

ESTIMATION OF GENETIC PARAMETERS FOR GROWTH AND MORPHOMETRIC TRAITS IN SAHIWAL CATTLE BREED IN PAKISTAN

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ABSTRACT

Genetic improvement in animals is based on selecting individuals for trait based on direct or indirect measurements. The present study was planned with the objectives of estimating genetic parameters for body weight and various morphometric traits to include them in the selection criteria for Sahiwal cattle. The animals (N=326) of both sexes (180 male and 146 females, from one month to adult age) having pedigree information were selected and body weight (BW), wither height (WH), hip height (HH), body length (BL), heart girth (HG) and paunch girth (PG) were measured thrice after an interval of 15-30 days. Genetic parameters were estimated using an animal model, with sex and five farms as fixed effects, and animal (error) as random effects. WOMBAT software was used for genetic analyses. Heritability estimates of BW, WH, HH, BL, HG and PG were 0.27 ± 0.239 , 0.18 ± 0.171 , 0.33 ± 0.209 , 0.26 ± 0.209 , 0.44 ± 0.23 and 0.54 ± 0.227 , respectively. Genetic correlations of hip height with BW, WH, HH, BL, HG and PG were 0.63 ± 0.772 , 0.99 ± 0.057 , 0.59 ± 0.313 , 0.89 ± 0.119 and 0.92 ± 0.123 , respectively. The Coefficient of determination to predict various body traits ranged between 88% and 97%. BW and HH could be predicted from age with high accuracy in both males ($R^2=95.0$, 93.8%) and females ($R^2=96.3$, 95.6%), respectively. WH and HH were strongly correlated; however, HH had slightly better genetic control and was easier to measure due to its independence from hump. It is concluded that hip height is a good indicator of animal height and can be used as selection criteria for Sahiwal cattle in Pakistan.

Key words: Cattle; Genetic parameters; Biometry; Linear traits

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INTRODUCTION

Sahiwal is a prominent tropical dairy breed in Pakistan, known for its heat tolerance and disease resistance attributes (Khan *et al.*, 2018). Sahiwal has been used in the development of various new breeds, such as Australian Milking Zebu, Karan Swiss, Frieswal, Mafriwal, Jamaica Hope, Taurindicus and Mpwapwa (Rehman *et al.*, 2014). It is also known as transboundary breed present in 29 countries (Rischkowsky & Pilling, 2007).

The major trait of interest has been milk yield during a standard lactation period of 305 days. Type evaluation (Khan & Okeyo, 2016) is expected to be incorporated as an objective trait in future. Body size and condition are critical for improving production efficiency in female livestock (de Lacerda *et al.*, 2018). Animal weight is typically associated with its size (Rosa *et al.*, 2014). The frame index is preferred over conventional criteria for selecting frame size (Sloniewski *et al.*, 2005). Characteristics such as height and mature body weight should be used in selection criteria to control cow size in

a herd (de Lacerda *et al.*, 2018; Silveira *et al.*, 2016). Body size characteristics, such as hip height and frame score, are used for genetic improvement in cattle. Hip height, positively correlated with body size but negatively with productivity, offers a simple and less environmentally affected measure of body size. Cattle reach 80% of mature height and 35-45% of mature weight by 7-8 months, and 90% of mature height and 50-60% of mature weight by 12 months (Baker *et al.*, 1988; Jenkins *et al.*, 1991; Herring, 2014). In improving cattle production, body measurements including body height, body length and back height are used as important indicator in selection criterion (Gritsenko *et al.*, 2023).

Genetic evaluation of body size can be enhanced by assessing HH, and weight at different ages. This approach aids in the selection and improvement of reproductive traits, decision-making for early replacement of breeding animals, and achieving directional changes in cattle size through selection (Vargas, 2000). Although hip height or body weight separately alone cannot fully explain genetic differences in body size, a multiple traits evaluation including body

weight and hip height is likely a better option (Hoffman, 1997).

Data on phenotypic and genetic parameters for body weight, hip height, and the relationship between weight and hip height are lacking in Pakistan. Therefore, this research aims to document genetic parameters, with a particular focus on hip height, to incorporate this trait into selection objectives for Sahiwal cattle.

MATERIALS AND METHODS

Experimental stations: Data were collected from Sahiwal cattle maintained at the following government and private farms. 1) Livestock Production Research

Institute Bahadurnagar (LPRI), Okara (30° 48' 5" North, 73° 26' 54" East). 2) Semen Production Unit Qadirabad (SPU), Sahiwal (30° 13' 18" North, 71° 33' 15" East). 3) Livestock Experiment Station Jahangirabad (LESJ), Khanewal (30° 13' 18" North, 71° 33' 15" East). 4) Livestock Experimental Station Klorkot (LESK), Bhakkar (31° 38' 0" North, 71° 4' 0" East). 5) Jahangirabad Cattle Farm (Watto farm), Khanewal (30° 13' 18" North, 71° 33' 15" East).

Experimental animals: The number of Sahiwal animals of both sexes (from one month to adult age) used in this study is provided in Table.1.

Table. 1. Experimental animals used for data collection

Experimental station	Male	Female	Total
Livestock Experimental Station, Bahadurnagar (Okara)	78	62	140
Livestock Experimental Station, Jahangirabad (Khanewal)	-	50	50
Semen Production Unit, Qadirabad (Sahiwal)	50	-	50
Livestock Experimental Station, Klorkot (Bhakkar)	31	41	62
Jahangirabad Cattle Farm (Khanewal)	21	3	24
Total	180	146	326

Data Collection: The following body traits were measured three times on each experimental animal at 15-30 days intervals in 2017.

a) Body weight: All animals were weighed after an overnight fast using a weighing scale.

b) Hip height: Measured from a point between the first sacral and the last lumbar vertebrae to the floor using a hippometer (height measuring rod)

c) Withers height: Measured from the withers to the ground surface using hippometer

d) Body length: Measured from the shoulder point to the pin bone using measuring tape

e) Heart girth: Measured around the body behind the front legs and slightly behind the shoulders using a measuring tape.

f) Paunch girth: Measured around body posterior to the last rib using a measuring tape

All measurements were recorded in centimeters (cm) and weight in kilograms. Sire and dam record were obtained from breeding record registers.

Statistical analyses

Regression model. Linear and quadratic regression equations were developed to determine the relationships among various body traits. A general quadratic regression model is given below.

$$Y = \alpha + \beta_1 X + \beta_2 X^2$$

Where

Y = dependent variable (e.g., body weight)

X = explanatory variable (e.g., age of the animal)

α = intercept

β = slope

Genetic parameters estimation. Heritability was estimated using WOMBAT software (Meyer, 2006). The mathematical model used was:

$$Y_{ijk} = \mu + A_j + F_j + e_{ijk}$$

Where:

Y_{ijk} = measurement of a particular trait (e.g., hip height)

μ = Overall population mean

A_i = random additive genetic effect of i^{th} animal with mean zero and variance $\sigma^2 A$

F_j = effect of the j -th fixed factor (e.g., sex and farms)

e_{ijk} = random error associated with observation with mean zero and variance $\sigma^2 E$

Heritability Calculation:

The heritability was calculated using the following formula:

$$\text{Heritability } (h^2) = \frac{\sigma^2 A}{\sigma^2 P}$$

Correlation Estimates: Phenotypic, genetic and environmental correlations were estimated using bivariate analyses with individual animal models as follows:

- Phenotypic Correlation (r_p): $r_p = \frac{\text{Cov } P_i P_j}{\sigma P_i \cdot \sigma P_j}$
- Genetic Correlation (r_G): $r_G = \frac{\text{Cov } A_i A_j}{\sigma A_i \cdot \sigma A_j}$

- Environmental Correlation (r_E): $r_E = \frac{Cov E_i E_j}{\sigma E_i \sigma E_j}$
- Where
- $\sigma A_i =$
additive genetic standard deviation for i –
th trait
 - $\sigma P_i =$ phenotypic standard deviation for i –
th trait
 - $\sigma E_i =$ residual standard deviation for the i –
th trait
 - $Cov P_i P_j =$
phenotypic covariance for the traits i and j
 - $Cov A_i A_j =$ additive genetic covariance for the
traits i and j
 - $Cov E_i E_j =$
residual covariance for the traits i and j

RESULTS AND DISCUSSION

Body traits: Means values for body weight, wither height, hip height, body length, heart girth and paunch girth were 192.9kg, 100.9cm, 106.9cm, 92.8cm, 125.3cm and 146.3cm, respectively. Average age for these animals was 512.2 days.

Relationships among various body traits: The curves of body traits against age were sigmoid, with the best fit was obtained using quadratic regression model, where coefficients of determination (R^2) were generally above 90 % (Table.2; Table. 3; Fig.1.). The regression equations for body weight based on heart girth in this study were $Y = -222.0 + 3.1530X$ and $Y = -232.3 + 3.2310X$ and coefficients of determination were 0.932 and 0.943 for males and females, respectively. The regression equation for body weight based on heart girth reported by Putra *et al.* (2015) was $Y = -127.47 + 2.59X$, with coefficient of determination of 0.88. Kashoma *et al.* (2011) reported a regression equation $Y = 4.55X - 409 (\pm 17.9)$ for Tanzania short horn zebu cattle. Bagui & Valdez, (2007) reported coefficient of determination of 0.94 for body weight with heart girth, similar to the present study. Heart girth showed the highest coefficient of determination with body weight (Alsiddig *et al.*, 2010; Bahashwan, 2014; Dim *et al.*, 2012). Tasdemir *et al.* (2011) reported coefficients of determination of 97.72% for wither height, 97.89% for body length, and 98% for height at the hip, higher than those observed in this study. Nesamvuni *et al.* (2000) reported linear regression equations for body weight as $\text{Body weight} = 16.58 + 0.81 \times \text{Heart girth}$ and $\text{Body weight} = -480.00 + 6.47 \times \text{Wither height}$ in Nguni type cattle. R^2 values for regression equations including all traits were 68.2%, 92.2%, and 95.0% for Holstein, Brown Swiss, and Crossbred animals, respectively. Ige *et*

al. (2015) reported R^2 values of 0.83 and 0.81 for body length and 0.69 and 0.67 for hip height in females and males, respectively, which were lower than those observed in the present study.

Genetic parameters estimation

Heritability: Fixed effects included sex and five different farms. Heritability estimates for traits ranged from 0.183 to 0.524. The highest heritability estimate was for paunch girth at 0.524 ± 0.227 , followed by heart girth at 0.439 ± 0.230 (Table 4). The heritability estimates for body length reported by Van-Marle-Köster *et al.* (2000) was 0.22, which is similar to the estimates in the present study. Magnabosco *et al.* (2002) reported a heritability estimate of 0.32 for body length in Brahman cattle, which is slightly higher, while Mantovani *et al.* (2010) reported a lower heritability estimate of 0.21. The weaning body length heritability of Bali cattle was 0.32 to 0.39 (Supriyantono *et al.* 2012). Khan *et al.* (2018) reported heritability estimate of 0.81 ± 0.02 for body length in Sahiwal cows. The differences may be due to the physiological stage at time of data collection and due to sex differences. Heritability estimates for hip height (0.68) and weight (0.49) reported by Arango *et al.* (2002) were higher than those found in the present study. Similarly, Choy *et al.* (2002) reported a high heritability estimate of 0.62 for hip height. Touchberry (1948) reported a heritability estimate of 0.265 for paunch girth in Holsteins, whereas Khan & Khan (2016) reported 0.75 ± 0.02 for experimental Sahiwal cows. Heritability for heart girth reported by Gallo *et al.* (2001) was 0.33, lower than the present study's estimate of 0.439. Touchberry (1951) previously reported higher values (0.61) for Height at Wither were reported by Khan *et al.* (2018). These differences in genetic parametric values for different traits may be due to differences of herds, management, animal's age, and large or small data set used for estimation. In a study on Bali cattle (yearling male), the heritability estimates 0.10 ± 0.02 , 0.50 ± 0.08 , 0.44 ± 0.07 and 0.46 ± 0.07 were observed for chest girth, body weight, body length and body height, respectively (Chaerunissa and Nurgiartiningsih, 2022). The univariate analysis of Brahman cattle data from birth to 600 days of age, presented heritability estimates of 0.28 ± 0.01 to 0.50 ± 0.06 , 0.27 ± 0.01 to 0.43 ± 0.09 , 0.28 ± 0.01 to 0.58 ± 0.08 and 0.34 ± 0.01 to 0.51 ± 0.08 for body weight, heart girth, hip height and body length respectively (Kamprasert *et al.*, 2019), yet heritability estimates were higher with the increasing age. Heritability estimates of 0.21 to 0.36 for body size measurements in Hanwoo steers were reported by Choy *et al.* (2017).

Table 2. Relationship among different body traits in male animals

Traits	Regression equation	R ² (%)
Age (x) and linear body weight (y)	$y = 20.22+0.4592x$	93.9
Age (x) and quadratic body weight (y)	$y = 1.689+0.6580x-0.00029 x^2$	95.0
Wither height (x) and body weight (y)	$y = -350.9+5.1330x$	92.6
Age (x) and wither height (y)	$y = 63.57+0.1759x-0.00014 x^2$	93.8
Hip height (x) and body weight (y)	$y = - 373.1+5.0440x$	90.8
Age (x) and hip height (y)	$y = 68.52+0.1859x-0.00015 x^2$	93.8
Body length (x) and body weight (y)	$y = -229.9+4.4460x$	93.6
Age (x) and body length (y)	$y = 50.30+0.1628x-0.00009 x^2$	93.2
Heart girth (x) and body weight (y)	$y = - 222.0+3.1530x$	93.2
Age (x) and heart girth (y)	$y = 61.95+0.2922x-0.00024 x^2$	93.7
Paunch girth (x) and body weight (y)	$y = - 192.6+2.4430x$	87.6
Age (x) and paunch girth (y)	$y = 66.73+0.3982x-0.00035 x^2$	92.9

Table 3. Relationship among different body traits in female animals

Traits	Regression equation	R ² (%)
Age (x) and linear body weight (y)	$y = 36.75+0.3092x$	92.8
Age (x) and quadratic body weight (y)	$y = 2.301+0.5462x-0.00025 x^2$	96.3
Wither height (x) and body weight (y)	$y = -369.8+5.3810x$	92.4
Age (x) and wither height (y)	$y = 66.63+0.1273x-0.00008 x^2$	95.4
Hip height (x) and body weight (y)	$y = - 396.5+5.3060x$	92.0
Age (x) and hip height (y)	$y = 72.40+0.1309x-0.00008 x^2$	95.6
Body length (x) and body weight (y)	$y = - 225.7+4.3180x$	94.9
Age (x) and body length (y)	$y = 50.30+0.1620x-0.00009 x^2$	93.2
Heart girth (x) and body weight (y)	$y = - 232.3+3.2310x$	94.3
Age (x) and heart girth (y)	$y = 67.71+0.2142x-0.00013 x^2$	96.2
Paunch girth (x) and body weight (y)	$y = - 228+2.7730x$	88.8
Age (x) and paunch girth (y)	$y = 80.23+0.2409x-0.00015 x^2$	91.1

Table 4. Heritability (h²) estimates of body traits

Trait	Heritability estimate (h ²)
Body weight	0.269±0.239
Wither height	0.183±0.171
Hip height	0.331±0.209
Body length	0.257±0.209
Heart girth	0.439±0.230
Paunch girth	0.524±0.227

Correlation among different body traits: Medium to high genetic and phenotypic correlations were found among body traits (Table 5). The highest phenotypic and genetic correlations were observed between hip height and wither height, with values of 0.932 ± 0.008 and 0.999 ± 0.057 , respectively. Environmental correlation between wither and hip height was also high, at 0.912 ± 0.030 (Table 6). Mantovani *et al.* (2010) reported a high genetic correlation of 0.96 between body size and body measurements. Supriyantono *et al.* (2012) reported lower phenotypic correlations for wither height with chest girth and body length at 0.42 and 0.50, respectively, and a chest girth correlation with body length of 0.33, which

are lower than those found in the present study. The correlation of heart girth with hip height was 0.80 in Hereford cattle, similar to the present study's 0.824 ± 0.019 , and 0.54 in crossbred cows as reported by Nelsen *et al.* (1982). Nelsen *et al.* (1985) reported correlations of body weight with hip height and heart girth as 0.82 and 0.94 in Hereford cattle and 0.63 and 0.94 in crossbred cows, respectively, which are higher than those found in the present study. Correlation coefficients for weight with heart girth, body length, and wither height were 0.871, 0.778, and 0.778, respectively, higher than in the present study. The correlation coefficients for heart girth with wither height and body length were the same at 0.782, as reported by Gunawan & Jakaria (2010). The live weight and body size are associated with animal's maintenance requirements (Schmidtman *et al.*, 2023). In Bali cattle moderate to high genetic correlation between body weight and chest girth (0.35), body weight and back height (0.67) and between body weight and body length (0.98) were reported by (Chaerunissa and Nurgartiningih, 2022). The positive genetic correlation (0.25 ± 0.04 to 0.97 ± 0.11) and phenotypic correlation (0.22 ± 0.01 to 0.72 ± 0.01) in Brahman cattle was reported by Kamprasert *et al.* (2019). The genetic correlation of

growth rate (weaning to 24 month of age) and weaning weight was negative (-0.32 ± 0.32) while with 12-month weight was positive (0.00 ± 0.34) in a study on 485 observations recorded on F2 et seq., 112 Brahman, 112 Sahiwal, 314 Brahman and 314 Sahiwal bulls in Queensland, the study also reported genetic correlation of 12-month weight with growth rate in wet season after

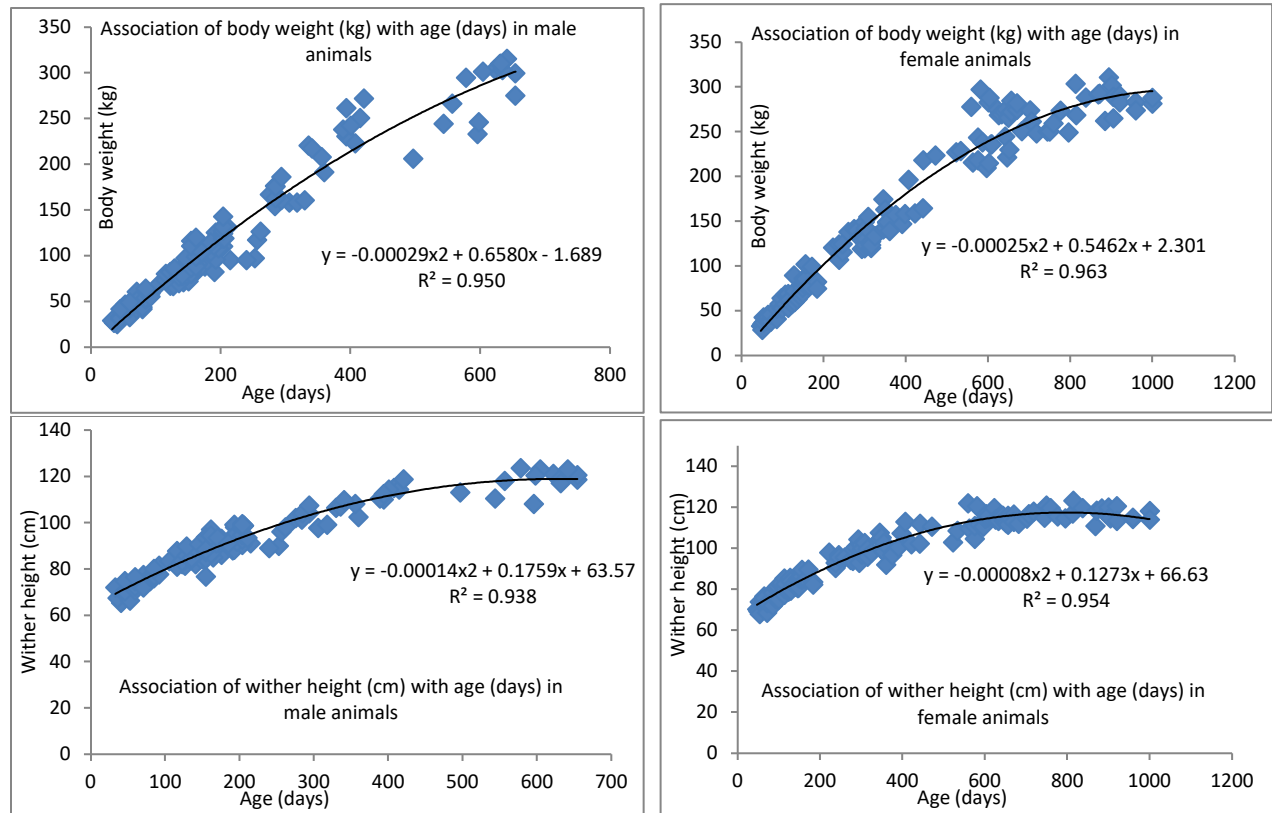
weaning as 0.13 ± 0.47 while for second dry season after weaning as 0.18 ± 0.47 (Fordyce *et al.*, 1996). In Holstein cattle, positive genetic correlation between stature and production traits (0.084-0.158) while negative genetic correlation between stature and body condition score (-0.072) was reported by (Schmidtman *et al.*, 2023).

Table 5. Phenotypic (above diagonal) and genetic (below diagonal) correlations among different body traits

Traits	Body weight	Wither height	Hip height	Body length	Heart girth	Paunch girth
Body weight	1.000	0.561±0.041	0.560±0.041	0.557±0.042	0.657±0.034	0.544±0.042
Wither height	0.625±0.869	1.000	0.932±0.008	0.726±0.030	0.824±0.019	0.755±0.027
Hip height	0.632±0.772	0.999±0.057	1.000	0.730±0.030	0.825±0.020	0.789±0.023
Body length	0.998±0.00	0.585±0.369	0.593±0.313	1.000	0.739±0.028	0.699±0.031
Heart girth	0.917±0.944	0.883±0.147	0.888±0.119	0.896±0.145	1.000	0.856±0.016
Paunch girth	0.888±0.00	0.913±0.227	0.917±0.123	0.864±0.168	0.997±0.057	1.000

Table 6. Environmental correlations among different body traits

Traits	Body weight	Wither height	Hip height	Body length	Heart girth
Wither height	0.574±0.125				
Hip height	0.601±0.135	0.912±0.03			
Body length	0.522±0.148	0.799±0.116	0.812±0.130		
Heart girth	0.682±0.112	0.814±0.075	0.785±0.092	0.638±0.142	
Paunch girth	0.563±0.144	0.707±0.116	0.703±0.123	0.579±0.170	0.742±0.104



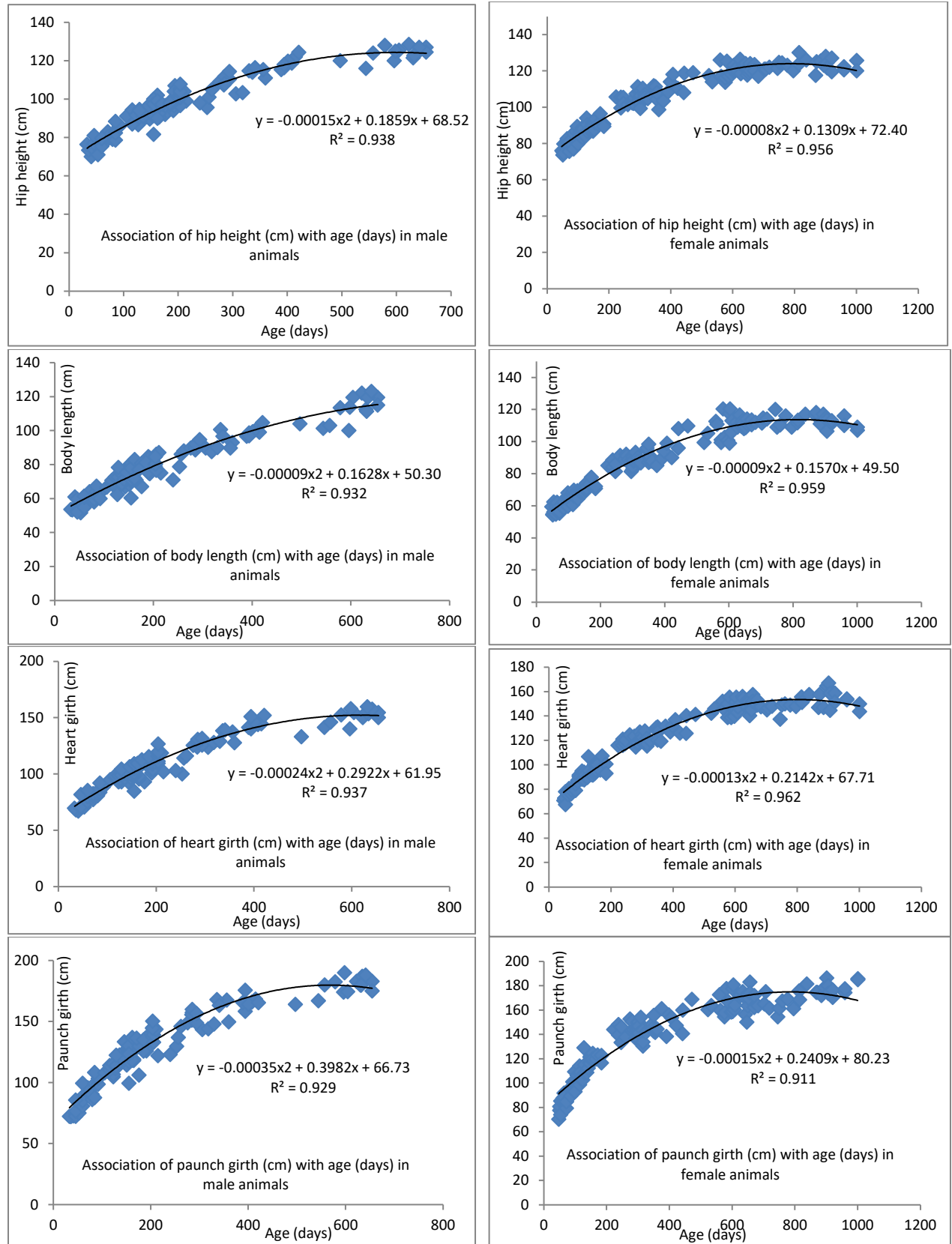


Fig. 1. Association of age with various body parameters in male and female animals

Conclusion: In conclusion, body traits in Sahiwal cattle exhibited strong correlations with one another, and the heritability of hip height was found to be in the medium to high range. The relationship between hip height and age, body weight, wither height, body length, heart girth, and paunch girth were also significant. Therefore, hip height can be effectively used as a selection criterion for improving height in Sahiwal cattle.

Statement of Animal Rights: The manuscript does not contain clinical studies or patient data, so no ethical approval is required.

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REFERENCES

- Alsiddig, M., S. Babiker, M. Galal and A. Mohammed (2010). Phenotypic characterization of Sudan Zebu cattle (Baggara type). *Research J. Animal and Veterinary Sciences*. 5: 10-17. <http://www.aensiweb.net/AENSIWEB/rjavs/rjavs/2010/10-17.pdf>.
- Arango, J., L.V. Cundiff and L.D. Van Vleck (2002). Genetic parameters for weight, weight adjusted for body condition score, height, and body condition score in beef cows. *J. Anim. Sci.* 80(12): 3112-3122. <https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1241&context=animalscifacpub>.
- Bagui, N.J.G. and C.A.Valdez (2007). Live weight estimation of locally raised adult purebred Brahman cattle using external body measurements. *Philipp J Vet Med*. 44(1):36-42.
- Bahashwan, S. (2014). Application of morphometric traits for live body weight estimation in Dhofari calves. *International J. Scientific Research in Agricultural Sciences*. 1(5): 90-96. <http://dx.doi.org/10.12983/ijrsas-2014-p0090-0096>.
- Baker, J., T. Stewart, C. Long and T. Cartwright (1988). Multiple regression and principal components analysis of puberty and growth in cattle. *J. Anim. Sci.* 66(9): 2147-2158. DOI: 10.2527/jas1988.6692147x.
- Chaerunissa, M. and V.A. Nurgartiningasih (2022). A predicted genetic parameter for body weight and body size at yearling age of male Bali cattle. *Jurnal Ilmu-Ilmu Peternakan*. 32(3): 398-406. <https://doi.org/10.21776/ub.jiip.2022.032.03.11>.
- Choy, Y., J. Brinks and R. Bourdon (2002). Repeated-measure animal models to estimate genetic components of mature weight, hip height, and body condition score. *J. Anim. Sci.* 80(8): 2071-2077. DOI: 10.2527/2002.8082071x.
- Choy, Y.H., J.G. Lee, A. Mahboob, T.J. Choi and S.H. Rho (2017). Genetic correlation between live body measurements and beef cutability traits in Hanwoo steers. *Asian-Australas J Anim Sci*. 30(8): 1074-1080. <https://doi.org/10.5713%2Fajas.16.0692>.
- de Lacerda, V.V., G.S. Campos, D.D. Silveira, V.M. Roso, M.L. Santana, F.R. Souza and A.A. Boligon (2018). Genetic associations between mature size and condition score of Nelore cows, and weight, subjective scores and carcass traits as yearlings. *Anim. Prod. Sci.* 59(7): 1209-1217. <https://doi.org/10.1071/AN17873>.
- Dim, N., J. Egahi and M.Tanko (2012). Zoometrical measurements of body parts and their relationship with live weight in Bunaji cows in Zaria, Nigeria. *International J. Advanced Biological Research*. 2(2): 339-341. [http://www.scienceandnature.org/IJABR/IJABR_Vol2\(2\)2012/IJABR_V2\(2\)27.pdf](http://www.scienceandnature.org/IJABR/IJABR_Vol2(2)2012/IJABR_V2(2)27.pdf).
- Fordyce, G., C. J. Howitt, R. G. Holroyd, P. K. Orouke and K. W. Entwistle (1996). The performance of Brahman-Shorthorn and Sahiwal-Shorthorn beef cattle in the dry tropics of northern Queensland 5. Scrotal circumference, temperament, ectoparasite resistance, and the genetics of growth and other traits in bulls. *Aust. J. Exp. Agric.* 36: 9-17. <https://doi.org/10.1071/EA9960009>.
- Gallo, L., P. Carnier, M. Cassandro, R. Dal Zotto and G. Bittante (2001). Test-day genetic analysis of condition score and heart girth in Holstein Friesian cows. *J. Dairy Sci.* 84(10): 2321-2326. [https://doi.org/10.3168/jds.S0022-0302\(01\)74680-2](https://doi.org/10.3168/jds.S0022-0302(01)74680-2).
- Gunawan, A. and J. Jakaria (2010). Application of linear body measurements for predicting weaning and yearling weight of Bali cattle. *Anim. Prod.* 12(3):163-168. <https://www.animalproduction.net/index.php/JA/P/article/viewFile/287/276>.
- Gritsenko, S., A. Ruchay, V. Kolpakov, S. Lebedev, H.Guo and A.Pezzuolo (2023). On-barn forecasting beef cattle production based on

- automated non-contact body measurement system. *Animals* (Basel). 13(04): 611. <https://doi.org/10.3390/ani13040611>.
- Herring, A.D. 2014. Beef cattle production systems. CABI. <https://doi.org/10.1079/9781780645070.0001>.
- Hoffman, P. 1997. Optimum body size of Holstein replacement heifers. *J Anim Sci.* 75(3): 836-845. DOI: 10.2527/1997.753836x.
- Ige, A., T. Adedeji, L.Ojedapo, S.Obafemi and O. Ariyo (2015). Linear body measurement relationship in white Fulani cattle in derived savannah zone of Nigeria. *J. Biology, Agriculture and Healthcare.* 5(15): 1-6. <https://core.ac.uk/download/pdf/234661601.pdf>.
- Jenkins, T., M. Kaps, L. Cundiff and C. Ferrell (1991). Evaluation of between-and within-breed variation in measures of weight-age relationships. *J Anim Sci.* 69(8): 3118-3128. DOI: 10.2527/1991.6983118x.
- Kashoma, I., C. Luziga, C. Werema, G. Shirima and D. Ndossi (2011). Predicting body weight of Tanzania shorthorn zebu cattle using heart girth measurements. *Livestock Res Rural Dev.* 23(4): 2011. <http://www.lrrd.org/lrrd23/4/kash23094.htm>.
- Kamprasert, N., N. Duijvesteijn and J.H.J. Van der Werf (2019). Estimation of genetic parameters for BW and body measurements in Brahman cattle. *Animal.* 13(8): 1576-1582. <https://doi.org/10.1017/S1751731118003348>.
- Khan, M.A., M.S. Khan and A.Waheed (2018). Morphological measurements and their heritabilities for Sahiwal cattle in Pakistan. *J. Anim. Plant Sci.* 28(2): 431-440. <https://thejaps.org.pk/Volume/2018/28-02/abstract/08.php>.
- Khan, M.S. and A. Okeyo (2016). Judging and selection in Beetal goats. GEF-UNEPILRI FAnGR Asia Project, University of Agriculture Faisalabad, Pakistan. <https://uaf.edu.pk/oubm/Files/books/Beetal%20Goats%20Judging%20and%20Selection.pdf>.
- Khan, M.A. and M.S. Khan (2016). Heritability, genetic and phenotypic correlations of body capacity traits with milk yield in Sahiwal cows of Pakistan. *Pakistan J. Life Soc. Sci.* 14(2): 77-82. https://www.pjlss.edu.pk/pdf_files/2016_2/77-82.pdf.
- Meyer, K. (2006). WOMBAT – A program for mixed model analyses by restricted maximum likelihood. User notes. Animal Genetics and Breeding Unit, University of New England Armidale, NSW 2351, Australia. <https://forge-dga.jouy.inra.fr/attachments/download/4788/WombatManual.pdf>.
- Magnabosco, C., M. Ojala, A. De los Reyes, R. Sainz, A. Fernandes and T. Famula (2002). Estimates of environmental effects and genetic parameters for body measurements and weight in Brahman cattle raised in Mexico. *J. Anim. Breed. Genet.* 119(4): 221-228. <https://doi.org/10.1046/j.1439-0388.2002.00339.x>.
- Mantovani, R., M. Cassandro, B. Contiero, A. Albera and G. Bittante (2010). Genetic evaluation of type traits in hypertrophic Piemontese cows. *J. Anim. Sci.* 88(11): 3504-3512. <https://doi.org/10.2527/jas.2009-2667>.
- Nelsen, T., C. Long and T. Cartwright (1982). Postinflection growth in straightbred and crossbred cattle, II, relationships among weight, height and pubertal characters. *J. Anim. Sci.* 55(2): 293-304. <https://doi.org/10.2527/jas1982.552293x>.
- Nelsen, T., R. Short, W. Reynolds and J. Urlick (1985). Palpated and visually assigned condition scores compared with weight, height and heart girth in Hereford and crossbred cows. *J. Anim. Sci.* 60(2): 363-368. <https://doi.org/10.2527/jas1985.602363x>.
- Nesamvuni, A., J. Mulaudzi, N. Ramanyimi and G. Taylor (2000). Estimation of body weight in Nguni-type cattle under communal management conditions. *S. Afr. J. Anim. Sci.* 30(1-1): 97-98. <https://doi.org/10.4314/sajas.v30i4.3927>.
- Putra, W., S. Sumadi, T. Hartatik and H. Saumar (2015). Relationship between body weight and body measurements of Aceh cattle. *Mal. J. Anim. Sci.* 18(1): 35-43. https://www.msap.my/pdf/mjas_18_1/3%20Putra.pdf.
- Rehman, Z., M. Khan and M.A. Mirza (2014). Factors affecting performance of Sahiwal cattle-a review. *J. Anim. Plant Sci.* 24(1):1-12. <https://thejaps.org.pk/docs/v-24-1/01.pdf>.
- Rischkowsky, B. and D. Pilling (2007). The state of the world's animal genetic resources for food and agriculture. Food and Agriculture Org. <https://www.fao.org/4/a1250e/a1250e.pdf>.
- Rosa, B.L., A.A.M. Sampaio, E.A. de Oliveira, W. Henrique, T.M. Pivarro, A.T. de Andrade, A.R.M. Fernandes and D.A. Mota (2014). Correlations between body measurements and carcass characteristics of Nellore young bulls finished in confinement. *Bol. Ind. Anim.* 71(4): 371-380. <https://doi.org/10.17523/bia.v71n4p371>.
- Schmidtman, C., D. Segelke, J. Bennewitz, J. Tetens and G.Thaller (2023). Genetic analysis of production traits and body size measurements and their relationships with metabolic diseases in German Holstein cattle. *J Dairy Sci.* 106 (1):

- 421-438. <https://doi.org/10.3168/jds.2022-22363>.
- Silveira, D., L. De Vargas, V. Roso, G. Campos, F. Souza and A. Boligon (2016). Genetic study of visual scores and hip height at different ages in Nelore cattle. *Anim. Prod. Sci.* 57(4): 614-621. <https://doi.org/10.1071/AN15657>.
- Sloniewski, K., I.Mao, J. Jensen and P. Madsen (2005). Changes in body weight and frame and its genetic variation during the productive life of dairy cows. *Acta Agric Scand. Section A*, 55(4): 128-136. <https://doi.org/10.1080/09064700500478564>.
- Supriyantono, A., M. Tomiyama and K. Suzuki (2012). Estimation of (co) variance components and genetic parameter of withers height, chest girth and body length of Bali cattle using animal model. *International J. Molecular Zoology*, 2(5): 45-50. <https://www.researchgate.net/publication/280768804>.
- Tasdemir, S., A. Urkmez and S. Inal (2011). Determination of body measurements on the Holstein cows using digital image analysis and estimation of live weight with regression analysis. *Comput. Electron. Agric.* 76(2): 189-197. <https://doi.org/10.1016/j.compag.2011.02.001>.
- Touchberry, R.W. (1951). Genetic correlations between five body measurements, weight, type and production in the same individual among Holstein cows. *J Dairy Sci.* 84: 242-255. [https://doi.org/10.3168/jds.S0022-0302\(51\)91701-8](https://doi.org/10.3168/jds.S0022-0302(51)91701-8).
- Touchberry, R.W. (1948). Genetic correlations in five body measurements, weight, type, and production of Holstein cows. Retrospective Theses and Dissertations. 12426. Ph.D. Thesis. Iowa State University. <https://doi.org/10.31274/rtd-180813-13696>.
- Van-Marle-Köster, E., B.E. Mostert and J. Van der Westhuizen (2000). Body measurements as selection criteria for growth in South African Hereford cattle. *Arch. Anim. Breed.* 43(1): 5-16. <https://doi.org/10.5194/aab-43-5-2000>.
- Vargas, C. (2000). Estimation of phenotypic and genetic relationships among hip height and productive and reproductive performance in Brahman cattle. PhD Dissertation. Gainesville, University of Florida. https://ufl-flvc.primo.exlibrisgroup.com/permalink/01FAL-SC_UFL/pek2if/cdi_proquest_journals_304587027.