



Multivariate analysis of biometric traits and their shared variance in Chhattisgarhi buffalo

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Received: 2 January 2017; Accepted: 16 February 2017

ABSTRACT

Principal component analysis (PCA) with a varimax rotation was applied to 18 highly inter-correlated body biometric traits in 157 adult female water buffalo from Chhattisgarh state of India to deduce the components that control body conformation, suitable for use in buffalo breeding, and to reveal the main sources of their shared variability. First principal component explained 34.47% of total variance in body biometric traits and can be used in the evaluation and comparison of body morphology in female water buffaloes using body height, neck circumference, rump width, leg length, paunch girth, chest girth and tail length. The shared variability due to common variance ranged from 92% (horn length) to 51% (rump length) whereas 8 to 49% of their variation was contributed by unique variance specific for each trait in Chhattisgarhi buffaloes.

Key words: Biometric traits, Buffalo, Morphology, PCA, Shared variance

An animal's breed characteristics and its characterization can be ascertained by recording a number of physical and morphological traits. Phenotypic characterization is the prerequisite of a population or a breed to provide overall picture of its diversity within a species. European Association of Animal Production (EAAP), and Food and Agriculture Organization (FAO 2012) have used wither height as a prime indicator of type (Simon and Buchenauer 1993). In addition to breed characteristic, body biometry is an indicator of growth, size, conformation and body condition score in livestock. Accurately measured body shapes could also improve selection for growth by enabling the breeder to recognize early-maturing and late-maturing animals of different size (Brown *et al.* 1973, 1974). Thus, morphological characterization forms an important aspect of breed characterization and animal production.

A multivariate technique of principal component analysis is a data reduction technique used to highlight variation in a dataset. PCA reveal patterns in dataset for an easy visualization and a better understanding. PCA have been successfully employed to highlight the breed morphology, differences due to age and sex and significant differences

in different body measurement/biometric traits in different breeds and species were reported by Gilbert *et al.* (1993), Shahin *et al.* (1995) and Yakubu *et al.* (2009) in cattle; Shahin *et al.* (1993) in Egyptian buffalo and Vohra *et al.* (2015) in Indian buffalo; Biedermann and Schmucker (1989), Jakubec *et al.* (1999), Miserani *et al.* (2002) and Sadek *et al.* (2006) in horses; and Salako *et al.* (2006) and Mishra *et al.* (2017) in sheep.

Large number of morphological traits are prerequisite to explain the body conformation characteristic for a breed or a population but these biometric traits are often highly correlated among themselves conveying more or less the same meaning. An attempt is being made to study and identify significant morphological traits using dimension reduction technique of classical principal component analysis which involves extracting linear composites of observed variables with component scores to define those measures which can best represent body morphology or breed characteristics and shared variance in Chhattisgarhi buffaloes with an aim to minimize the number of traits for morphological evaluation in buffaloes which can reduce the cost, labour and time.

MATERIALS AND METHODS

Population: Chhattisgarhi buffaloes (Fig.1) are physically uniform and distinct buffalo population and their breeding tract includes Kawardha, Korba, Sarguja, Balrampur, Jashpur, Bilaspur, Pendra, Mahasumund, Kawardha, Bemetra, Dhamtari and Kanker blocks/locations of Chhattisgarh state, which is distributed between 23.1355°N and 20.1990°N Latitude and 83.1818°E to

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Fig. 1. Adult female Chhattisgarhi buffalo with typical phenotype and Characteristic horn orientation. The area in red indicates the breeding tract of these buffaloes in India.

81.0755°E Longitude. Buffaloes in Chhattisgarh constitute 14.5% of the total livestock in the state. Murrah and Nagpuri buffalo are the only registered breeds of buffalo available in the state. About 93.67% of buffaloes in the state are non-descript (DAHD&F 2013) which may include Chhattisgarhi buffaloes along with extant breeds and their grades.

Traits recorded: Eighteen different body morphological traits which are used to describe the body biometry in buffaloes were recorded in 157 Chhattisgarhi animals from its breeding tract. Traits included were height at withers (BH), leg length (Leg), neck length (NL), neck circumference (NC), body length (BL), chest girth (CG), paunch girth (PG), face length (FL), face width (FW), ear length (EL), horn length (HL), horn circumference (HC), rump width (RW), rump length (RL), pin bone width (PB), tail length (TL), tail length up to switch (TUS). Only adult (3.0 yr and above) buffaloes were studied in order to avoid the effect of age and sex. All the measurements were recorded once in upright animal standing on a level ground and by the same technical person to avoid between-recorder effects. All the biometric traits were measured with measuring tape.

Statistical analysis: To study the effect of location on all recorded body measurements, data were analysed using first model of Harvey (Harvey 1987).

$$\text{Model: } Y_{ij} = \mu + L_i + e_{ij}$$

Where, Y_{ij} , observation of one of the 18 biometric traits; μ , overall mean; L_i , fixed effects of a block/location while e_{ij} is the random residual error associated with each observation $\sim \text{NID}(0, \sigma^2)$. The least square analysis revealed absence of significant effect of different location on biometric traits.

Principal component analyses: The objective of principal component analyses is to account for the maximum portion of the variance present in the original set of variables with a minimum number of synthetic variables. Varimax rotation was used for rotation of principal components through the transformation of the components to approximate a simple

structure. Kaiser-Meyer-Olkin (KMO) test of sampling adequacy and Bartlett's test of sphericity were computed to establish the validity of data set, at 1% level of significance.

All the analysis were carried out using the SPSS (2001) statistical package for social sciences statistics.

RESULTS AND DISCUSSION

Place or location of the animal in breeding tract did not affect the morphological traits. Average of biometric traits (cm) in Chhattisgarhi buffaloes were 123.48±0.40 (BH), 79.94±0.25 (Leg), 120.57±0.50 (BL), 176.51±0.69 (CG), 193.6±0.82 (PG), 43.73±0.16 (FL), 18.28±0.09 (FW), 51.06±0.89 (HL), 18.11±0.13 (HC), 15.57±0.11 (DBH), 25.37±0.12 (EL), 45.81±0.72 (NL), 73.63±0.68 (NC), 46.62±0.24 (RW), 18.89±0.22 (PB), 38.50±0.19 (RL), 83.39±0.68 (TUS) and 94.15±0.85 (TL), respectively. In Gojri buffalo, Vohra *et al.* (2015), reported higher estimates for BH (128.66), BL (133.33), CG (195.91), PG (213.91), FL (48.58), FW (22.23), EL (28.76), RW (53.58) and PB (24.29). In Murrah buffalo, the averages of BL, BH, and CG were 148, 133 and 202 cm, respectively (<http://www.buffalopedia.cirb.res.in>). In Nilli Ravi buffalo, Nivsarkar *et al.* (2000) also reported on an average higher estimates of BH, CG and BL as 134.2, 207.7 and 165.4 cm respectively, whereas Ahmad *et al.* (2013) reported BH to be 140.2±7.2 cm in Nilli Ravi females. According to Kataria *et al.* (2007), Nagpuri buffalo had BH, BL and CG as 123.6, 121.21 and 175.02, respectively. Body biometric estimates in Kalahandi buffalo were reported as 172.11 (CG), 122.16 (BL) and 123.77 (BH) (Dash *et al.* 2009). Thus, based on comparison of biometric traits like average height, chest girth and body length, Chhattisgarhi buffalo is comparable with Kalahandi buffalo and is lighter, smaller, shorter and medium sized buffalo than Murrah, Nilli Ravi, Nagpuri and Gojri buffaloes.

Coefficient of variation for different biometric traits ranged from 1.02 to 92.19%. The FW (1.02%), DBH (1.5%) and EL (1.8%) in Chhattisgarhi buffaloes were found to be most consistent morphological traits in the studied population. Horn length (92%) and tail length (82%) showed maximum variability and least consistency among the studied traits. It may be due to the fact that either selection was not applied for these traits in the past or these body parts respond more to the environment compared to the other traits. In Gojri buffaloes, Vohra *et al.* (2015) reported more variability (18.01%) in the tail length. Face width on the other hand, had little variability which may be due to the fact that it is a cephalic measurement and its close association with cranial bone leads to limited scope in variability. Majority of body measurements showed less variability, indicating that the Chhattisgarhi buffaloes are almost similar in their body size.

Among various biometric traits, correlation coefficient were estimated, which ranged between -0.47 (pin bone width and neck length) to 0.80 (tail up to switch and tail length). Besides tail, a high positive correlations were also

observed for body height with leg length, and body length and neck circumference. A total of 171 correlations (in all combinations) were estimated. Among the correlations estimated, 127 were significant, and out of which, 156 were positive (Table 1). These positive and significant ($P < 0.05/0.01$) correlations among different biometric traits suggest high predictability among the different traits. Body height had significant higher correlations with Leg, NC, CG, PG, RL and TL, while it showed lowest correlations with HL, NL and EL which was nonsignificant. Another important trait body length had shown higher correlations with CG and PG, while it had the lowest correlation with FL. The face length had positive correlation with face width and pin bone. The neck length had small negative correlations with NC, FL, HL, FW and PB. Face length showed negative but significant correlation with TL and TUS.

PCA was applied to 18 body biometric traits in Chhattisgarhi buffalo and Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was obtained as 0.74.

Varimax, the widely used and accepted method of rotation was applied (Fernandez 2002) as it maximizes the sum of the variances of the squared loadings (squared correlations between variables and components). The estimate of sampling adequacy Kaiser-Meyer-Olkin (KMO) revealed the proportion of the variance in different biometric traits caused by the underlying components (Kaiser 1958). The overall significance of the correlation matrix was tested with Bertlett's test of sphericity for the biometric traits and chi-square was 1.164.64, and was significant ($P < 0.01$), which means correlation matrix is not an identity matrix and provided enough support for the validity of the component analysis of data. Sampling adequacy (MSA) below 0.5 is not acceptable and KMO-MSA greater than 0.5 is must for satisfactory analysis to proceed. Pundir *et al.* (2011) reported higher estimates of sampling adequacy (0.89) in Kankrej cows. Yakuba *et al.* (2009) also reported higher estimates of sampling adequacy (0.90 and 0.92) in age groups of 1.5 to 2.4 years and 2.5 to 3.6 years, respectively,

Table 1. Phenotypic correlation among 18 different body biometry traits in Chhattisgarhi buffaloes

Trait	BH	LEG	NL	NC	BL	CG	PG	FL	FW
BH	1								
LEG	0.765**	1							
NL	0.103	0.195*	1						
NC	0.583**	0.515**	-0.104	1					
BL	0.361**	0.235**	0.139	0.432**	1				
CG	0.536**	0.4**	0.1	0.52**	0.512**	1			
PG	0.563**	0.524**	0.162*	0.544**	0.459**	0.582**	1		
FL	0.353**	0.314**	-0.385**	0.435**	0.186*	0.217*	0.387**	1	
FW	0.229**	0.2*	-0.401**	0.182*	-0.081	0.15	0.14	0.49**	1
EL	0.113	0.074	0.019	0.105	0.438**	0.236**	0.039	0.017	-0.033
HL	0.027	0.077	-0.076	0.173*	-0.09	0.223**	0.092	0.141*	0.138
HC	0.417**	0.444**	0.24**	0.419**	0.305**	0.345**	0.298**	0.206**	0.222**
DBH	0.378**	0.415**	0.16*	0.35**	0.138*	0.257**	0.375**	0.391**	0.507**
RW	0.632**	0.45**	0.057	0.563**	0.465**	0.502**	0.47**	0.237**	0.186*
PB	0.364**	0.267**	-0.474**	0.399**	-0.109	0.146	0.226**	0.488**	0.59**
RL	0.546**	0.543**	0.129	0.442**	0.252**	0.265**	0.454**	0.32**	0.098
TL	0.530**	0.461**	0.106	0.565**	0.45**	0.503**	0.399**	-0.039**	0.039
TUS	0.448**	0.368**	0.09	0.468**	0.335**	0.441**	0.319**	-0.092**	-0.002

Trait	EL	HL	HC	DBH	RW	PB	RL	TL	TUS
EL	1								
HL	0.037	1							
HC	0.104	0.084	1						
DBH	-0.105	0.123	0.359**	1					
RW	0.159*	0.17*	0.494**	0.362**	1				
PB	-0.185*	0.284**	0.004	0.406**	0.435**	1			
RL	-0.033	0.175*	0.265**	0.244**	0.589**	0.324**	1		
TL	0.099	0.028	0.305**	0.216*	0.439**	0.066	0.261**	1	
TUS	0.062	0.107	0.136	0.079	0.407**	0.047	0.359**	0.833**	1

The lower triangle shows the phenotypic correlation among the different biometric traits with superscripts showing their respective level of significance i.e. ** means $P < 0.01$ and * means $P < 0.05$ respectively. BH, Height at withers; Leg, leg length; NL, neck length; NC, neck circumference; BL, body length; CG, chest girth; PG, paunch girth; FL, face length; FW, face width; EL, ear length; HL, horn length; HC, horn circumference; RW, rump width; PB, pin bone width; RL, rump length; TL, tail length; TUS, tail length up to switch

Table 2. Total variance explained by different components in Chhattisgarhi buffalo (N=157).

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.206	34.479	34.479	6.206	34.479	34.479	3.734
2	2.645	14.695	49.174	2.645	14.695	49.174	3.223
3	1.412	7.846	57.020	1.412	7.846	57.020	2.706
4	1.331	7.392	64.412	1.331	7.392	64.412	1.801
5	1.030	5.722	70.135	1.030	5.722	70.135	1.160
6	0.972	5.400	75.535				
7	0.794	4.410	79.945				
8	0.671	3.728	83.673				
9	0.630	3.499	87.172				
10	0.511	2.838	90.010				
11	0.440	2.443	92.453				
12	0.308	1.714	94.166				
13	0.278	1.546	95.712				
14	0.222	1.233	96.945				
15	0.187	1.038	97.984				
16	0.147	0.816	98.800				
17	0.123	0.682	99.481				
18	0.093	0.519	100				

N, number of adult buffaloes.

for White Fulani cattle. In Gojri buffaloes, Vohra *et al.* (2015) reported similar (0.74) sampling adequacy but they had studied less number of biometric traits.

Among the 18 principal components, 5 components were extracted using Kaiser Rule criterion (Johnson and Wichern 1982) to determine the number of components i.e. retaining only the components that have Eigen value greater than 1 (Table 2). There could be more than one criterion to decide how many components to be used for analysis. Scree plot could be one such criteria which can be used to decide the actual number of the components to be included for analysis, and components having Eigen values up to the point “bent of elbow” are usually considered (Fig. 2) in analysis. In present study, the identified five components could explain cumulative percentage of variance of 70.13%. First component accounted for 34.47% of the variation. It was represented by significant positive high loading of body height, neck circumference, rump width, leg length, paunch girth, chest girth, tail length and rump length. First component seemed to be explaining the maximum of general body conformation in these buffaloes. The second component explained 14.69% of total variance with high loading of pin bone width, face width and face length. Third component explained 7.84% of variance and showed high component loadings for neck length and distance between horns. The fourth component also accounted for around 7.3% of total variability with comparatively higher loading for ear length and body length (Table 2). The fifth component explained the least variability (5.72%) with high loading for horn length. In Gojri buffalo, Vohra *et al.* (2015) reported that BH, BL, FL, FW, HL and CG represent the first component with 31.45% of total variability using 13

morphological parameters. In Egyptian buffalo bull, Shahin *et al.* (1993) reported that most of the common variability (88%) in body dimensions could be accounted for by components representing general size, body depth and height and head width. Tolenkomba *et al.* (2013) used factor analysis with promax rotation in Manipur cattle of India which revealed 6 components and explained about 69.77% of total variation, with first component explaining 21.93% of total variation and was represented by significant positive high loading of height at wither, body length, heart girth, paunch girth and ear length. The proportion of total variance explained by first component was more in our study (34.47%) compared to Tolenkomba *et al.* (2013). Varimax is a method of rotation of components and was used to simplify the interpretation of component analysis. Table 3 indicate the rotated five components. The first component was represented by significant positive high loading of leg length, distance between horns, horn circumference, body height, rump length and rump width. The second component had high loading of tail up to switch, tail length and neck circumference. Third component showed high component loadings for neck length, pin bone width, face width and face length. The fourth component showed comparatively higher loading for ear length and body length. The fifth component explained the least variability with high loading for horn length.

Communalities indicate the amount of variance in each variable that is accounted for. The shared variance ranged from 0.92 (horn length) to 0.51 (rump length) and unique variance ranged from 0.08 to 0.49 for all these 18 different biometric traits (Table 4). The relatively higher estimates of shared variance in horn length, neck length, tail length

Table 3. Extracted and rotated principal component matrix for biometric traits in Chhattisgarhi buffalo

Trait	Extracted Principal Components					Rotated Principal Components				
	1	2	3	4	5	1	2	3	4	5
Body height	0.835	-0.033	0.113	-0.046	-0.153	0.634	0.529	0.202	0.103	-0.058
Neck circumference	0.796	0.039	-0.186	-0.061	-0.044	0.415	0.570	0.335	0.242	0.088
Rump width	0.781	-0.024	-0.016	0.008	0.142	0.542	0.449	0.180	0.233	0.220
Leg length	0.749	-0.030	0.306	-0.039	-0.087	0.705	0.396	0.098	-0.017	-0.028
Paunch girth	0.728	-0.066	0.089	0.110	-0.040	0.594	0.367	0.137	0.223	0.002
Chest girth	0.701	-0.203	-0.223	0.103	0.160	0.375	0.469	0.079	0.459	0.201
Tail length	0.664	-0.402	-0.198	-0.382	-0.187	0.201	0.870	-0.065	0.125	-0.070
Rump length	0.644	0.036	0.219	-0.166	0.142	0.551	0.377	0.098	-0.077	0.225
Tail up to switch	0.573	-0.397	-0.244	-0.551	-0.072	0.064	0.913	-0.105	0.023	0.069
Horn circumference	0.556	-0.103	0.307	0.337	0.100	0.688	0.039	-0.040	0.243	0.039
Body length	0.546	-0.430	-0.320	0.401	-0.106	0.272	0.350	-0.053	0.730	-0.159
Distance between horns	0.541	0.336	0.416	0.155	-0.040	0.702	-0.019	0.314	-0.114	0.003
Pin bone width	0.441	0.745	-0.101	-0.229	0.021	0.197	0.180	0.786	-0.241	0.254
Face width	0.339	0.701	-0.043	0.104	-0.127	0.253	-0.064	0.750	-0.070	0.019
Neck length	0.468	0.604	-0.097	0.331	-0.114	0.372	-0.079	0.733	0.185	-0.010
Ear length	0.066	-0.633	0.644	0.109	0.193	0.489	-0.060	-0.790	-0.040	-0.007
Ear length	0.153	-0.310	-0.494	0.554	0.170	-0.054	-0.013	-0.052	0.831	0.066
Horn length	0.205	0.244	-0.126	-0.180	0.878	0.057	0.033	0.115	0.017	0.950

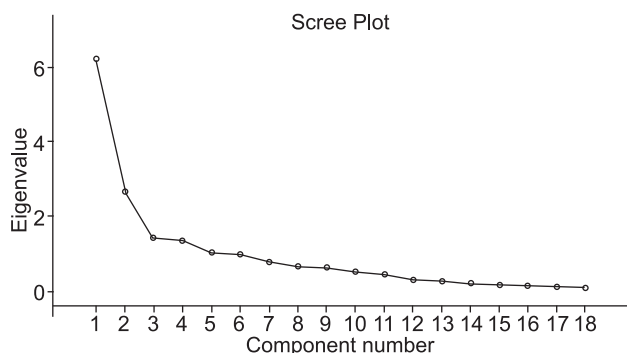


Fig. 2. Scree plot showing component number with Eigen values.

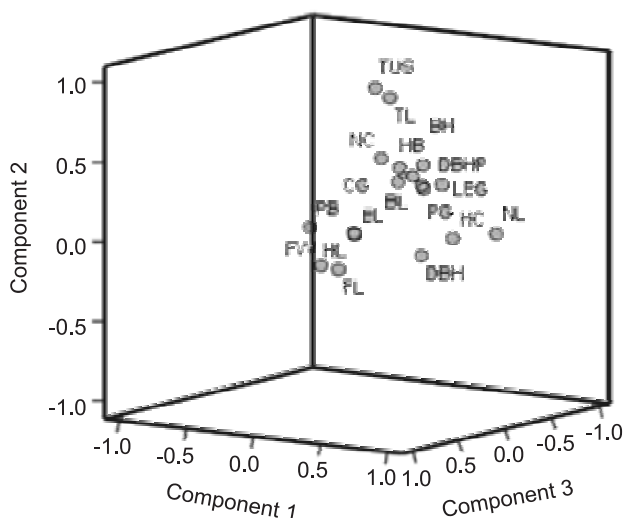


Fig. 3. Component plot in rotated space showing different biometric traits.

and pin bone width indicates that selection for improving any one of them could result in simultaneous improvement in the remaining body biometric traits in Chhattisgarhi buffaloes. According to Shahin *et al.* (1993) in Egyptian buffalo, body conformation appeared to be controlled by shared and unique variance and communalities ranged from 0.96 (height at hips, height at withers) to 0.78 (rump width) and the uniqueness (special size factors) made the balance. In Gojri buffaloes, Vohra *et al.* (2015) reported the communality ranged from 0.83 (RW) to 0.44 (HL). The lower estimates of communalities of rump length and horn circumference indicates that they did not explain the body conformation in Chhattisgarhi buffaloes. Component matrix indicate that the first principal component can be used in the evaluation and comparison of body biometry in female buffaloes using body and leg length, neck, heart girth, paunch girth and rump width and its distance with pin bone width. Our findings were similar to Vohra *et al.* (2015) and Tolankhomba *et al.* (2013) where they reported that first factor explained 31.45% and 34.47% of total variation in Gojri buffalo and Manipur cattle, respectively. However, literature is scanty on component analysis of body conformation traits and not much is available for to compare among water buffaloes.

In conclusion, body conformation or body condition score is one of the selection and management criteria in livestock and the results indicate that principal component analysis can be successfully applied as a data reduction technique for body conformation traits in buffalo breeding programme. The positive and significant correlations among different biometric traits suggest high predictability among them, and also making biometric traits amenable for analysis through PCA. Results of PCA suggest that the use of orthogonal synthetic variable i.e. first principal component

Table 4. Communalities and unique variance of biometry traits in Chhattisgarhi buffalo

Trait	Communalities	Unique variance
Horn length	0.921	0.079
Neck length	0.869	0.131
Tail up to switch	0.854	0.146
Tail length	0.823	0.177
Pin bone width	0.812	0.188
Body length	0.758	0.242
Body height	0.736	0.264
Face length	0.716	0.284
Ear length	0.700	0.300
Neck circumference	0.675	0.325
Leg length	0.665	0.335
Face width	0.635	0.365
Rump width	0.631	0.369
Chest girth	0.619	0.381
Distance between horns	0.604	0.396
Paunch girth	0.557	0.443
Horn circumference	0.538	0.462
Rump length	0.511	0.489

seemed to be explaining the maximum of general body conformation in Chhattisgarhi buffaloes and provided a means of reduction in the number of biometric traits to be recorded in buffaloes which could be used in explaining their body conformation and can further be used in phenotypic selection as a means to explain body conformation of better early maturing buffaloes to be used in breeding programmes.

ACKNOWLEDGEMENT

Authors wish to thank Director, ICAR-NBAGR for providing financial and logistic support to carry out the work and sincere gratitude to all the livestock keepers who allowed measurements of their buffaloes. Special thanks to Mr. Subhash Chander, NBAGR for taking meticulous biometric measurements of animals under study.

REFERENCES

- Ahmad N, Abdullah M, Javed K, Khalid M S, Babbar M E, Younas U and Nasrullah. 2013. Relationship between body measurements and milk production in Nili Ravi buffaloes maintained at commercial farms in peri-urban vicinity of Lahore. *Buffalo Bulletin* **32**: 792–95.
- Biedermann G and Schmucker F. 1989. Body measurements of thoroughbreds and their relationship with racing performance. *Zuchtungskunde* **61**: 181–89.
- Brown C J, Brown J E and Butts W T. 1973. Evaluating relationship among immature measures of size shape and performance of beef a bulls.II. The relationships between immature measures of size, shape and feedlot traits in young beef bulls. *Journal of Animal Science* **36**: 1021–31.
- Brown C J, Brown J E and Butts W T. 1974. Evaluating relationship among immature measures of size, shape and performance of beef a bulls. IV. Regression models for predicting post weaning performance of young Hereford and Angus bulls using pre-weaning measures of size and shape. *Journal of Animal Science* **38**: 12–19.
- DAHD&F. 2013. Estimated livestock population breed wise based on breed survey. Department of Animal Husbandry, Dairying & Fisheries, Krishi Bhawan, New Delhi, India.
- Dash S K, Sethi B P and Ray P C. 2009. Buffalo genetic resource of Orissa–Kalahandi. A Monograph. Orissa Livestock Resources Development Society and Orissa University of Agriculture and Technology.
- FAO. 2012. Phenotypic characterization of animal genetic resources. FAO. Animal Production and Health Guidelines No. 11. Rome.
- Fernandez G. 2002. Data mining using SAS application. Chapman & Hall/ CRC press, USA, pp. 367
- Gilbert R P, Bailey D R C and Shannon N H. 1993. Linear body measurements of cattle before and after 20 years of selection for post weaning gain when fed two different diets. *Journal of Animal Science* **71**: 1712–20.
- Harvey W R. 1987. Least-squares analysis of data with unequal sub-class numbers. ARS H-4, USDA, Washington, D.C.
- Jakubec V, Scholte W, Jelinek J, Scholz A and Zalis N. 1999. Linear type trait analysis in the genetic resources of the old kladrub horse. *Archiv fur Tierzucht* **42**: 215–24.
- Johnson R A and Wichern D W. 1982. *Applied Multivariate Statistical Analysis*. Prentice-Hall, Inc., Englewood Cliffs.
- Kaiser Henry F. 1958. The varimax criterion for analytic rotation in factor analysis. *Psychometrika* **23**(3): 187–200.
- Kataria R S, Sirothia A R, Mishra B P, Sadana D K, Fuke N H, Singh G and Singh P K. 2007. Buffalo genetic resource of India – Nagpuri. Monograph No.54. National Bureau of Animal Genetic Resources, Karnal.
- Miserani M G, McManus C, Santos S A, Silva J A, Mariante A S, Abreu U G P, Mazza M C and Sereno J R B. 2002. Variance analysis for biometric measures of the pantanerio horses in Brazil. *Archivos de Zootecnia* **51**: 113–20.
- Mishra A K, Vohra V, Raja K N, Singh S and Singh Y. 2017. Principal component analysis of biometric traits to explain body conformation in Kajali sheep of Punjab, India. *Indian Journal of Animal Sciences* **87**(1): 93–98.
- Nivsarkar A E, Vij P K and Tantia M S. 2000. *Animal genetic resources of India: Cattle and Buffalo*. Directorate of Information and Publications of Agriculture, ICAR, New Delhi.
- Pundir R K, Singh P K, Singh K P and Dangi P S. 2011. Factor analysis of biometric traits of Kankrej cows to explain body conformation. *Asian Australasian Journal of Animal Science* **24**(4): 449–56.
- Sadek M H, Al-Aboud A Z and Ashmawy A A. 2006. Factor analysis of body measurements in Arabian horses. *Journal of Animal Breeding and Genetics* **123**: 369–77.
- Salako A E. 2006. Principal component factor analysis of the morpho-structure of immature uda sheep. *International Journal of Morphology* **24**(4): 571–74.
- Shahin K A, Soliman A M and Moukhtar A E. 1993. Sources of shared variability for the Egyptian buffalo body shape (conformation). *Livestock Production Science* **36**(4): 323–34.
- Shahin K A, Soliman A M and Moukhtar A E. 1995. Sources of shared variability for the Egyptian cattle body shape (conformation). *Indian Journal of Animal Science* **65**: 759–64.
- Simon D L and Buchenauer. 1993. Genetic diversity of European livestock breeds, Wageningen. The Netherlands, Hardback, 582 pp.

- SPSS. 2001. Statistical Package for Social Sciences. SPSS Inc., Chicago.
- Tolenkhomba T C, Singh N S and Konsam D S. 2013. Principal component analysis of body measurements of bulls of local cattle of Manipur India. *Indian Journal of Animal Sciences* **83**(3): 281–84.
- Vohra V, Niranjana S K, Mishra A K, Jamuna V, Chopra A, Sharma N and Jong D K. 2015. Phenotypic characterization and multivariate analysis to explain body confirmation in lesser known buffalo (*Bubalus bubalis*) from North India. *Asian Australasian Journal of Animal Science* **28**: 311–17.
- Yakubu A, Ogah D M and Idahor K O. 2009. Principal component of the morphostructural indices of White Fulani cattle. *Trakia Journal of Science* **7**(2): 67–73.