015	0,0880	0,2484	0,3587
BF	0,1335	0,1284	0,1319	0,0876	0,0868	0,1886
RF	0,2409	0,2362	0,2395	0,0929	0,1817	0,3078
WBSF	0,1622	0,1025	0,1385	0,1616	0,0473	0,4245

[A]SC365 and SC450: scrotal circumference at 365 and 450 days of age respectively; AFC: age at first calving, AP: accumulated productivity, STAY: stayability; LMA: loin eye area; BF: thickness of subcutaneous fat over the 12th -13th ribs; RF: thickness of subcutaneous fat over the rump; WBSF: Warner-Bratzler shear force.

[B]CI, credible interval.

Table 3
Estimated posterior means, modes, medians, standard deviations, and 95% credible intervals for genetic correlations and residuals for reproductive traits of Polled Nellore cattle.

Trait[A]	Mean	Mode	Median	Standard Deviation	CI[B] 2.5%	CI 97.5%
	Genetic correlations					
SC365 x SC450	0,91	0,93	0,92	0,03	0,85	0,96
SC365 x AFC	-0,24	-0,22	-0,24	0,13	-0,49	0,04
SC365 x AP	0,61	0,63	0,61	0,08	0,43	0,75
SC365 x STAY	0,26	0,31	0,27	0,14	-0,02	0,51
SC450 x AFC	-0,38	-0,41	-0,38	0,09	-0,55	-0,19
SC450 x AP	0,62	0,64	0,63	0,06	0,49	0,73
SC450 x STAY	0,33	0,33	0,33	0,11	0,09	0,55
AFC x AP	-0,69	-0,70	-0,69	0,07	-0,81	-0,55
AFC x STAY	-0,38	-0,37	-0,38	0,11	-0,59	-0,15
AP x STAY	0,83	0,86	0,84	0,06	0,71	0,94
	Residuals correlations					
SC365 x SC450	0,74	0,74	0,74	0,02	0,70	0,77
AFC x AP	-0,24	-0,24	-0,24	0,02	-0,28	-0,20
AFC x STAY	-0,24	-0,24	-0,24	0,02	-0,27	-0,20
AP x STAY	0,61	0,61	0,61	0,02	0,58	0,64

[A]SC365 and SC450: scrotal circumference at 365 and 450 days of age respectively; AFC: age at first calving, AP: accumulated productivity, STAY: stayability.

[B]CI, credible interval.

Table 4
Estimated posterior means, modes, medians, standard deviations, and 95% credible intervals for genetic correlations and residuals for carcass traits of Polled Nellore cattle.

Trait[A]	Mean	Mode	Median	Standard Deviation	CI[B] 2.5%	CI 97.5%
	Genetic correlations					
LMA x BF	0.25	0.28	0.26	0.12	0.01	0.46
LMA x RF	0.06	0.08	0.06	0.09	-0.12	0.25
BF x RF	0.49	0.50	0.50	0.11	0.26	0.69
	Residuals correlations					
LMA x BF	0.15	0.16	0.15	0.02	0.11	0.20
LMA x RF	0.16	0.16	0.16	0.03	0.10	0.21
BF x RF	0.34	0.34	0.34	0.02	0.30	0.38

[A]LMA: loin eye area; BF: thickness of subcutaneous fat over the 12th -13th ribs; RF: thickness of subcutaneous fat over the rump.

[B]CI, credible interval.

Table 5
Estimated posterior means, modes, medians, standard deviations, and 95% credible intervals for genetic correlations and residuals for reproductive and carcass traits for Polled Nellore cattle.

Trait[A]	Mean	Mode	Median	Standard Deviation	CI[B] 2.5%	CI 97.5%
	Genetic correlations					
SC365 x LMA	0,36	0,35	0,35	0,10	0,16	0,55
SC365 x BF	0,13	0,13	0,13	0,16	-0,20	0,43
SC365 x RF	0,02	0,02	0,02	0,13	-0,23	0,28
SC450 x LMA	0,35	0,36	0,35	0,09	0,18	0,51
SC450 x BF	0,10	0,10	0,10	0,14	-0,17	0,37
SC450 x RF	0,06	0,05	0,06	0,11	-0,15	0,26
LMA x AFC	-0,25	-0,26	-0,25	0,08	-0,41	-0,08
LMA x AP	0,70	0,71	0,70	0,05	0,60	0,79
LMA x STAY	0,35	0,35	0,35	0,11	0,14	0,57
BF x AFC	-0,28	-0,30	-0,28	0,13	-0,53	-0,02
BF x AP	0,23	0,23	0,23	0,13	-0,02	0,49
BF x STAY	0,08	0,06	0,08	0,16	-0,23	0,39
RF x AFC	-0,23	-0,24	-0,23	0,11	-0,44	-0,02
RF x AP	0,01	0,00	0,01	0,10	-0,19	0,22
RF x STAY	0,22	0,23	0,22	0,13	-0,03	0,46
	Residuals correlations					
SC365 x LMA	0,21	0,23	0,21	0,04	0,13	0,29
SC365 x BF	0,05	0,05	0,05	0,04	-0,03	0,13
SC365 x RF	0,07	0,07	0,07	0,05	-0,02	0,16
SC450 x LMA	0,22	0,22	0,22	0,04	0,14	0,30
SC450 x BF	0,02	0,02	0,02	0,04	-0,05	0,09
SC450 x RF	0,04	0,04	0,04	0,04	-0,04	0,12

[A]SC365 and SC450: scrotal circumference at 365 and 450 days of age respectively; AFC: age at first calving; AP: accumulated productivity; STAY: stayability; LMA: loin eye area; BF: thickness of subcutaneous fat over the 12th -13th ribs; RF: thickness of subcutaneous fat over the rump.

[B]CI, credible interval.

Trait[A]	Mean	Mode	Median	Standard Deviation	CI[B] 2.5%	CI 97.5%
LMA x AFC	0,01	0,02	0,01	0,18	-0,33	0,35
LMA x AP	-0,09	-0,05	-0,09	0,18	-0,47	0,26
LMA x STAY	-0,49	-0,53	-0,50	0,18	-0,80	-0,10
BF x AFC	0,02	0,03	0,02	0,16	-0,29	0,34
BF x AP	0,35	0,38	0,36	0,14	0,06	0,60
BF x STAY	0,04	0,01	0,04	0,19	-0,32	0,38
RF x AFC	0,01	0,01	0,01	0,11	-0,21	0,22
RF x AP	0,12	0,16	0,12	0,15	-0,18	0,41
RF x STAY	-0,28	-0,27	-0,29	0,17	-0,61	0,06

[A]SC365 and SC450: scrotal circumference at 365 and 450 days of age respectively; AFC: age at first calving; AP: accumulated productivity; STAY: stayability; LMA: loin eye area; BF: thickness of subcutaneous fat over the 12th -13th ribs; RF: thickness of subcutaneous fat over the rump.

[B]CI, credible interval.

Table 6
Estimated posterior means, modes, medians, standard deviations, and 95% credible intervals for genetic correlations and residuals for reproductive and meat quality traits of Polled Nellore cattle.

Trait[A]	Mean	Mode	Median	Standard Deviation	CI[B] 2.5%	CI 97.5%
	Genetic correlations					
SC365 x WBSF	-0,13	-0,82	-0,34	0,67	-0,92	1,00
SC450 x WBSF	0,27	0,85	0,50	0,62	-0,93	0,97
AFC x WBSF	-0,61	-0,59	-0,64	0,24	-0,94	-0,02
AP x WBSF	-0,52	-0,95	-0,61	0,39	-0,99	0,36
STAY x WBSF	-0,86	-0,99	-0,98	0,27	-1,00	0,06
LMA x WBSF	-0,09	-0,14	-0,10	0,45	-0,94	0,95
BF x WBSF	-0,12	-0,19	-0,12	0,39	-0,81	0,63
RF x WBSF	-0,10	-0,12	-0,11	0,30	-0,68	0,46
	Residuals correlations					
SC365 x WBSF	-0,84	-0,98	-0,90	0,21	-1,00	-0,21
SC450 x WBSF	-0,20	-0,22	-0,21	0,19	-0,56	0,17
LMA x WBSF	-0,06	-0,09	-0,06	0,11	-0,27	0,17
BF x WBSF	-0,01	0,00	-0,01	0,05	-0,11	0,09
RF x WBSF	-0,02	-0,02	-0,02	0,08	-0,16	0,14

[A]SC365 and SC450: scrotal circumference at 365 and 450 days of age respectively; AFC: age at first calving; AP: accumulated productivity; STAY: stayability; LMA: loin eye area; BF: thickness of subcutaneous fat over the 12th -13th ribs; RF: thickness of subcutaneous fat over the rump; WBSF: Warner-Bratzler shear force.

[B]CI, credible interval.

Except for Table 6, the range of 95% credibility intervals of the posterior density of estimates of heritabilities and genetic and residual correlations between reproductive and carcass traits and among them presented adequate amplitudes, indicating their consistency and reliability. Also, they presented low standard errors, indicating good accuracy.

The genetic and residual correlations between SC365 and SC450 (0.91 and 0.74, respectively) were positive and high, similar to literature values. Therefore, most of the genes that influence SC365 also influence SC450, suggesting that selection for change in the first will result in changes in the other, and *vice versa*. Conversely, the residual correlation indicates a high non-additive and/or genetic association between these traits.

Genetic correlations of SC365 and SC450 with AFC were moderate and negative (-0.24 and − 0.38, respectively). Genetic correlations of SC365 and SC450 with STAY were moderate and positive (0.26 and 0.33, respectively).

Discussion

The mean of SC365 and SC450 and AFC, BF, and RF were similar to those previously found in Nellore which indicates that although Polled Nellore is raised separately from common Nellore in Brazil, in general both herds have the same pattern of development (Barbosa et al., 2010; Boligon and Albuquerque, 2011; De Faria et al., 2015; Grossi et al., 2008; Regatieri et al., 2012; Yokoo et al., 2007; Yokoo et al., 2008).

The WBSF values reported here are comparable to the values commonly found for Bos taurus breeds (Wheeler et al., 2005), whose meat has good acceptability by the consumer for tenderness. On the other hand, Tizioto et al. (2013), reported greater values of WBSF in meat from Nellore cattle. Possibly, this divergence can be attributed to the intense meat quality selection conducted by OB for the last 15 years.

The AP per female averaged 130 ± 22.57 kg of calves weaned per year of life, like those reported for Nellore females by Schwengber et al. (2001) and De Faria et al. (2007). The value of AP is well below the average weaning weight (191 kg) of the animals participating of the Nellore Brazil Program because weaning weight does not include time factor as AP does (De Faria et al., 2007).

Heritability estimates for SC365 (0.31) and SC450 (0.37) indicated moderate magnitude, similar to those reported by Mercadante et al. (2000), but were lower than most reports in the literature, ranging from 0.49 to 0.65 (Corbet et al., 2013; De Faria et al., 2009). The present study was conducted using data from two Polled Nellore herds with a very similar genetic basis, therefore it had a lower population effective size and may present lower genetic variability for these traits. Moreover, SC was not a priority selection criterion for the herds analyzed in this study.

The 95% credible intervals and the posterior heritability estimates were similar for AFC and STAY (0.12 to 0.20 and 0.16, respectively), confirming several previous studies in Nellore cattle, ranging from 0.16 to 0.35 (Mercadante et al., 2000; Gutierrez et al., 2002; Regatieri et al. 2012) and 0.11 to 0.22 (De Vasconcelos Silva et al., 2003; (van Melis et al., 2010), respectively. Even with their low heritabilities, selection for these two traits can aid in genetic progress and maximize gains in reproductive efficiency of the herd (De Vasconcelos Silva et al., 2003; Eler et al., 2014).

The negative genetic correlation between AFC and STAY (-0.38) indicates favorable genetic correlations in terms of selection, that is, some of the genes that act to increase the scrotal circumference also act in favor of decreasing age at first calving, as well as in favoring the increase of the cow's ability to remain in the herd. Therefore, scrotal circumference can be considered a good criterion for the selection of sexual precocity for Nellore males and females, promoting genetic progress in important reproductive traits, as well as its positive and favorable genetic association with growth characteristics.

The posterior mean heritability for AP (0.25) lies within the 95% credible intervals (0.20 to 0.30) for AFC and STAY (both posterior mean heritabilities equal to 0.16). This suggests that AP may be adopted as a selection criterion by Nellore genetic improvement programs, favoring improved reproductive efficiency of females and males. Genetic correlations were favorable and high (Table 3) between AP and AFC (-0.69), STAY (0.83), SC365 (0.61) and SC450 (0.62). Therefore, when selecting for AP, we would also tend to increase the frequency of genes that also act to increase STAY, SC365 and SC450, and to decrease AFC. Considering the high and favorable genetic correlations found in this study, direct selection for any of these characteristics should favor improvements in the others.

Genetic correlations among characteristics measured in different animals (i.e., reproductive traits of males *vs.* females) may be estimated due to use of the kinship matrix to include genetic connections between the animals. By contrast, residual correlations can be estimated only for traits measured in the same animals (e.g., between SC365 and SC450 in males; AFC, STAY and AP in females*).* Residual correlations of the same direction with lower values, such as between AFC and AP and between AP and STAY (both equal to -0.24), indicate moderate non-additive genetic associations and/or environmental effects on these traits. By contrast, residual correlations were greater between SC365 and SC450 (0.74) and between AP and STAY (0.61).

The mean heritability estimates and the 95% credible intervals for BF (0.13, 0.09 to 0.19, respectively), RF (0.24, 0.18 to 0.31, respectively) and LMA (0.30, 0.25 to 0.36, respectively), were of low magnitude compared to values previously reported for Nellore cattle. Heritabilities for BF, RF, and LMA have ranged from 0.17 to 0.52 (Yokoo et al., 2008; De Faria et al., 2015); 0.23 to 0.65 (Zuin et al., 2012); and from 0.29 to 0.65 (Barbosa et al., 2010; Zuin et al., 2013; De Faria et al., 2015), respectively. However, despite of the lower magnitude, they indicated a response to direct selection, confirming their recommendation as selection criteria in the Nellore breed to improve carcass yield and quality.

The heritability estimate obtained in this study for WBSF (0.16) was of similar magnitude to Tizioto et al. (2013) (0.16) and De Castro et al. (2014) (0.11). However, direct measurement of WBSF is laborious and expensive, besides requiring the slaughter of the animals. Due to the difficulty of obtaining the phenotypic measures for WBSF, there are few reports in the literature regarding shear force in Nellore cattle, as well as its relationship with other characteristics of economic interest. More studies are necessary to investigate and identify other methodologies and tools to obtain new tenderness criteria.

Among carcass traits, it was observed that the posterior means genetic correlation and its 95% credible interval between BF and RF (0.49, 0.26 to 0.69, respectively) were high and positive, indicating that these traits are influenced by many of the same genes. However, the mean genetic correlations between LMA and BF and between LMA and RF were lower. Therefore, a small proportion of the genes responsible for LMA expression may be common only with BF, indicating that selection for increased LMA may also result in a slight increase in BF. Genetic correlations reported in the literature (Yokoo et al., 2008; Caetano et al., 2013; Zuin et al., 2013) for these same characteristics are small, indicating little genetic association and suggesting that selection for increased LMA should not necessarily influence fat thickness.

Residual correlations for the carcass characteristics studied indicated small non-additive genetic associations (dominance, overdominance and epistasis) and/or environmental effects, except for the residual correlation between BF and RF (0.34).

Genetic correlations between reproductive and carcass characteristics were of low to moderate magnitude, except between LMA and AP (0.70) (Table 5). These results suggest a possible association between AP and higher carcass yield, however further studies are needed to confirm this and elucidate the nature of this association.

Genetic correlations involving LMA with SC365, SC450 and STAY were positive and moderate, around 0.35, while with AFC it was slightly lower, however negative and favorable (-0.25). However, the correlations involving BF or RF were of low magnitude, although they were all favorable. Of particular note were the genetic correlations of BF with AFC (-0.28) and AP (0.23) and of RF with AFC (-0.23) and STAY (0.22). Thus, inclusion of reproductive characteristics such as scrotal circumference in males and the AP and AFC in females as selection criteria in genetic improvement programs in Nellore cattle should improve reproductive and productive efficiency, as well as carcass traits due to favorable genetic associations.

The residual correlations between most reproductive and carcass characteristics were close to zero. That is, there were little or no non-additive genetic effects and/or a common environment between them. Exceptions include residual correlations involving LMA with STAY (-0.49), SC365 (0.21) and SC450 (0.22), between BF and AP (0.35) and between RF and STAY (-0.28).

The 95% confidence intervals of the genetic correlation estimate of WBSF with SC365, SC450, LMA, BF and RF were very broad (Table 6), indicating imprecision of the estimates. The distribution of these estimates showed high standard deviations and the posterior means of WBSF with SC365 and SC450 were quite different. The estimated means for these genetic correlations were of low magnitude and could be considered null. These results indicate that selection to improve scrotal circumference and WBSF should be conducted independently.

Except for WBSF with SC365 (-0.84), residual correlations were close to zero, that is, the characteristics were not associated by common environmental effects. This is not surprising, since meat shear force is subject to multi-factorial environmental influences pre- and post-mortem, therefore, is much more susceptible to changes than those related to morphological characteristics such scrotal circumference and even carcass traits. In this data set, the environmental influences favorable to increased SC365 contributed favorably to decreased WBSF, suggesting that the environment interfered in sexual precocity and finishing in a positively.

Genetic correlations of WBSF with AFC, CAP and STAY were calculated based only on the genetic association contained in the kinship matrix, since reproductive efficiency measures were obtained only for females and that WBSF were obtained only in slaughtered males. Due to this limitation, and the inherent difficulty of obtaining measurements, biological interpretation of these values must be approached with caution.

Despite the crucial importance of the variables associated with the reproductive efficiency of the females for the sustainability of the beef production system, they presented low estimates of heritability, which should result in slower genetic progress. This low heritability for female reproductive traits is known to be strongly influenced by environmental factors and management.

Based on the results obtained in this study, it is expected that in the medium term, animals with greater sexual precocity will also have greater accumulated productivity and longer stay of females in the herd, along with superior carcass traits. However, due to the low heritabilities and small genetic associations with reproductive traits, fat thickness characteristics (BF and RF) will still require direct selection.

Due to the heritabilities of the scrotal perimeter measured at 365 and 450 days of age, as well as their genetic correlations with the reproductive characteristics of females, direct selection for them will indirectly result in improvements in accumulated productivity, stayability, and age at first calving.

Accumulated productivity proved to be an attractive selection criterion to be adopted by breeding programs, indirectly favoring rapid genetic progress for reproductive characteristics of females and males (SC365, SC450, AFC and STAY), as well as for LMA.

Declarations

Acknowledgments

The authors thank to Guaporé Pecuária for provide the data set (phenotypes and DNA).

Funding

The authors received research financial support from Brazilian Agricultural Research Corporation - Embrapa (project number 020802006) and CNPq (National Council of Technological and Scientific Development - project number 450417/2014-0). Author M. M. S. Mamede has received support from CAPES (Coordination for the Improvement of Higher Education Personnel) for providing Ph.D. and Ph.D. sandwich scholarship.

Statement of Animal Rights

The present study was exempt of the local ethical committee evaluation as phenotipic and pedigree data was granted from comercial animal breeding program.

Conflict of Interest Statement

The authors of this paper declare there is no conflict of interest.

Author Contributions

All authors contributed to the study conception and design. Material preparation and data collection were performed by M. M. S. Mamede, E. C. Eifert, C. U. Magnabosco and F. Baldi, M.F.Costa. Analysis were perfomed by G.J.M. Rosa and F. B. Lopes. The first draft of the manuscript was written by M. M. S. Mamede, A.S. Carmo, A. S. Mascioli and R. D. Sainz and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript

Data Availability

The datasets generated during and/or analysed during the current study are not publicly available because it belongs to a commercial genetic improvement program, but are available from the corresponding author on reasonable request.

References

1. Amaral, R. dos S., Carneiro, P.L.S., Martins Filho, R., Ambrosini, D.P., Malhado, C.H.M., 2014. Trends, phenotypic and genetic parameters for growth traits in cattle Nellore polled Northeast Brazilian. Rev. Bras. Saude e Prod. Anim. 15, 261–271. https://doi.org/10.1590/s1519-99402014000200003
2. AMSA. 2016. Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness. American Meat Science Association, Champaign, Illinois, USA.
3. Azevêdo, D.M.M.R., Filho, R.M., Lôbo, R.N.B., Lôbo, R.B., De Moura, A.A.A.N., Filho, E.C.P., Malhado, C.H.M., 2005. Accumulated productivity of nellore cows raised in north and northeast of brazil. Rev. Bras. Zootec. 34, 54–59. https://doi.org/10.1590/s1516-35982005000100007
4. Boligon, A.A., Albuquerque, L.G., 2011. Genetic parameters and relationships of heifer pregnancy and age at first calving with weight gain, yearling and mature weight in Nelore cattle. Livest. Sci. 141, 12–16. https://doi.org/10.1016/j.livsci.2011.04.009
5. Boligon, A.A., Silveira, F.A., Silveira, D.D., Dionello, N.J.L., Santana, M.L., Bignardi, A.B., Souza, F.R.P., 2015. Reduced-rank models of growth and reproductive traits in Nelore cattle. Theriogenology 83, 1338–1343. https://doi.org/10.1016/j.theriogenology.2015.01.025
6. Brumatti, R.C., Ferraz, J.B.S., Eler, J.P., Formigonni, E.I.B., 2011. Desenvolvimento de índice de seleção em gado corte sob o enfoque de um modelo bioeconômico*. Arch. Zootec. 60, 205–213. https://doi.org/10.4321/S0004-05922011000200005
7. Caetano, S.L., Savegnago, R.P., Boligon, A.A., Ramos, S.B., Chud, T.C.S., LÔbo, R.B., Munari, D.P., 2013. Estimates of genetic parameters for carcass, growth and reproductive traits in Nellore cattle. Livest. Sci. 155, 1–7. https://doi.org/10.1016/j.livsci.2013.04.004
8. Campos, B.M., do Carmo, A.S., da Silva, T.B.R., Verardo, L.L., de Simoni Gouveia, J.J., Mendes Malhado, C.H., Barbosa da Silva, M.V.G., Souza Carneiro, P.L., 2017. Identification of artificial

selection signatures in Caracu breed lines selected for milk production and meat production. Livest. Sci. 206. https://doi.org/10.1016/j.livsci.2017.10.014

9. Chud, T.C.S., Caetano, S.L., Buzanskas, M.E., Grossi, D.A., Guidolin, D.G.F., Nascimento, G.B., Rosa, J.O., Lôbo, R.B., Munari, D.P., 2014. Genetic analysis for gestation length, birth weight, weaning weight, and accumulated productivity in Nellore beef cattle. Livest. Sci. 170, 16–21. https://doi.org/10.1016/j.livsci.2014.09.024
10. Corbet, N.J., Burns, B.M., Johnston, D.J., Wolcott, M.L., Corbet, D.H., Venus, B.K., Li, Y., McGowan, M.R., Holroyd, R.G., 2013. Male traits and herd reproductive capability in tropical beef cattle. 2. Genetic parameters of bull traits. Anim. Prod. Sci. 53, 101–113. https://doi.org/10.1071/AN12163
11. De Castro, L.M., Magnabosco, C.U., Sainz, R.D., De Faria, C.U., Lopes, F.B., 2014. Quantitative genetic analysis for meat tenderness trait in polled nellore cattle. Rev. Cienc. Agron. 45, 393–402. https://doi.org/10.1590/s1806-66902014000200022
12. de Faria, C.U., de Andrade, W.B.F., de Pereira, C.F., da Silva, R.P., Lôbo, R.B., 2015. Análise bayesiana para características de carcaça avaliadas por ultrassonografia de bovinos da raça Nelore Mocho, criados em bioma Cerrado. Cienc. Rural 45, 317–322. https://doi.org/10.1590/0103-8478cr20140331
13. de Faria, C.U., de Ulhôa Magnabosco, C., de Albuquerque, L.G., Framartino Bezerra, L.A., Lôbo, R.B., 2009. Avaliação genética de características de escores visuais de bovinos da raça Nelore da desmama até a maturidade. Rev. Bras. Zootec. 38, 1191–1200. https://doi.org/10.1590/S1516-35982009000700005
14. de Faria, C.U., de Ulhôa Magnabosco, C., de los Reyes, A., Lôbo, R.B., Bezerra, L.A.F., Sainz, R.D., 2007. Bayesian inference on field data for genetic parameters for some reproductive and related traits of Nellore cattle (Bos indicus). Genet. Mol. Biol. 30, 343–348. https://doi.org/10.1590/s1415-47572007000300008
15. De Vasconcelos Silva, J.A., Eler, J.P., Ferraz, J.B.S., De Oliveira, H.N., 2003. Genetic analysis of stayability among nelore females. Rev. Bras. Zootec. 32, 598–604. https://doi.org/10.1590/s1516-35982003000300011
16. De Vasconcelos Silva, J.A.I.I., Dias, L.T., De Albuquerque, L.G., 2005. Genetic studies of sexual precocity of heifers in a Nellore herd. Rev. Bras. Zootec. 34, 1568–1572. https://doi.org/10.1590/s1516-35982005000500017
17. Genetic analysis of growth traits in polled Nellore cattle raised on pasture in tropical region using bayesian approaches. - Portal Embrapa [WWW Document], n.d. URL https://www.embrapa.br/busca-de-publicacoes/-/publicacao/978407/genetic-analysis-of-growth-traits-in-polled-nellore-cattle-raised-on-pasture-in-tropical-region-using-bayesian-approaches (accessed 10.8.20).
18. Grossi, D.A., Frizzas, O.G., Paz, C.C.P., Bezerra, L.A.F., Lôbo, R.B., Oliveira, J.A., Munari, D.P., 2008. Genetic associations between accumulated productivity, and reproductive and growth traits in Nelore cattle. Livest. Sci. 117, 139–146. https://doi.org/10.1016/j.livsci.2007.12.007

19. 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. https://doi.org/10.1016/S0301-6226(02)00100-8
20. Lopes, F.B., Magnabosco, C.U., Paulini, F., da Silva, M.C., Miyagi, E.S., Lôbo, R.B., 2013. Genetic Analysis of Growth Traits in Polled Nellore Cattle Raised on Pasture in Tropical Region Using Bayesian Approaches. PLoS One 8, e75423. https://doi.org/10.1371/journal.pone.0075423
21. Mercadante, M.E.Z., Lôbo, R.B., De Oliveira, H.N., 2000. Estimativas de (Co)Variâncias entre Características de Reprodução e de Crescimento em Fêmeas de um Rebanho Nelore. Rev. Bras. Zootec. 29, 997–1004. https://doi.org/10.1590/s1516-35982000000400008
22. Misztal, I., Tsuruta, S., Lourenco, D., Aguilar, I., Legarra, A., Vitezica, Z., Manual for BLUPF90 family of programs. http://nce.ads.uga.edu/wiki/lib/exe/fetch.php?media=blupf90_all1.pdf>
23. Regatieri, I.C., Boligon, A.A., Baldi, F., Albuquerque, L.G., 2012. Genetic correlations between mature cow weight and productive and reproductive traits in Nellore cattle. Genet. Mol. Res. 11, 2979–2986. https://doi.org/10.4238/2012.May.10.4
24. Schwengber, E.B., Bezerra, L.A.F., Lôbo, R.B., 2001. Produtividade acumulada como critério de seleção em fêmeas da raça nelore. Ciência Rural 31, 483–486. https://doi.org/10.1590/s0103-84782001000300020
25. Short, R.E., Staigmiller, R.B., Bellows, R.A., Greer, R.C., n.d. BREEDING HEIFERS AT ONE YEAR OF AGE: BIOLOGICAL AND ECONOMIC CONSIDERATIONS 1.
26. Sorensen, D., Gianola, D., 2002. Likelihood, Bayesian, and MCMC Methods in Quantitative Genetics, Statistics for Biology and Health. Springer New York, New York, NY. https://doi.org/10.1007/b98952
27. Tizioto, P.C., Decker, J.E., Taylor, J.F., Schnabel, R.D., Mudadu, M.A., Silva, F.L., Mourão, G.B., Coutinho, L.L., Tholon, P., Sonstegard, T.S., Rosa, A.N., Alencar, M.M., Tullio, R.R., Medeiros, S.R., Nassu, R.T., Feijó, G.L.D., Silva, L.O.C., Torres, R.A., Siqueira, F., Higa, R.H., Regitano, L.C.A., 2013. Genome scan for meat quality traits in nelore beef cattle. Physiol. Genomics 45, 1012–1020. https://doi.org/10.1152/physiolgenomics.00066.2013
28. van Melis, M.H., Eler, J.P., Rosa, G.J.M., Ferraz, J.B.S., Figueiredo, L.G.G., Mattos, E.C., Oliveira, H.N., 2010. Additive genetic relationships between scrotal circumference, heifer pregnancy, and stayability in Nellore cattle. J. Anim. Sci. 88, 3809–3813. https://doi.org/10.2527/jas.2009-2127
29. Wheeler, T.L., Cundiff, L. V., Shackelford, S.D., Koohmaraie, M., 2005. Characterization of biological types of cattle (Cycle VII): Carcass, yield, and longissimus palatability traits. J. Anim. Sci. 83, 196–207. https://doi.org/10.2527/2005.831196x
30. Wheeler, T.L., Shackelford, S.D., Koohmaraie, M., 1998. Cooking and Palatability Traits of Beef Longissimus Steaks Cooked with a Belt Grill or an Open Hearth Electric Broiler. J. Anim. Sci. 76, 2805–2810. https://doi.org/10.2527/1998.76112805x
31. Yokoo, M.J., Albuquerque, L.G., Lôbo, R.B., Bezerra, L.A.F., Araujo, F.R.C., Silva, J.A. V, Sainz, R.D., 2007. Genetic and environmental factors affecting ultrasound measures of longissimus muscle area and backfat thickness in Nelore cattle . https://doi.org/10.1016/j.livsci.2007.12.006

32. Zuin, R.G., Buzanskas, M.E., Caetano, S.L., Venturini, G.C., Guidolin, D.G.F., Grossi, D.A., Chud, T.C.S., Paz, C.C.P., Lôbo, R.B., Munari, D.P., 2012. Genetic analysis on growth and carcass traits in Nelore cattle. Meat Sci. 91, 352–357. https://doi.org/10.1016/j.meatsci.2012.02.018