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Genetic evaluation of the scrotal circumference of beef bulls in the Czech Republic

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Abstract: The objective of the present study was to estimate the genetic parameters for the scrotal circumference of bulls of beef breeds in the Czech Republic. The used database for the years 1996–2020 comprised information on the scrotal circumference measurements from 22 065 bulls of 19 pure breeds and crossbred animals of the Beef Simmental, Charolais, and Hereford breeds. After adjustments, the database contained 16 404 records. To test the influence of systematic fixed effects, the GLM/SAS procedure using the least-squares method was applied. The contemporary group, weight and age of the bulls were included as significant systematic environmental effects (< 0.05). The genetic parameters were determined by a single-trait model using the AIREMLF90 program. The heritability coefficient of the scrotal circumference was 0.27. Environmental correlations of the scrotal circumference with the bull weight were moderate and positive (r = 0.2), but the correlations between the age in days and the scrotal circumference were almost zero (r = 0.03). The results indicate that the scrotal circumference of beef cattle breeds provides sufficiently high genetic variability that can be used to identify individuals with an above-average circumference and, in this way, increase the probability of selection of a young bull with a better reproduction potential.

Keywords: beef cattle; reproduction potential; fertility indicator

Fertility is one of the economically most important traits of most production systems in beef cattle management (Van Eenennaam 2013; Krupova et al. 2020). Greater attention is commonly paid to female fertility; however, bull fertility does not play a less important role. The wrong selection of a bull can dramatically influence the number of calves born, causing great economic losses in this way. The scrotal circumference is one of the fertility indicators (Chenoweth and McPherson 2016). Its correct measurement can provide an idea of the reproduction potential of a bull in a relatively easy, rapid, and cheap way (Menegassi et al. 2019). The scrotal circumference is correlated with many productive and reproductive traits of bulls and their offspring. A relationship was proven between the scrotal circumference and the quantity and quality of the produced semen (Schmidt et al. 2019; Brinks 2021) or on the growth traits of a bull (Boligon et al. 2015; Abreu Silva et al. 2018; Schmidt et al. 2019). It was also found that the daughters of bulls with slightly above-average values of the scrotal circumference reached sexual maturity and first calving earlier than the daughters of bulls with an average or below-average scrotal circumference (Buzanskas et al. 2017; Bonamy et al. 2018), while

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the stayability of these daughters was also longer (Martinez-Velazquez et al. 2020). The heritability coefficient of the scrotal circumference is in the range of 0.26 to 0.53 (Buzanskas et al. 2017; Bonamy et al. 2018; da Silva Neto et al. 2020, etc.). Medium heritability of the trait facilitates the efficient selection for this trait or for traits correlated with it. Although selection for this trait is carried out in many countries with advanced cattle breeding, the scrotal circumference only remains as an indicator of a bull's fertility, and the reproduction potential of below-average animals should be complemented by semen testing to confirm or reject the breeding ability of a bull in a herd. The objective of the present study was to determine the genetic parameters and to predict the breeding values for the scrotal circumference for the beef cattle population in the Czech Republic.

MATERIAL AND METHODS

Database and data editing

The scrotal circumference is measured around its widest point using a measuring tape in cm. The data for the scrotal circumference evaluation in beef cattle were collected at breeding bull test stations. The database comprised the scrotal circumference measurements in bulls of different breeds for the years 1996–2020. A total number of 22 065 bulls were measured over this period. In total, 19 pure breeds of bulls and crossbred bulls of the Beef Simmental, Charolais, and Hereford breeds (from the begging of testing) were included in the analysis. The SAS program (SAS v9.4; SAS Institute, Cary, NC, USA) was used for the data file preparation and evaluation of all the results.

Connectedness

To determine the variance components, the database had to be prepared. Contemporary groups were created based on the breeding bull test station and day of measurement. Every contemporary group had to contain a sufficient number of cases and, thus, the effects of the individual factors influencing the result can be estimable. Sires of bulls with less than five measured offspring were excluded from the database. Contemporary groups with less than five bulls were excluded, and finally, contemporary groups with offspring of one identical sire were also excluded. Parallelly, missing or meaningless data on the scrotal circumference were exempted from the evaluated data file. Nevertheless, after such adjustments, a sufficient amount of 16 404 records (animals) were used to test the suitable evaluation methods.

Pedigree

A total number of 55 296 animals were involved in the pedigree including four generations of ancestors. Unknown groups of ancestors in the pedigree were created based on the breeds. In total, 36 unknown groups of ancestors based on the breed and gender (18 for male and 18 for female) were created. The total fraction of both known ancestors in the pedigree was 77.94% of the animals, one known ancestor and one unknown ancestor were involved in 0.35% cases, and of both unknown ancestors were determined in 21.71% of the cases.

Statistical models

To test the influence of systematic fixed effects, the GLM/SAS procedure (Statistical Analysis System v9.4; SAS Institute, Cary, NC, USA) using the least-squares method was applied. The effects of the weight, age of the animals in days, and the contemporary groups were tested. The value of $P < 0.05$ was considered as statistically significant.

Variance components were estimated by the Average Information Restricted Maximum Likelihood method (AIREMLF90) (Misztal et al. 2002) using a general linear mixed model (a single trait). The convergence criterion for the analyses was 10^{-17}. The assumption is that the animal and random residuum were distributed as N (0, $\mathbf{A}\sigma_u^2$) and N (0, $\mathbf{I}\sigma_e^2$), respectively, and Cov $(u,e) = 0$, where **A** is the additive relationship matrix and **I** is an identity matrix of the order equal to the number of observations; σ_u^2 is the additive genetic variance and σ_e^2 is the error variance.

Based on the calculated genetic parameters, a single-trait BLUP animal model was employed for the estimation of the breeding values. Calculations were run on the BLUPf90 program (Misztal et al. 2002).

https://doi.org/10.17221/84/2022-CJAS

The following model equation was used for the estimation of the genetic parameters and prediction of the breeding values:

$$Y_{ijklmn} = \mu + HYS_i + \text{weight}_j + \text{weight}_k^2 + \text{age}_l + \text{age}_m^2 + GH_n + e_{ijklmn} \quad (1)$$

where:

Y_{ijklmn} – measured trait;
μ – is the population mean;
HYS_i – random effect of a contemporary group created by a combination of the breeding bull test station and the date of measurement;
weight_j – linear regression on the bull's weight;
weight_k^2 – quadratic regression on the bull's weight;
age_l – linear regression on the bull's age in days;
age_m^2 – quadratic regression on the bull's age in days;
GH_n – random effect of the additive genetic value of an animal;
e_{ijkmnl} – random residual error.

RESULTS AND DISCUSSION

Basic statistical data

The evaluated database showed that the scrotal circumference of the bulls was measured on an age range of 317–531 days (10–17 months). The most frequent measurements of the scrotal circumference were undertaken between 365 and 426 (85.4%) days of age. The bulls reached a weight of 286–960 kg and the measured scrotal circumference was determined in a range from 20 to 53 cm. The highest number of animals was recorded in the Charolais (*n* = 4 941), Beef Simmental (*n* = 3 475), Aberdeen Angus (*n* = 3 142), and Limousine (*n* = 2 862) breeds. The basic descriptive statistics of the scrotal circumference, weight, and age of the bulls are documented in Table 1.

The smallest scrotal circumference, on average, was measured in the Galloway, Belgian Blue

Table 1. Basic descriptive statistics for the scrotal circumference, weight and age in pure breeds of beef cattle and their crossbred animals

Breed	*n*	Scrotal circumference (cm)			Weight (kg)			Age (months)		
		mean ± SD	min.	max.	mean ± SD	min.	max.	mean ± SD	min.	max.
Belgian Blue	43	33.5 ± 3.2	26	40	538.1 ± 60.8	425	680	13.9 ± 1.5	12	17
Bazadaise	10	36.0 ± 2.6	30	40	517.8 ± 80.7	425	668	13.3 ± 0.9	12	15
Salers	65	37.4 ± 1.8	32	44	592.8 ± 60.4	459	798	13.9 ± 1.1	12	17
Aberdeen Angus	3 142	39.3 ± 2.7	20	53	607.3 ± 62.1	400	850	13.2 ± 0.9	11	17
Rouge des Prés	3	41.3 ± 3.5	38	45	716 ± 30.3	681	734	14.7 ± 0.6	14	15
Piedmontese	259	34.3 ± 3.3	25	42	538.7 ± 62.3	370	760	13.2 ± 1.1	11	17
Parthenaise	56	36.0 ± 2.1	29	39	562.5 ± 51.3	478	717	13.4 ± 1.1	11	16
Blonde d'Aquitaine	619	35.7 ± 2.6	27	46	610.2 ± 61.3	402	803	13.4 ± 1.1	11	17
Gasconne	181	36.4 ± 2.4	30	42	569.2 ± 55.1	427	718	13.3 ± 0.9	12	16
Beef Simmental	3 475	40.3 ± 2.9	27	51	654.4 ± 68.2	430	960	13.3 ± 1.1	11	17
Crossbred of Beef Simmental	46	39.4 ± 2.5	35	45	613.0 ± 74.4	411	768	13.5 ± 1.2	11	16
Shorthorn	7	37.0 ± 0.8	36	38	542.1 ± 25.7	500	572	14.0 ± 0.0	14	14
Charolais	4 941	38.5 ± 2.7	25	49	642.5 ± 66.2	443	886	13.5 ± 1.1	11	17
Crossbred of Charolais	3	36.0 ± 2.6	34	39	581.3 ± 66.5	540	658	12.3 ± 0.6	12	13
Hereford	561	38.0 ± 2.9	27	51	568.6 ± 65.3	339	796	13.3 ± 1.0	10	17
Crossbred of Hereford	3	33.3 ± 4.0	31	38	524.3 ± 89.8	470	628	14.0 ± 0.0	14	14
Uckermärker	8	41.0 ± 4.0	36	49	659.9 ± 52.5	589	729	13.4 ± 0.9	12	15
Aubrac	94	37.9 ± 1.5	34	43	573.3 ± 64.8	445	709	13.2 ± 0.9	12	16
Vosgienne	2	38.5 ± 0.7	38	39	491.5 ± 14.8	481	502	13.0 ± 0.0	13	13
Galloway	24	30.7 ± 1.6	28	33	370.7 ± 37.1	286	453	13.3 ± 0.9	12	16
Limousine	2 862	36.4 ± 2.2	22	46	591.8 ± 60.8	386	810	13.5 ± 1.1	11	17

https://doi.org/10.17221/84/2022-CJAS

and Piedmontese breeds when these breeds also belonged to those with the lowest average body weight at the same time. Low average weights were also found in the Vosgienne (n = 2) and Bazadaise (n = 10) breeds represented by a few individuals. The largest scrotal circumference and, at the same time, the highest average weight were reached by the Rouge des Prés, Uckermärker, Beef Simmental, and Charolais breeds. However, the average of the former two breeds (Rouge des Prés and Uckermärker) may be distorted due to the low number of bulls of those breeds being included in the measurements (n < 10). The highest variability was revealed in Aberdeen Angus bulls when a difference of 33 cm was found between the smallest and the largest scrotal circumference. This breed was also one of the three most numerous breeds included in the analysis (n = 3 142), but, in the other numerous breeds (Beef Simmental and Charolais), the difference between the smallest and largest scrotal circumference was only 24 cm. So, the high variability of the scrotal circumference in Aberdeen Angus bulls is probably not related to the range of the body weight (differences in the body weight of the Charolais and Beef Simmental breeds were within a much larger interval), but it is rather associated with the long-term above-average selection of this breed for fertility traits.

In other countries, the bull breeding soundness evaluation (BBSE) was used to assess the quality of bulls in a complex way. Such an evaluation should help to reduce the risk of selecting a poor performance bull, and this procedure is applied to test the sperm motility, the sperm's morphology, the reproductive organs (penis, scrotum, testicles, etc.), and other reproductive functions (Chenoweth and McPherson 2016). In the framework of the BBSE minimum, scrotal circumference measurements were set down for particular age groups and/or bull breeds. In case the bull does not have the minimum scrotal circumference, no additional examination of the sperm motility and semen morphology was carried out and the bull was excluded from reproduction (Garcia-Paloma 2015). The fertility and semen quality of bulls with a below-average or above-average scrotal circumference compared to the remaining population will likely be low (Brinks 2021), while the bulls whose scrotal circumference is in the range of 31 and 44 cm have the best quality spermiogram (Beggs 2014). By discarding the bulls with a below-average scrotal circumference, it is possible to increase the productive and reproductive potential of bulls in the population within several years (Eriksson et al. 2012).

Influence of genetic and non-genetic factors

As shown by our results, the scrotal circumference was influenced by the genetic constitution of a bull roughly from 28% of the total influence. The remaining variability was influenced by the internal and external environmental factors. The weight of the bull and its age belong among the crucial factors influencing the scrotal circumference. These two traits are mutually correlated, and it is assumed that the body weight of the bull and its scrotal circumference will increase with age until the body development of the animal is finished. In the present study, the scrotal circumference was measured at 10 to 17 months of age, and although the bull's age was included among the statistically significant traits, its effect was not very noticeable in comparison with the effect of the bull's weight (Figure 1).

Several studies have demonstrated a positive medium-high genetic correlation between the growth abilities of a bull and its scrotal circumference; it suggests that the additive effect of genes influencing the growth also contributes to the scrotal circumference growth (Crews and Porteous 2003; Schmidt et al. 2019). This relationship can be used vice versa as the selection of bulls with an above-average scrotal circumference should be reflected in the higher growth ability of the bulls (Boligon et al. 2015; Abreu Silva et al. 2018). Figure 2 illus-

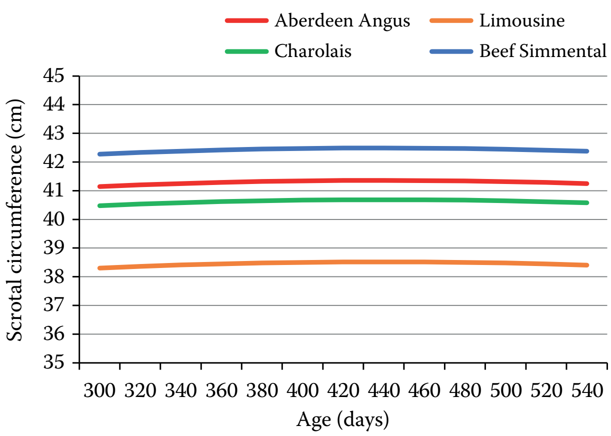

Figure 1. Evaluation of the scrotal circumference in relation to the age in days for the selected breeds of bulls

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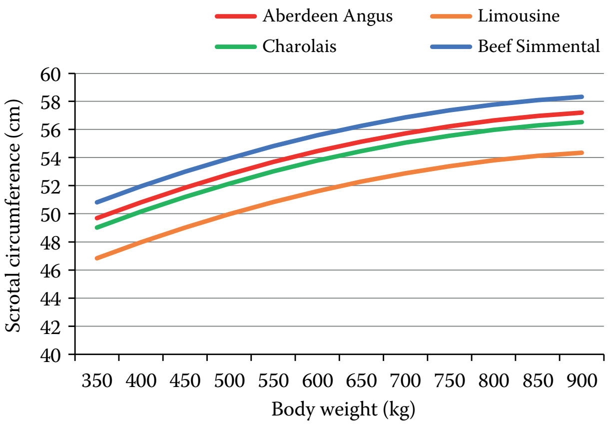

Figure 2. Evaluation of the scrotal circumference in relation to the body weight of a bull for the selected breeds of bulls

trates the relationship of the scrotal circumference to the bull's weight for the four most numerous breeds. It is believed that the scrotal circumference is an even better indicator of sexual maturity than the age or body weight itself (Brinks 2021). The growth of bulls is not linear when it declines with the increasing age (Pribyl et al. 2008a). The scrotal circumference measurement in young animals should ideally be carried out every year until the animal reaches three years of age when the growth intensity decreases and the body development is gradually completed (Menegassi et al. 2019). In the present study, each bull was measured only once, therefore, the growth over time was not investigated. The effect of the breed was not included in the model equation as a separate effect, but it was considered in the group of unknown ancestors. It is cited that differences in the scrotal circumference between breeds are roughly 5–7 cm when bulls with a larger mature size usually have a larger scrotal circumference than breeds with a smaller mature size (Menegassi et al. 2011). In our data file (if average values are used), the difference between breeds was as large as 11 cm. The differences between the breeds were also studied by Geske et al. (1995), who used, for the prediction of the 365-day scrotal circumference, data from the 205-day measurement including various adjustment factors in cm per day for the various breeds.

The growth intensity of a bull is also influenced by the nutrition and management. The bulls whose scrotal circumference was measured were kept for 120 days before the measurement at the breeding bull test stations, where they received standardised nutrition and management. The combined effect of the breeding unit and date of the test completion was used to involve the influence of the factors acting during the test. However, any weight gains during the test can be influenced by the herd management before the bull was included in the test (Pribyl et al. 2008b). Unfortunately, it would be difficult to consider environmental conditions before inclusion in the test as it was not possible to create sufficiently large groups.

The scrotal circumference can slightly change in the course of the year. The circumference is larger in the summer and in the autumn when there is a decrease in the testosterone level, sperm concentration, and individual sperm motility at the same time. The influence on the semen volume was not confirmed (Quezada-Casasola et al. 2016). Compared to breeds originating from tropical and subtropical areas, European breeds of beef cattle are more sensitive to these changes (Quezada-Casasola et al. 2016; Morrell 2020) and, therefore, any changes in the semen quality may limit the use of bulls in hot summer months.

Heritability

The heritability coefficient estimated by the single-trait model for the scrotal circumference was 0.28 (Table 2). This value is consistent with the values of other authors who published heritability coefficients in a range from 0.18 to 0.50 in dependence on the chosen population, breed, and age of the scrotum measurement (Crews and Porteous 2003; Garmyn et al. 2011; McAllister et al. 2011; Buzanskas et al. 2017; Bonamy et al. 2018; Schmidt et al. 2019; da Silva Neto et al. 2020; Martinez-Velazquez et al. 2020). Many authors concluded that the heritability coefficient of the scrotal circumference was usually higher if it was evaluated at an older age. da Silva Neto et al. (2020) and some other authors reported that the heritability coefficient for the scrotal circumference, measured at 365 days of age, was 0.33, but when the scrotal circumference was measured

Table 2. Estimates of the genetic (σ^2_g), environmental (σ^2_e) and phenotypic (σ^2_p) variance and heritability of the scrotal circumference

Trait	σ^2_g	σ^2_e	σ^2_p	h^2 ± SD
Scrotal circumference (cm)	1.91	3.01	6.84	0.28 ± 0.11

https://doi.org/10.17221/84/2022-CJAS

at 450 days of age, it increased to 0.37. A similar trend was published by Buzanskas et al. (2017). Bonamy et al. (2018) evaluated the scrotal circumference (SC) of Aberdeen Angus bulls of different ages. The highest value of the heritability coefficient was obtained for SC in 400 days (0.704 ± 0.07), followed by SC in 630 days (0.576 ± 0.08) and SC in 300 days (0.429 ± 0.07)

Influence of the scrotal circumference on the other productive and reproductive traits

Using the least-squares method, positive phenotype correlations were proven across the breeds between the scrotal circumference and the weight (r = 0.20, P < 0.001), between the scrotal circumference and the contemporary group (r = 0.28, P < 0.001), and between the scrotal circumference and the age in days (r = 0.03, P < 0.001). The genetic correlations of the scrotal circumference with the other traits were not studied. However, moderate to medium positive genetic correlations with the growth at weaning and with the yearling growth have been published (Kluska et al. 2018; Schmidt et al. 2019). A negative genetic correlation of the scrotal circumference with the gestation length (–0.116 ± 0.020), days to calving (–0.084 ± 0.028), and calving interval (–0.054 ± 0.038) was published by Schmidt et al. (2019). A genetic correlation close to zero was related to the heifer fertility (McAllister et al. 2011; Martinez-Velazquez et al. 2020) and heritability of 0.35 and 0.76 for the stayability was reported by Kluska et al. (2018) and Martinez-Velazquez et al. (2020), respectively. Negative correlations were revealed between the age at the first calving and the scrotal circumference (Buzanskas et al. 2017; Bonamy et al. 2018; Kluska et al. 2018). A moderate positive correlation was found between the carcass traits (rump fat, rib eye area, and subcutaneous backfat thickness) and the scrotal circumference at 365 and 450 days of age (Kluska et al. 2018).

Prediction of the breeding values

Figure 1 illustrates the predicted differences in the scrotal circumference in the four most numerous breeds of bulls. The difference in the scrotal circumference between the Limousine and Beef Simmental breeds is up to 4 cm.

Considering the genetic correlations of the scrotal circumference with the reproductive and productive traits, it is expected that the reproduction and growth ability of the animals will be improved within several generations if the selection for bulls with a higher breeding value for the scrotal circumference is carried out.

CONCLUSION

Breeding bulls are selected on the basis of several selection criteria. The scrotal circumference is easily measurable and cheaply available information that can serve as an indicator of a bull's fertility. Genetic variability in the scrotal circumference in the Czech population is sufficiently high enough to introduce selection for this trait. In addition, the trait is genetically correlated with many reproductive and productive traits of beef cattle. Through selection for this trait, it is possible to indirectly influence the reproduction and production of the beef cattle population in the Czech Republic.

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Conflict of interest

The authors declare no conflict of interest.

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