Asian-Aust. J. Anim. Sci.
Vol. 24, No. 4 : 449 - 456
April 2011

www.ajas.info

Factor Analysis of Biometric Traits of Kankrej Cows to Explain Body Conformation

R. K. Pundir*, P. K. Singh, K. P. Singh[1] and P. S. Dangi
National Bureau of Animal Genetic Resources, Karnal 132001 India

ABSTRACT : Eighteen different biometric traits in 407 Kankrej cows from their breeding zone, i.e. Palanpur district of Gujarat, India, were recorded and analyzed by factor analysis to explain body conformation. The averages of body length, height at withers, height at shoulder, height at knee, heart girth, paunch girth, face length, face width, horn length, horn diameter, distance between horns, ear length, ear width, neck length, neck diameter, tail length with switch, tail length without switch and distance between hip bones were 123.44±0.37, 124.49±0.28, 94.68±0.30, 38.2±0.14, 162.56±0.56, 178.95±0.70, 44.09±0.10, 15.91±0.05, 42.47±0.53, 26.07±0.19, 13.34±0.08, 31.24±0.12, 16.10±0.05, 50.63±0.18, 73.21±0.32, 111.62±0.53, 89.34±0.34 and 17.28±0.10 cm, respectively. The correlation coefficients between different traits ranged from -0.806 (horn diameter and distance between horns) to 0.815 (heart girth and paunch girth). Most of the correlations were positive and significant. Factor analysis with promax rotation with power 3 revealed three factors which explained about 66.02% of the total variation. Factor 1 described the cow body and explained 38.89% of total variation. The second factor described the front view/face of the cow and explained 19.68% of total variation. The third factor described the back of the cow and explained 7.44% of total variation. It was necessary to include some more variables for factor 3 to obtain a reliable estimate of the back view of the cow. The lower communities shown for distance between horns, horn diameter, ear width and neck diameter indicated that these traits did not contribute effectively to explaining body conformation and can be dropped from recording, whereas all other traits are important and needed to explain body conformation in Kankrej cows. The result suggests that principal component analysis (PCA) could be used in breeding programs with a drastic reduction in the number of biometric traits to be recorded to explain body conformation. (**Key Words :** Biometric Traits, Body Conformation, Factor Analysis, Principal Component Analysis, Kankrej Cattle)

INTRODUCTION

Biometric traits are used to characterize the different breeds of livestock as they give an idea of body conformation. Biometric traits are also used for comparison of growth in different individuals. In addition to weight measurements they also describe an individual or population in a better way than the conventional methods of weighing and grading. Body dimensions have been used to indicate breed, origin and relationship or shape and size of an individual. EAAP and FAO have used height at withers as a prime indicator for their type (Simon and Buchenauer, 1993). Recently, alternative body measurements and indices estimated from different combinations of different body traits produced a superior guide to weight and were also used as an indicator of type and function in domestic animals (Schwabe and Hall, 1989; Salako, 2006). Body shapes measured objectively could improve selection for growth by enabling the breeder to recognize early-maturing and late-maturing animals of different size (Brown et al., 1973; 1974). The exploitation of body dimensions could be achieved by grouping them more meaningfully. Significant differences in different body measurement/biometric traits due to age and sex were reported by many workers in different breeds and species. i.e. Gilbert et al. (1993), Shahin et al. (1995), Pundir et al. (2007a, b,c and 2008), Singh et al. (2008) and Yakubu et al. (2009) in cattle; Biedermann and Schmucker (1989), Jakubec et al. (1999), Miserani et al. (2002) and Sadak et al. (2006) in horses; and Sarako et al. (2006) in sheep.

Analysis of variance and correlations are used to obtain relationships among different body measurements. The factor and principal component analysis (PCA) can explain relationships in a better way when the recorded traits are

* Corresponding Author : R. K. Pundir. Tel: +91-941-6153870, Fax: +91-184-2267654, E-mail: Pundir.rakesh@gmail.com
[1] Central Institute for Research on Buffako, Hisar, India.
Received September 27, 2010; Accepted November 15, 2010

correlated. This analysis transforms an original group of variables into another group, principal components, which are linear combination of original variables. The purpose of factor analysis is to reduce a set of data that may describe and be used easily. For genetic improvement, principal components simultaneously consider a group of attributes which may be used for selection purpose. Fumio et al. (1982), Hammock et al. (1986), Karacaroen et al. (2008) and Yakuba et al. (2009) used factor analysis to study the different biometric traits in Japanese Black cattle, beef cattle, Swiss dairy cattle and White Flauni cattle, respectively. Salako (2006) and Sadek et al. (2006) used factor analysis to study the principal component factor analysis of the morpho-structural traits in Uda sheep and factor analysis of body measurements in Arabian horses, respectively.

Kankrej is one of the recognized breeds of Indian cattle and probably has the largest size among the different breeds of Indian origin. This breed is available in Gujarat and Rajasthan states of India and provides a livelihood to many people by providing milk and draft power. Cows of the breed have high genetic potential for milk production and can produce up to 4,200 kg of milk in a lactation of 300 days. Presently, the size of the cow, represented by different body measurements, is one of the important criteria in selection of elite animals. There is an urgent need to describe the body conformation by recording a minimum number of body measurements/biometric traits which reduce the cost, labor and time. The present study was undertaken to study the different body measurements, relationships among different body measurements and to develop unobservable factors (latent) to define which of these measures best represent body conformation in Kankrej cows.

MATERIALS AND METHODS

Data

Data consisted of 18 different body measurements on 407 Kankrej cows (from 4 to 8 years of age) from their native zone i.e. Palanpur district of Gujarat, India. All cows recorded were from 9 villages in Palanpur district. All measurements were recorded by the same recorder to avoid between-recorder effects. All traits were recorded from the left side of the cows. The circumference measurements were taken by a tape while the other measures were taken by a mapping stick. The recorded body measurements were body length (bl), height at withers (hw), height at shoulder (hs), height at knee (hk), heart girth (hg), paunch girth (pg), face length (fl), face width (fw), horn length (hl), horn diameter (hdia), ear length (el), ear width (ew), neck length (nl), neck diameter (nd), tail length with switch (tl), tail length without switch (tls) and distance between hip bones(dhb).

Statistical analysis

To study the effects of village on all recorded body measurements, data were analyzed using the following model

$$Y_{ij} = \mu + V_{j+} + e_{ij}$$

Where Y_{ij} is the observation of one of the 18 studied biometric traits of the cows, μ is the overall mean, V_j is the fixed effects of village and e_{ij} is the random residual error associated with each observation ~ NID (0, σ^2). Data were adjusted for village effects and correlations between different measurements were estimated using partial correlations.

Factor and principal component analyses

Factor analysis is a general expression for a group of statistical techniques dealing with the reduction of a set of observable variables in terms of a small number of latent factors. It includes both factor and principal component analyses. They are functionally the same and used for the same purpose. However, they are quite different in terms of underlying assumptions. Factor analysis assumes that a variable's variance can be decomposed into two parts (Johnson and Wichern, 1982). The first part is called common variance (Communality Factor) that is shared by other variables included in the model. The estimate of communality for each variable measures the proportion of variance of that variable explained by all the other factors jointly. The second part is called specific variance (Unique Factor) as it is specific to a particular variable and includes the error variance. Factor analysis deals only with the common variance of the observed variables. However, principal component analysis considers both the total variance and unique variance and does not make any differentiation between these two. The objective of factor analysis is the reduction of the original variables into a limited number of unobservable latent factors (variables) that are extracted to account for inter-correlation among the observed variables and to explain why these variables are correlated with each other. It assumes that the unique variance represents a significant portion of the total variance. On the other hand, the objective of principal component analysis is to account for the maximum portion of the variance present in the original set of variables with a minimum number of composite variables. It assumes that the unique variance represents a small portion of the total variance (Sadak et al., 2006).

Rotation of factors

Rotation of principal factors was through the transformation of the factors to approximate a simple structure. Factor analysis using oblique (promax) rotation with power 3, was used with the following model:

$$Y_{ij} = \sum_{K=1}^{q} a_{ik} c_{kj} + e_{ij}$$

Where y_{ij} is the value of the i^{th} observation on the j^{th} measure (j = 1,2,….,,18), q is the number of common factor a_{ik} is the value of the i^{th} observation on the k^{th} common factor (factor loadings), C_{kj} is the regression coefficient of the k^{th} common factor for predicting the j^{th} measure and e_{ij} is the value of the i^{th} observation on the j^{th} unique (specific) factor.

The Kaiser rule criterion (Johnson and Wichern, 1982) was used to determine the number of factors i.e. retaining only the factors that have eigen value greater than 1. Kaiser's measure of sampling adequacy (MSA) was used to determine whether the common factor model was appropriate. A MSA below 0.5 was not accepted. All the analysis were carried out using the SPSS (2001) statistical package for social sciences.

RESULTS AND DISCUSSIONS

Biometric traits

The descriptive statistics for all the biometric traits are presented in Table 1. The effect of villages were significant on all traits. To avoid age and sex effects only cows from 4.0 to 8.0 years of age were considered in the present study. The year effects on different biometric traits were non-significant. The estimates for body length, height at withers and heart girth were in close agreement with the reports of Pundir et al. (2007a) in Kankrej cows, Pundir et al. (2007b) in Red Sindhi cows, Singh et al. (2008) in Hallikar cows and Anonymous (2004) in Amrit Mahal cows. The lower estimates of all these biometric traits as compared to Kankrej cow were reported by Pundir et al. (2008) in Red Kandhari cows and Pundir et al. (2007c) in Kenkatha cows. The estimates of paunch girth were similar to the cows of Amrit Mahal (Anonymous, 2004), Hallikar cows (Singh et al., 2008) and Red Sindhi cows (Pundir et al., 2007b). The estimates of face length were similar to the Hallikar, Red Kandhari, Red Sindhi and Kenkatha cows as reported by Singh et al. (2008), Pundir et al. (2008) and Pundir et al. (2007b; c), respectively. Face width was similar to the cows of Hallikar and Red Sindi breed (Pundir et al., 2007b; Singh

Table 1. Means (cm) with standard error of different traits

Traits	Measurement	Mean±SE	Standard deviation	Coefficient of variation
Body length (bl)	Distance from the point of the shoulder joint to the point of the pin bone	123.44±0.37	7.46	6.04
Height at wither (hw)	Distance from the highest point of wither to the ground	124.49±0.28	5.64	4.53
Height at shoulder (hs)	Distance from shoulder to ground	94.68±0.30	6.05	6.38
Height at knee (hk)	Foreleg length distance from the proximal extremity of the olecranen priers of the ground	38.2±0.14	2.82	7.38
Heart girth (hg)	Circumference of the heart	162.56±0.56	11.29	6.89
Paunch girth (pg)	Circumference around the chest	178.95±0.70	14.11	7.88
Face length (fl)	Distance from between the horn site to the lower lip	44.09±010	2.01	4.55
Face width (fw)	Distance between front of both the eyes	15.91±0.05	1.05	6.56
Horn length (hl)	Distance from point of horn attachment to the tip of the horn	42.47±0.53	10.77	25.35
Horn diameter (hdia)	Circumference of horn at base	26.07±0.19	3.83	15.08
Distance between horns (hdist)	Distance between both of the horns	13.34±0.08	1.61	12.41
Ear length (el)	Distance from the point of attachment of ear to the tip of the ear	31.24±0.12	2.43	7.78
Ear width (ew)	Circumference of ear at the mid- ear	16.10±0.05	1.08	6.70
Neck length (nl)	Distance from neck attachment to breast	50.63±0.18	3.63	7.16
Neck diameter (nd)	Girth of the neck from mid neck	73.21±0.32	6.45	8.81
Tail length with switch (tl)	Measured from the tail droop to the tip of the tail including switch	111.62±0.53	10.86	9.73
Tail length without switch (tls)	Measured from the tail droop to the tip of the tail excluding switch	89.34±0.34	6.85	7.66
Distance between hip bones (dhb)	Distance between both of the hip bones	17.28±0.10	2.01	11.63

et al., 2008). The estimate of horn length was in close agreement with the reports of Singh et al. (2008) in Hallikar cow and higher than the cows of Red Kandhari, Red Sindhi and Kenkattha breeds (Pundir et al., 2007b; c; Pundir et al., 2008). The average distance between horns and horn diameter ranged from 12.03 to 15.01 cm and 22.19 to 30.34 cm, respectively in different villages. The estimate of ear length was higher compared to that reported in Hallikar, Red Kandhari, Red Sindhi and Kenkatha (Pundir et al., 2007 b; c; Singh et al., 2008; Pundir et al., 2008). The tail length without switch was more or less similar to Hallikar and Red Sindhi cows (Pundir et al., 2007b; Singh et al., 2008) and higher than Red Kandhari and Kenkatha cows (Pundir et al., 2007c; Pundir et al., 2008). The distance between hip bones was lower compared to Hallikar cows (Singh et al., 2008).

The coefficient of variation for different biometric traits ranged from 4.53 (height at withers) to 25.35 (horn length). It was observed that horn traits, i.e. horn length, horn diameter and distance between horns and distance between hip bones, had more variability which may be due to the fact that selection was not applied for these traits or that these parts respond more to the environment than others. The tail length with switch had more variability than without the switch, indicating that tail switch had more variability. Face length had little variability which may be due to the fact that it is a cephalic measurement and its close association with cranial bone.

Phenotypic correlations

The correlation coefficients between studied biometric traits are given in Table 2a and 2b. The correlation coefficients ranged from -0.806 (horn diameter and distance between horns) to 0.815 (heart girth and paunch girth). A total of 153 correlations (in all combinations) were estimated. Among these 126 were significant of which 120 were positive correlations. Out of the 153 correlations, 141 were positive and 12 were negative. Body length had higher correlations with height at withers (0.69), heart girth (6.64) paunch girth (0.68) and neck diameter (0.63), while body length had the lowest phenotypic correlation with horn diameter. The correlation between neck length and distance between horns was high (0.69). The horn diameter had negative correlations with height at shoulder (-0.64), distance between horns (-0.80), ear width (-0.11) and neck length (-0.41). Distance between horns had negative correlations with height at knee (-0.28), face width (-0.19), horn diameter (-0.80) and distance between hip bones (-0.36). The positive and significant ($p<0.05/0.01$) correlations among different biometric traits suggest high

Table 2. a) Correlations among different biometric traits in Kankrej cows

	bl	hw	hs	hk	hg	pg	fl	fw	hl	hdia	hdist	el	ew	nl	nd	tl	tls	dhb
Bl	-	0.69*	0.47	0.46	0.64	0.68	0.57	0.32	0.41	0.03	0.22	0.44	0.42	0.41	0.63	0.34	0.52	0.40
Hw		-	0.64	0.61	0.69	0.67	0.54	0.33	0.42	-0.34	0.30	0.39	0.48	0.59	0.57	0.23	0.43	0.23
Hs			-	0.06	0.40	0.44	0.27	-0.05	0.05	-0.64	0.76	0.19	0.37	0.69	0.41	0.12	0.26	-0.12
Hk				-	0.50	0.49	0.44	0.53	0.49	0.51	-0.28	0.28	0.29	0.15	0.39	0.20	0.34	0.47
Hg					-	0.81	0.53	0.35	0.41	0.11	0.10	0.36	0.45	0.43	0.60	0.24	0.42	0.45
Pg						-	0.47	0.33	0.38	0.04	0.16	0.34	0.45	0.44	0.62	0.24	0.44	0.39
Fl							-	0.38	0.33	0.18	0.13	0.39	0.38	0.26	0.45	0.29	0.42	0.39
Fw								-	0.47	0.50	-0.19	0.28	0.28	0.08	0.24	0.18	0.29	0.41
hl									-	0.39	-0.09	0.31	0.29	0.23	0.29	0.16	0.28	0.32

Table 2. b) Correlations among different biometric traits in Kankrej cows

	BL	HW	HS	HK	HG	PG	FL	FW	HL	Hdia	Hdis	EL	EW	NL	ND	TL	TLS	DHB
hdia										-	-0.80	0.15	-0.11	-0.41	0.01	0.10	0.11	0.50
hdist											-	0.05	0.25	0.69	0.41	0.12	0.26	-0.36
el												-	0.48	0.23	0.33	0.37	0.46	0.35
fw													-	0.39	0.40	0.23	0.38	0.19
nl														-	0.33	0.10	0.27	-0.08
nd															-	0.29	0.37	0.35
tL																-	0.14	0.31
Tls																	-	0.37
dhb																		-

Bold values indicated significant correlation coefficients.

Body length (bl), Height at wither (hw), Height at shoulder (hs), Height at knee (hk), Heart girth (hg), Paunch girth (pg), Face length (fl), Face width (fw), Horn length, (hl), Horn diameter (hdia), Distance between horns (hdist), Ear length (el), Ear width (ew), Neck length (nl), Neck diameter (nd), Tail length with switch (tl), Tail length without switch (tls), Distance between hip bones (dhb).

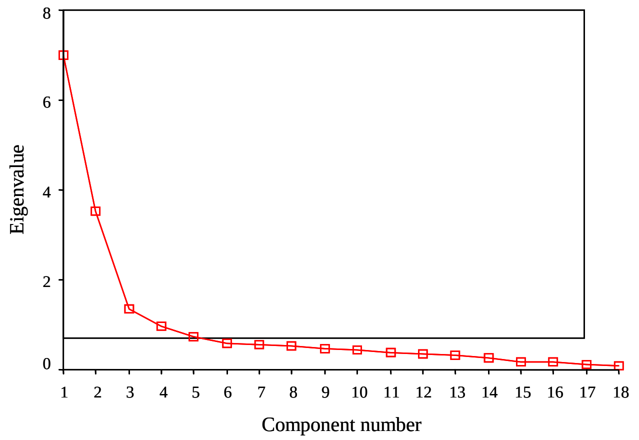

Figure 1. Scree plot showing component number with eigen values.

predictability among the different traits.

Factor analysis

The measure of sampling adequacy, Kaisee-Meyor-Olicn (KMO), was 0.891. Yakuba et al. (2009) reported similar estimates of sampling adequacy as 0.90 and 0.92 in age groups of 1.5 to 2.4 years and 2.5 to 3.6 years, respectively, in White Fulani cattle. The estimate of sampling adequacy Kaisee-Meyor-Olicn (KMO) revealed the proposition of the use in different biometric traits caused by the underlying factors. The overall significance of the correlations tested with Bertlett's test of Sphericity for the biometric traits (chi-square was 5,182.01, $p<0.01$) was significant and provided enough support for the validity of the factor analysis of data. Lower estimates of Bertlett's test of Sphericity (1,948.84 and 1,977.59) as compared to the present study were observed by Yakuba et al. (2009).

The estimated factors loading extracted by factor analysis, eigen values and variation explained by each factor are presented in Table 4. The scree plot is given in Figure 1. There were three factors extracted with eigen values greater than 1 and accounted for 66.02% of total variance. Yakuba et al. (2009) extracted two factors in the age group of 1.5 to 2.4 years which accounted for 85.37% of total variation, and four factors in the age group of 2.5 to 3.6 years explained 86.47% of the total variation by studying the 14 morpho-structural traits of White Flauni cattle. Salako (2006) extracted two factors from 10 different biometric traits in Uda sheep which accounted for 75% of total variation. Sadek et al. (2006) extracted three factors for Arabian mares and stallions separately by studying 14 different traits and these explained 66% and 67% of total variation. In the present study, the first factor accounted for 38.89% of the variation out of the total of 18 original measurements. It was represented by significant positive high loading of body length, heart girth, paunch girth, height at withers and height at knee. This factor seemed to be explaining the body of the cow, i.e. general size of the cow. Yakuba et al. (2009) reported in White Flauni cattle that the first factor explained 78.99% and 67.05% of total variation in two age groups and it represented the general size of the cattle. Similar to the present study, Yakuba et al. (2009), Salako (2006), Sadek et al. (2006), Fumio et al. (1982), Hammock et al. (1986) and Karacaroen et al. (2008) reported that the first factor explained maximum/highest variation. The second factor accounted for 19.68% of total variability. It had high loading for face length, face width, horn length, ear length, neck length and height at shoulder and seemed to be representing the front view or face of the

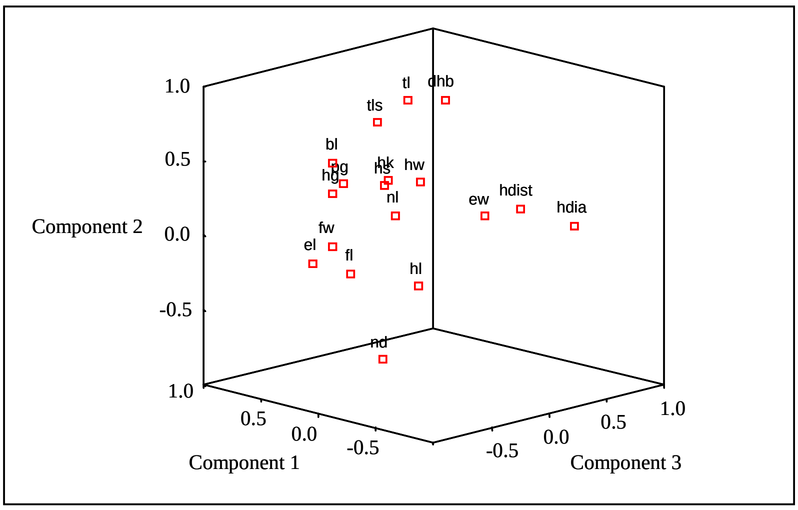

Figure 2. Component plot in rotated space. Body length (bl), Height at withers (hw), Height at shoulder (hs), Height at knee (hk), Heart girth (hg), Paunch girth (pg), Face length (fl), Face width (fw), Horn length (hl), Horn diameter (hdia), Distance between horns (hdist), Ear length (el), Ear width (ew), Neck length (nl), Neck diameter (nd), Tail length with switch (tl), Tail length without switch (tls), Distance between hip bones (dhb).

cow. Yakuba et al. (2009) reported that the second factor explained 6.38% and 7.68% of total variation, while Salako (2006) reported that the second factor explained 11.03% of total variation in Uda sheep and Sadek et al. (2006) observed it as 15% and 17% of total variation in Arabian mares and stallions, respectively. The third factor accounted for 7.44% of total variation. It contained high loading for tail length, tail length without switch and distance between hip bones and may describe the back view of the cow. While a commonly used rule is that there would be at least three variables per factor (SAS, 1998), in this case there was a need to include some more variables for a reliable analysis of a third factor as there were only three variables in the present study. Sadek et al. (2006) reported 12% of variation was explained by the third factor in Arabian horses. The component plot of the three factors in rotated space is shown in Figure 2.

The communality ranged from 0.372 (ear width) to 0.613 (horn length) and unique factors ranged from 0.387 to 0.268 for all these 18 different biometric traits (Table 3). Higher estimates of communality (ranged from 0.79 to 0.93) were observed by Yakuba et al. (2009) and approximate estimates of communality (0.42 to 0.87 and 0.32 to 0.83) were reported by Sadek et al. (2006). In the present study, common variance explains approximately 66.02% of the total variance present among all 18 measures. The inter-factor correlations between factor 1 and 2, 1 and 3, 2 and 3 were 0.481, 0.447 and 0.391, respectively, indicating high positive correlations among the extracted factors.

Table 3. Communalities and unique factors of different biometric traits

Trait	Communalities	Unique factors
Body length	0.569	0.431
Distance between hip	0.501	0.499
Ear lenghth	0.541	0.459
Ear width	0.372	0.628
Face length	0.529	0.471
Face width	0.538	0.462
Heart girth	0.683	0.317
Paunch girth	0.650	0.350
Distance between horns	0.487	0.513
Horn diameter	0.462	0.538
Height at shoulder	0.537	0.463
Height at knee	0.556	0.442
Horn length	0.613	0.387
Height at withers	0.719	0.281
Neck diameter	0.445	0.555
Neck length	0.588	0.412
Tail length	0.690	0.310
Tail length without switch	0.501	0.499

The lower communalities for some of the traits like ear width, distance between horns, horn diameter and neck diameter might indicate that these traits were less effective to account for total variation of body conformation as compared to the other traits in Kankrej cows.

The coefficients of the principal analysis of the three extracted factors are presented in Table 5. The first factor

Table 4. Total variance explained by different factors

	Component initial eigen values loading			Extraction sums of square		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.00	38.89	38.89	7.00	38.89	38.89
2	3.54	19.68	58.58	3.54	19.68	58.581
3	1.34	7.44	66.02	1.34	7.44	66.02
4	0.95	5.31	71.34			
5	0.74	4.11	75.45			
6	0.59	3.30	78.76			
7	0.56	3.14	81.90			
8	0.52	2.89	84.79			
9	0.47	2.65	87.45			
10	0.44	2.45	89.90			
11	0.36	2.04	91.95			
12	0.34	1.93	93.88			
13	0.31	1.72	95.60			
14	0.26	1.45	97.06			
15	0.17	0.95	98.02			
16	0.16	0.92	98.95			
17	0.10	0.58	99.53			
18	8.37E-02	0.46	100.00			

Table 5. Component matrix of different factors

Component	1	2	3
Body length	0.781	0.335	0.471
Distance between hips	-0.367	0.401	0.556
Ear length	0.496	0.692	0.092
Ear width	0.460	0.403	0.332
Face length	0.432	0.680	0.106
Face width	0.286	0.601	-0.277
Heart girth	0.843	0.255	0.456
Paunch girth	0.813	0.319	0.461
Distance between horns	0.045	0.409	0.074
Horn diameter	0.114	0.302	-0.843
Height at shoulder	0.391	0.512	0.279
Height at knee	0.768	-0.206	0.307
Horn length	0.252	0.640	-0.080
Height at wither	0.827	0.463	0.434
Neck diameter	0.334	0.309	0.495
Neck length	0.460	0.745	0.235
Tail length	0.213	0.30	0.552
Tail length without switch	0.419	0.142	0.734

gave different weights and positive sign to all the traits except distance between hip bones. This factor represents the general shape and size of the cow. The second factor assigned negative weights to height at knee and positive sign to all other traits. The third factor assigned negative weights to face width, horn diameter and horn length and positive weights to all other measurements. These factors explained 38.89%, 19.68% and 7.44% of the total sample variance, respectively.

CONCLUSIONS

The three extracted factors determine the source of shared variability to explain body conformation in Kankrej cows. These factors represent the body of the cow, front view/face of the cow and back view of the cow. The communalities estimates indicated that ear width, distance between horns, horn diameter and neck diameter did not contribute effectively to explain body conformation in Kankrej cows, while the remaining traits contributed effectively,and these traits could be considered to explain the body conformation of the Kankrej cows. The result suggests that principal component analysis (PCA) could be used in breeding programs with a drastic reduction in the number of biometric traits to be recorded to explain the body conformation.

REFERENCES

Anonymous. 2004. Final report on network project on animal genetic resources for survey, evaluation and characterization of Amrit Mahal cattle. University of Agriculture sciences, Bangalore, India.

Biedermann, G. and F. Schmucker. 1989. Body meseaurments of Thorough breds and their relationship with racing performance. Zuchtungskunde, 61:181-189 (in German with English summary).

Brown, C. J., J. E. Brown and W. T. Butts. 1973. Evaluating relationship among immature measures of size shape and performance of beef a bulls.II. The relation ships between immature measures of size, shape and feedlot traits in young beef bulls. J. Anim. Sci. 36:1021, 1973.

Brown, C. J., J. E. Brown and W. T. Butts. 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 preweaning measures of size and shape. J. Anim. Sci. 38:12.

Fumio, M., N. Hideaki and F. Toyokazu. 1982. Application of principal component analysis for defining size and shape in Japanese black cattle sires. The Science reports of Faculty of Agriculture, Kobe University, Vol. 15:169-176.

Gilbert, R. P., D. R. C. Bailey and N. H. Shannon. 1993. Linear body measurements of cattle before and after 20 years of selection for post weaning gain when fed two different diets. J. Anim. Sci. 71:1712-1720.

Hammock, S. P. and R. P. Shrode. 1986. Calfhood weights, body measurements and measures of fatness versus criteria of overall size and shape for predicting yearling performance in beef cattle. J. Anim. Sci. 63:447-452.

Jakubec, V., W. Scholte, J. Jelinek, A. Scholz and N. Zalis. 1999 Linear type trait analysis in the genetic resources of the old kladrub horse. Arch. Tierzucht. 42:215-224.

Johnson, R. A. and D. W. Wichern. 1982. Applied multivariate statistical analysis. Prentice-Hall, Inc., Englewood Cliffs, Nj.

Karacaroen, B. and H. N. Kadarmindeen. 2008. Principal component and clustering analysis of functional traits in swiss dairy cattle. Turk J. Vet. Anim. Sci. 32:163-171.

Miserani, M. G., C. McManus, S. A. Santos, J. A. Silva, A. S. Mariante, U. G. P. Abreu, M. C. Mazza and J. R. B. Sereno. 2002. Variance analysis for biometric measures of the pantanerio horses in Brazil. Arch. Zootec. 51:113-120.

Pundir, R. K., B. L. Pathak and S. P. S. Ahalawat. 2007a. Characterization and Evaluation of Kankrej breed of Cattle in its native tract. Indian J. Anim. Sci. 77(4):323-327.

Pundir, R. K., P. K. Singh, S. N. Uppadhaya and S. P. S. Ahlawat. 2007b. Status, characteristics and performance of Red Sindhi cattle. Indian J. Anim. Sci. 77(8):755-758.

Pundir, R. K., P. K. Singh, B. Prakash and S. P. S. Ahlawat. 2007c. Characterization and evaluation of Kenkatha breed in its native tract. Indian J. Anim. Sci. 77(2):177-180.

Pundir, R. K. and P. K. Singh. 2008. Status, characteristics and performance of red Kandhari cattle breed in its native tract. Indian J. Anim. Sci. 78(1):56-61.

Sadek, M. H., A. Z. Al-Aboud and A. A. Ashmawy. 2006. Factor analysis of body measurements in Arabian horses. J. Anim. Breed Genet. 123:369-377.

SAS, 1998. SAS/STAT User’s Guide, release 6.03 edn. SAS Institute Inc., Cary, NC, USA.

Salako, A. E. 2006. Principal component factor analysis of the morpho structure of immature uda sheep. Int. J. Morphol. 24(4):571-574.

Schwabe, A. E. and S. J. G. Hakk. 1989. Distokia in nine British breeds of cattle and its relationship to the dimensions of the dam and calf. Vet. Rec. 125:636-689.

Simon, D. L. and Buchenauer. 1993. Genetic diversity of European livestock breeds, wageningen.

Shahin, K. A., A. M. Soliman and A. E. Moukhtar. 1995. Sources of shared variability for the Egyptian cattle body shape (conformation). Indian J. Anim. Sci. 65:759-764.

Singh, P. K., R. K. Pundir, S. P. S. Alhawat, N. S. Kumar, M. G. Govindaiah and K. Asija. 2008. Phenotypic characterization and performance evaluation of Hallikar cattle in its native tract. Indian J. Anim. Sci. 78(2):211-214.

SPSS. 2001. Statistical Package for Social Sciences. SPSS Inc., 444 Michigan Avenue, Chicago, IL 60611.

Yakubu, A., D. M. Ogah and K. O. Idahor. 2009. Principal component of the morphstructural indices of White Fulani cattle. Trakia J. Sci. 7 (2):67-73.