Evaluation and prediction of scrotal circumference in beef bulls

Silvio R.O. Menegassi a, Gabriel R. Pereira a, Concepta McManus b, Vanerlei M. Roso c, Carolina Bremm a, Celso Koetz Jr. d, Juseclêa F. Lopes a, Júlio O.J. Barcellos a, *.

a Department of Animal Science, Federal University of Rio Grande do Sul, Bento Gonçalves Avenue no 7712, 91540-000, Porto Alegre, Rio Grande do Sul, Brazil
b Department of Animal Sciences, University of Brasilia, Darcy Ribeiro University Campus, 70910-900, Brasilia, DF, Brazil
c GenSys Consultores Associados S/C Ltda, Guilherme Alves Street 170, 90450-190, Porto Alegre, Rio Grande do Sul, Brazil
d College of Veterinary Medicine, University of Northern Paraná, Paris Avenue 675, 86041-120, Londrina, Paraná, Brazil

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ABSTRACT

Scrotal circumference (SC) is considered a useful tool for predicting age at puberty and is performed to improve the reproductive performance in beef cattle industry. We aimed to fit several nonlinear mixed models for SC measurements of five different breeds to better predict testicular growth. Data of SC (cm), body weight (BW; kg), and age (A; days), farm location, sire and dam, and birth dates of 169,094 beef bulls were collected from five breeds: Nelore (N) (n = 110,814); Angus (AA) (n = 6541); Brangus (BA) (n = 34,910); Polled Hereford and Hereford (HH) (n = 4640); and Brahford (BH) (n = 7480). Data comprise a total of 8640 sires and 115,172 dams and grouped in 2908 contemporary groups (CG). The full model development for SC was defined as: SC = CG + A + A*A + BW + BW*B + E. Bulls from HH (34.1 ± 3.2) and AA (33.5 ± 3.0) had the highest value of SC, followed by BH (32.2 ± 3.7), BA (30.6 ± 4.1), and N (26.9 ± 3.6). There was a curvilinear effect of BW on the SC measurements of HH and AA bulls, reaching the maximum point around 600 kg, whether both breeds presented a similar testicular growth pattern. In British breeds, inflection points of average daily SC growth of 0.039 and 0.042 cm/kg were obtained from 700 kg HH and 600 kg AA bulls, respectively. Scrotal circumference values of 0.042 and 0.046 cm/kg reaching the maximum growth point at 450 kg BW were obtained for BH and BA bulls, respectively. We also observed SC values of 0.044 and 0.048 cm/d reaching the maximum growth point at 550 d of age for BH and BA bulls, respectively. Thus, estimate testicular size at maturity should be measured between 500 and 600 kg BW in British genotypes and between 550 and 600 d in Bos indicus and crossbreeds animals. Therefore, SC adjustment can be used by breed-specific criteria associated with BW and/or age to determine testis growth as a selection criterion in beef cattle breeding programs.

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1. Introduction

Problems inherent to beef cattle production, such as the low genetic potential of the herds and the lack of adaptation to the environment and management practices, may impair the productivity of breeding systems. Genetic improvement resources, particularly sire selection, may contribute to improve cattle productivity [1]. Scrotal circumference (SC) is a highly heritable trait to its offspring and appears to be an accurate predictor of puberty regardless of breed [2-4]. The heritability of SC in bulls from 1 to 2 years of age is ~0.5 and responds quickly to selection [5]. In addition, SC is correlated with paired testis weight, daily sperm production and semen quality traits, and reproductive performance of male and female offspring, reaching puberty earlier [6-9].

Bulls with a large SC have half-sib heifers and daughters that reach puberty earlier and are considered more fertile. Coulter et al. [10] suggested that only age is used as a reference to assess whether a bull’s SC may be used according to the pre-established range for each breed. However, Menegassi et al. [11] showed that bulls experience a wide range of nutritional conditions and concluded that SC depends on the increase in testicular weight that is proportional to the increase in live BW rather than age. In agreement, Mwansa et al. [12] also suggested that genetic models evaluating SC should include BW as a correlated trait and age at the time of SC measurement as a covariate variable to improve model accuracy.

* Corresponding author.
E-mail address: julio.barcellos@ufrgs.br (J.O.J. Barcellos).

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Recently, Fordyce et al. [13] showed that SC is positively correlated with BW, particularly at 18 months of age, reinforce that SC prediction models must include live BW parameter in order to compare SC measurements among different sires. In this sense, Ortiz Peña et al. [14] demonstrated a better fit of SC prediction models that were corrected for both BW and age rather than only for age in Nelore breeding programs.

In this context, we aimed to fit several nonlinear mixed models for SC measurements of five different breeds to better predict testicular growth. The objectives of this study were to determine the effects of BW and age on the SC from five different beef breeds' bulls.

2. Materials and methods

2.1. Database

The records of SC (cm), BW (kg), age (days), farm location, sire and dam, and birth dates of 169,094 beef bulls from five different breeds were retrieved from databank of specific genetic programs as followed: Nelore (N) (Conexão Delta G Breeding Program; \( n = 110,814 \)); Angus (AA) (Natura Program; \( n = 6541 \)); Brangus (BA) (Natura Program; \( n = 42,910 \)); Polled Hereford and Hereford (HH) (Pampa Plus Genetic Program; \( n = 4640 \)); and Braford (BH) (Pampa Plus Genetic Program; \( n = 7480 \)). In addition, a total of 8640 sires and 115,172 dams were used for analyzes. Data was retrieved from bulls born between 1984 and 2015 from different regions in Brazil.

Information on dam age, birth date, calving month, sire, feeding (diet supplementation, creep feeding, improved and natural pastures), and farm geographic location (county) were extracted from the spreadsheets from the databanks of each genetic evaluation programs analyzed. Contemporary groups (CG) are formed to identify a group of animals that undergone the same management and environmental conditions during a particular phase of their life. Data comprises 2908 CG were used as a categorical random effect and consider all possible interactions among the effects of herd location, month and year of birth, year of SC measurement, season of calving, and feeding group.

Scrotal circumference was measured at yearling using a millimeter tape, in cm, positioned around the largest circumference of the scrotum. It is recognized that variation in this technique may occurred and caused some SC overestimates, although the data use in this study were provide from each breeding program and the operator responsible to collect the measurements at different animal population were approved by the each breeding program.

2.2. Statistical procedure

The first step was to perform the descriptive analysis of SC of each breed group. As we were interested to estimate the importance of factors influencing SC, an a priori order of effects was fit in the linear mixed-effects model, and these effects were tested using sequential sum of squares model (Type I SS). The residual heteroscedasticity and normal distribution of data were tested to verify the model assumptions. Considering that age and BW of animals are significantly correlated, the multicollinearity was tested by the variance inflation factor (VIF <10). The models presented no collinearity problem and, therefore, both BW and age were included in the prediction models for SC. Contemporary groups were included as random effect in the model, because when CG effects are treated as random, the effective offspring number of each individual evaluated increase, and consequently, the variance of the prediction error decreases [15].

Model development for SC proceeded by simplification of a full model. The full model was:

\[
SC = CG + age + age^2 + BW + BW^2 + \varepsilon;
\]

Where, SC is scrotal circumference; CG is nominal contemporary group; BW is body weight at the time of the SC measurement are continuous variables; and \( \varepsilon \) is the residual random effect, mainly due to variation among animals.

The fixed effects were simplified by removing the last non-significant effect (\( P > 0.05 \), according to the sequential sum of squares) not involved in a significant interaction. Thus, the final SC models for Nelore (N), Angus (AA), and Brangus (BA) breeds were:

\[
SC = CG + age + age^2 + BW + BW^2 + \varepsilon
\]

In addition, the final SC models for Hereford and Polled Hereford (HH), and Braford (BH) breeds were:

\[
SC = CG + age + BW + BW^2 + \varepsilon
\]

The models for HH and BH did not include the effect of age\(^2\) BW interaction, because it was not significant (\( P > 0.05 \)).

The relationships among data were explored by decision tree analysis, using question hierarchy (\( P < 0.05 \)), with the objective of obtaining an accurate prediction model for SC. The first step of the decision tree analysis is the training data set, which is split by testing one of the independent variables, resulting in more homogeneous subsets of dependent variable data. This procedure is repeated until very homogeneous sample sets are obtained, for which it is possible to assign a single value to the dependent variable. In this study, SC was considered as the dependent variable, and BW, age, and year of birth from bulls of each breed, adjusted by CG, were considered the independent variables. Statistical analyzes were conducted using the software JMP v.12 [16].

3. Results

The descriptive statistical analysis results had that SC, BW, and age were different among breeds (Table 1). The SC measurements recorded in the data banks of the evaluated genetic selection programs widely varied with age and BW, although the average values (515.6 days; 369.9 kg, respectively) were close to the values established in the models used to adjust these parameters.

The highest SC values were found in HH (34.1 ± 3.2 cm) and AA (33.5 ± 3.0 cm) bulls, followed by BH (32.2 ± 3.7 cm) and BA (30.6 ± 4.1 cm), and the lowest in N (26.9 ± 3.6 cm) bulls. The first joint analysis of the data included the factor “farm location”, but this factor did not improve (\( P > 0.05 \)) the SC accuracy of the model. However, the inclusion of CG improved the prediction of these effects, which explained 65.3% of the variation in SC values.

A previous analysis between BW and age did not show any collinearity among the variables included in the SC prediction model. Consequently, the effect of age at the time of SC measurement (\( P < 0.01 \)) on BW was evaluated. The regression analysis, including BW and age, determined the following average daily weight gain (ADG: kg \(^{-1}\)) coefficient of 0.817 (HH), 0.793 (BH), 0.700 (AA), 0.660 (BA) and 0.596 kg/d for N bulls, respectively. These values reflect the effects of genetic and environmental factors at the evaluated age on bulls’ daily growth rate, which may influence SC measurements.

There was a curvilinear effect of BW on the SC measurements of HH and AA bulls, reaching the maximum point around 600 kg, whether both breeds presented a similar testicular growth pattern (Fig. 1A). On the other hand, BW overestimated the SC of younger BH bulls that showed testicular growth at a slower rate compared to British genotypes. For this reason, a mixed model was used, which included age as covariate and BW as independent variable.
In our prediction models, CG was considered as random effect, and we included the linear and quadratic effects of BW and age into the equations (Table 2). The use of CG as a random effect adjusted the model and generated a SC prediction equation, which may allow for the extrapolation of the results.

Interestingly, we observed a combined effect of BW and age on the SC for BH, BA, and N bulls, whereas only BW affected the SC of HH and AA bulls. The SC of BH bulls was influenced by age; however, BA and N bulls were quadratically influenced by age and BW, whereas in N bulls, age was more important than BW due to the testicular growth pattern of this breed.

Inflection points of average daily SC growth of 0.039 and 0.042 cm/kg were obtained in 700 kg HH and 600 kg AA bulls, respectively. Indeed, decreasing and curvilinear SC growth curves determined as a function of BW increase. In both BH and BA bulls, age had a combined effect with BW, that makes it difficult to establish the SC growth coefficient for these breeds. Scrotal circumference values of 0.042 and 0.046 cm/kg reaching the maximum point at 450 kg BW were obtained for BH and BA bulls, respectively. In addition, we observed SC values of 0.044 and 0.048 cm/d reaching maximum point at 550 d of age were obtained for BH and BA bulls, respectively. Thus, each kg of BW increase produced a similar effect on the SC of both BH and BA bulls.

Based on the regression equations in our study, the models were adjusted to compare observed vs. predicted SC values, and the results demonstrated the efficacy of the models used for all breeds (Fig. 2).

**Table 2**

Prediction equations of the scrotal circumference (SC) growth rate of beef bulls according to breed, body weight, and age.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Equation</th>
<th>R² (%)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH</td>
<td>$y = 23.3329 + 0.02517x + (x-437.2939)^2(x-437.2939)^{-0.00003328}$</td>
<td>65.36</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>AA</td>
<td>$y = 23.2878 + 0.02910x + (x-352.2002)^2(x-352.2002)^{-0.00005055}$</td>
<td>54.67</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BA</td>
<td>$y = 16.4618 + 0.04125x + (x-338.3873)^2(x-338.3873)^{-0.000005415} + 0.001335z + (z-510.0192)^2(z-510.0192)^{-0.00005314}$</td>
<td>61.46</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

HH — Hereford; AA — Angus; BA — Braford; BA — Brangus; N — Nellore; y — SC; x — body weight; z — age; R² — Coefficient of determination (%).
Fig. 2. Scrotal circumference (SC) observed and predicted in Aberdeen Angus (AA; A), Polled Hereford and Hereford (HH; B), Braford (BF; C), Brangus (BA; D) and Nelore (N; E) breeds. $z$ – mean observed SC; $y$ – mean predicted SC.
Other variables were included in a complementary analysis to try to improve SC estimation models within breeds by including the effects of BW, age, year of birth, year of SC collection and sire. A decision tree analysis was performed with the objective of finding specific and independent effects for estimating SC, with a more practical application (Table 3).

In general, the analysis that split the general model to five evaluated breeds predicted models showed that SC values were determined by age limits: lower than 353 kg in BA bulls, and higher than 604 kg BW in BH bulls (Table 3).

4. Discussion

The results of this study indicate a genetic trend resulting from the selection for SC in those selection programs, as well as of the effects of environmental factors and CG applied into the programs. Coutsouropoulos et al. [10] found an average SC dispersion value of 3.0 cm in 7918 Angus, Charolais, Hereford, Shorthorn, and Limousine bulls. In a recent study, Menegassi et al. [11] evaluated 9664 two-year-old bulls of various breeds, including Bos indicus breeds, and determined a variation in SC values similar to that observed in the current study. However, those authors obtained higher absolute SC values, because bulls were considered older (730 days) at the time of scrotal measurement performed during the andrological examination of bulls.

In a study conducted in Brazil by Silva et al. [9] with 51,161 N bulls evaluated at approximately the same age as those in the present study, obtaining similar SC values (26.8 cm) for this breed. A recent study [17] determined the average SC by breed and age of bulls evaluated at approximately the same age as those in the present study, which constituted our database, may be confused with breed effects in the estimation of SC.

The measure of SC is performed during puberty, between 510 and 550 days of age. At the evaluated age, the obtained SC values corresponded, on average, to 90% of the SC values of mature bulls [11], which clearly demonstrates the genetic progress achieved in the above-mentioned authors.

The measure of SC is performed during puberty, between 510 and 540 d old, allowing to identify bulls presenting fast testicular growth rate that is considered a characteristic of early sexual maturity. A study performed by Dal-Farra et al. [27], determined that SC values stabilized around 590 d of age in N bulls, similar to the findings of Garcia Guerra et al. [17], which was expected since the scrotal measurement was performed at 16–17 months, older animals, in the Angus and Hereford breeds.

In the present study, it was expected that the farm environment would influence bull growth rate, and consequently the adjustment of the SC prediction model, because the HH, AA, BH and BA breeds are predominant in the Brazilian subtropical region, and BH and BA in the subtropical-tropical transition region, and N in the tropical region. Therefore, the imbalance or inconsistency in the number of bulls evaluated in each region, which constituted our database, may be confused with breed effects in the estimation of SC. Because of the differences among Brazilian micro regions, genetic selection should target animals that are better adapted to each environment.

When yearling bulls were fed low, medium, or high energy levels post-weaning, puberty was reached at 57, 49, and 43 weeks of age, respectively, with BW of 255, 287, and 329 kg [18], as also found later by Pruitt et al. [19], who fed bulls with different energy levels after weaning. Experiments were performed to investigate the effects of calf hood nutrition on puberty development and confirmed that superior nutrition augmented gonadotropin secretion, which is probably mediated by metabolic hormones to enhance larger testis development at yearling to have an overall earlier onset of spermatogenesis [19–21]. Indeed, sexual development of bulls calves depends not only on nutrition [21] but also on the feed intake of their mothers during pregnancy.

A high-nutrition diet fed to the mother during the first trimester has negative effects on the reproductive performance of their offspring [22]. In addition, there is now evidence that the nutritional differences in feed during the prepubertal period [23,24] or even the feed intake of the mothers [25,26] can affect the development of the calves during later stages of life.

The results of the present study are consistent with those found by Dal-Farra et al. [27], who applied a mathematical model for SC prediction in N bulls using fixed values of 330 kg BW and 550 d of A., and determined a SC of 28.4 cm, which are similar to obtained in the present study, of 26.9 cm at 370 kg BW and 514 d of age. These results emphasize the importance of A, in addition to BW, as a discriminatory factor of SC in bulls.

Scrotal circumference values, as a testicular size parameter, present a curvilinear behavior both as a function of age [28] and BW [29]. Testicular growth dramatically changes with age, presenting a distinctive sigmoid curve. Bulls' testis growth slowly before 25 weeks of age, and then undergo a rapid growth phase until puberty, returning to slow growth rate until maturity, around 37–50 weeks of age [30]. At puberty, SC values are close to those observed at maturity; however, after puberty, testicular growth rate becomes slower, until testicular mature size is achieved [6,31]. In the present study, bulls of all evaluated breeds presented similar adjusted SC values at 560–600 days old or weighed 650-600 kg, because at that age and/or BW, testicular growth rate had already decreased in European bulls, and were still increasing in Bos indicus breeds and their crosses [BH and BA]. At the evaluated age, the obtained SC values corresponded, on average, to 90–92% of the SC values of mature bulls [11], which clearly demonstrates the genetic progress of SC, particularly in BH, BA, and N bulls. It should be mentioned that the analyzed databanks included a higher amount of evaluated bulls using a more recent data compared with those evaluated by the above-mentioned authors.

Table 3

Specific factors influencing the scrotal circumference (SC) of beef bulls based on the decision tree analysis.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Independent variable</th>
<th>R² (%)</th>
<th>SC (cm) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>&lt;450 kg</td>
<td>37.2</td>
<td>22.1 ± 3.0</td>
</tr>
<tr>
<td>N</td>
<td>&gt;450 kg</td>
<td>39.2</td>
<td>23.9 ± 3.2</td>
</tr>
<tr>
<td>N</td>
<td>&lt;500 kg</td>
<td>39.2</td>
<td>26.1 ± 2.9</td>
</tr>
<tr>
<td>N</td>
<td>&gt;500 kg</td>
<td>39.2</td>
<td>27.2 ± 3.0</td>
</tr>
<tr>
<td>N</td>
<td>&lt;550 kg</td>
<td>45.8</td>
<td>28.1 ± 2.7</td>
</tr>
<tr>
<td>N</td>
<td>&gt;550 kg</td>
<td>45.8</td>
<td>29.3 ± 2.6</td>
</tr>
<tr>
<td>N</td>
<td>&lt;430 kg</td>
<td>31.9</td>
<td>32.2 ± 2.7</td>
</tr>
<tr>
<td>N</td>
<td>&gt;430 kg</td>
<td>31.9</td>
<td>35.8 ± 2.5</td>
</tr>
<tr>
<td>N</td>
<td>&lt;373 kg</td>
<td>39.4</td>
<td>30.8 ± 2.6</td>
</tr>
<tr>
<td>N</td>
<td>&gt;373 kg</td>
<td>39.4</td>
<td>33.4 ± 2.3</td>
</tr>
<tr>
<td>N</td>
<td>&lt;2009 kg</td>
<td>46.2</td>
<td>34.0 ± 2.0</td>
</tr>
<tr>
<td>N</td>
<td>&gt;2009 kg</td>
<td>35.3</td>
<td>35.3 ± 2.4</td>
</tr>
<tr>
<td>N</td>
<td>&lt;337 kg</td>
<td>29.8</td>
<td>31.7 ± 2.5</td>
</tr>
<tr>
<td>N</td>
<td>&gt;337 kg</td>
<td>29.8</td>
<td>35.0 ± 2.4</td>
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<tr>
<td>N</td>
<td>&lt;411 kg</td>
<td>40.1</td>
<td>34.4 ± 2.2</td>
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<td>&gt;411 kg</td>
<td>40.1</td>
<td>36.2 ± 2.4</td>
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<td>35.8 ± 2.2</td>
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<td>N</td>
<td>&gt;411 kg</td>
<td>42.7</td>
<td>37.6 ± 2.3</td>
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<tr>
<td>N</td>
<td>&lt;497 kg</td>
<td>34.0</td>
<td>29.3 ± 2.8</td>
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<td>N</td>
<td>&gt;497 kg</td>
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<td>32.8 ± 2.9</td>
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<tr>
<td>N</td>
<td>&lt;604 kg</td>
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<td>31.8 ± 3.3</td>
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<tr>
<td>N</td>
<td>&gt;604 kg</td>
<td>32.3</td>
<td>33.0 ± 3.0</td>
</tr>
<tr>
<td>AA</td>
<td>&lt;353 kg</td>
<td>39.2</td>
<td>26.0 ± 3.5</td>
</tr>
<tr>
<td>AA</td>
<td>&gt;353 kg</td>
<td>39.2</td>
<td>28.3 ± 3.4</td>
</tr>
<tr>
<td>AA</td>
<td>&lt;457 kg</td>
<td>43.0</td>
<td>30.7 ± 3.1</td>
</tr>
<tr>
<td>AA</td>
<td>&gt;457 kg</td>
<td>43.0</td>
<td>31.0 ± 3.1</td>
</tr>
</tbody>
</table>

N = Nellore; AA = Angus; BA = Brangus; HH = Hereford; BH = Brahford; BW = body weight.

R²: Cumulative coefficient of determination (%); SD: Standard deviation (P < 0.05).
in BW and age at puberty among breeds.

Neves et al. [33] evaluating a CG of N bulls between 2004 and 2008 and obtained values of 18.2 cm at 5–7 mo, 18.8 cm at 7–12 mo, 22.9 cm at 12–18 mo, and 31.9 cm at 18–24 mo of age. It should be noted that inference is relative, because the lack of SC data measured from birth in the evaluated databank limits its conclusion. However, based on the scientific evidences demonstrated in the growth predicted models by Hammond [34], Berg and Butterfield [35] and, more recently, by Lawrence and Fowler [29], determined that early-maturing genotypes present higher relative growth of some body structures and organs at the beginning of puberty. This may explain the higher SC values obtained in HH and AA animals, which are early-maturing breeds, compared to BH and BA, which are crosses breeds with intermediate growth rates, and the latter with N breed that is a late-maturing breed. However, these models do not allow comparisons among breeds, because of the inclusion of CG in each of the specific model used from each association-breeding program. The differences in SC values as a function of BW or the association between BW and age may be due to testicular growth rates during the phase immediately after birth and before the measurements were taken. The 10 cm higher SC values obtained with the prediction model for HH and AA bulls relative to N bulls may be explained by the slower body growth rate of N cattle.

Loaiza-Echeverri et al. [36] found that the model that best estimated SC from 366 to 550 d old Guzerá bulls (Bos indicus) was the logistic model, but mentioned that none of the evaluated models properly fit SC during the early growth phase or at maturity. Neves et al. [33] applied the logistic model to estimate SC in N bulls and obtained values of 40 cm at maturity (70 mo), and an inflection point of 20 cm (point of maximum growth) at 11.32 mo of age. The high and positive correlations between SC and age may allow selecting grazing of N bulls at 12 and 18 mo, with a SC values of approximately 20.15 and 25.41 cm, respectively. In contrast, we applied a different model using a high number of CG included as random effect and observed values at <550 and >550 d of age, with a SC of 28.1 and 29.3 cm, respectively.

Similarity to our data, Barth and Ominski [37] observed a decrease in the SC growth from 10 to 15 mo when evaluated a short period of growth and used bulls fed under higher levels of nutrient diet. The authors showed that SC measurement in weaned bulls may not be a useful culling tool for breeding programs, due a large portion of bulls that did not met the minimum requirements for SC size at 240 d achieved these requirements at 365 d of age [37]. Perhaps, Entwistle and Holroyd [38] evaluated the effects of nutrition on SC values, and mentioned the impact of year due to seasonal differences and significant direct effects of BW and body condition on SC parameter. Pruitt et al. [19] had that Simmental and Hereford bulls fed higher energy levels after weaning were heavier and had larger SC at one year of age compared to lower diet fed. Perhaps, bulls fed with higher energy levels may have larger SC measurements due to fat deposition in the scrotum [39]. Anatomically, Bos indicus animals showed a long testicular shape conformation compared to Bos taurus, and also present a higher amount of sweat glands on the scrotal skin and a higher testicular artery length [40,41]. The small amount of subcutaneous fat and the high concentration of sweat glands in the skin covering the testes and the tunica dartus are also important contributors to testicular thermoregulation [40].

The degree of testicular growth rate reduction was lower in N bulls, followed by BH and BA bulls, and finally by HH and AA bulls. In fact, testicular growth was stabilized (i.e., point at which the decrease in growth rate is close to zero), at 500 and 550 d in HH and AA, 550 and 600 d in BH and BA, and after 600 d in N bulls. These parameters of the SC growth curve are related to the maturity rate of each breed evaluated in the study. The testes of bulls of early-maturing breeds, such as HH and AA, tend to reach their mature size earlier [35] than late-maturing breeds, and this may explain their faster testicular growth rate reduction determined in the present study compared with N bulls, which testes continue to grow until a later age [33]. Lunstra et al. [8], working with several Bos taurus genotypes, obtained a daily SC growth rate of 0.085 cm from 7 to 13 mo, which is higher compared to HH and AA bulls in the present study, although we evaluated a wider age interval. Due to the high correlation between BW gain and SC, it is possible that these differences are also associated with different feeding regimes between both studies, as it has been shown that the higher nutritional levels during the post-weaning period result in higher SC in young bulls [8]. On the other hand, deficient nutrition delays testis growth and reduces their size at puberty [42]. Therefore, testicular tissue growth is highly correlated with body growth rate, which explains why BW is a better predictor for SC than age in British genotypes [11,13].

Wilson [43] proposed a SC linear regression coefficient of 0.031 cm/d for Angus bulls between weaning and 365 d of age, and Tozser et al. [44] obtained a SC daily growth rate of 0.028 cm/d and 0.032 cm/kg from 6 to 7 mo Charolais bulls. Baker et al. [45] working with Hereford and Angus bulls, found that SC daily growth rates decreased from 0.055 cm/d at 9–10 mo to 0.030 cm/d at 12–13 mo, and its stabilized at 15 mo (0.010 cm/d), similar to results obtained in the present study in HH and AA bulls at puberty.

In the study by Ortiz-Beña et al. [14] using N bulls in Paraguay, obtained SC growth rates of 0.07 cm/kg and 0.03 cm/d at 540 d of age and 570 kg BW, lower compared to the present study, possibly due to geographic differences management in bulls distributed into five different CG. In AA and HH bulls, year of birth was especially important, indicating that SC values of AA bulls should be corrected in 2.0 cm after 2011, as also shown by Garcia-Guerra et al. [17] in AA and Canadian Hereford bulls evaluated during the last decade. Therefore, SC adjustment can be simplified using breed-specific criteria associated with BW and/or age ranges as correction factors, aiding the comparison and selection within populations of future sires. Although it is well established that SC is correlated with semen quality [46,47], the SC indicates whether semen or sperm production is considered normal. Other authors [48,49] describe that breeding bull soundness exam methods particularly involves the assessment of several fertility parameters, including SC, general body condition, specific genital soundness exam, semen quality, and natural mating capacity.

5. Conclusions

Body weight and age are important variables used as a selection criterion in beef cattle breeding programs, as they support the biological interpretation of testicular growth that are easily comparable among various production scenarios. The observed SC growth curve are essential to best estimate testicular size at maturity and it should be measured between 500 and 600 kg of BW in British genotypes and at age between 550 and 600 days in Bos indicus genotypes and their crosses with the British breeds.

Conflicts of interest

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

Ethics statement

This study did not require the approval of the Animal Care and
Use Committee because data were retrieved from an existing database.

Software and data repository resources

The data sets and programs used in the current study are available from the corresponding author on reasonable request.

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