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RESEARCH ARTICLE

Unravelling the relationship between udder morphometric traits and milk production, composition and clinical mastitis in Karan Fries cattle via principal component analysis

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Abstract: The present study was aimed at reduction in dimensionality using principal component analysis of 16 linear udder type traits and to identify those components having strongest relationship with milk production traits and clinical mastitis in Karan Fries cattle. Kaiser statistic for sampling adequacy with a lower limit of 0.50, and Bartlett's sphericity test was used to determine the adequacy of variables for use in factor analysis. Components were chosen based on auto values greater than one and scree test. The relationship of these principal components with milk production traits was analysed using the general linear model and effect of the components on the incidence of clinical mastitis were analysed through binomial logistic regression model. The general mean value of KMO was obtained as 0.695, indicated the existence of true factors. Five principal components were extracted using Kaiser Rule criterion contributing 70.11% of the cumulative variance between the linear udder type traits. The communality ranged from 0.277 (udder balance) to 0.879 (distance between rear teats) for all these 16 different udder type traits. The relation between principal component 1 and 305-day milk yield was positive and significant with a non-significant effect of 305-day milk-fat (305 DF), milk-protein (305 DP) and Solids not fat yield (305 DSNF). The principal component 1 was also found to have a significant effect on incidence of clinical mastitis. Results of PCA suggest that the use of orthogonal synthetic variables principal component one (PC1), two (PC2) and three (PC3) provided a means of reduction in the number of linear udder type traits to be recorded in Karan Fries cattle which could explain the whole udder biometric traits. The PC1 can be used in breeding programmes as a means to explain the mammary system for better milk production with lesser incidence of clinical mastitis in Karan Fries dairy cows.

Keywords: Clinical Mastitis; Karan Fries cattle; Milk production traits; Principal component analysis; Udder type traits

Introduction

Linear type classification is an important aspect of selection of highly productive animals based on their morphologic traits, making it a key component in decision making process in the herds (Posadas et al. 2008). A higher 305-day milk yield and productive life in the herd can be achieved by selecting the animals based on final score of linear type traits along with the conformation traits of mammary system (Kern et al. 2014). Moreover, the unified score card for dairy cows that describes ideal dairy conformation gives significant weightage to udder traits i.e. 40% of the total score (Stamschror, 2000). In terms of milk storage capacity, udder anatomy may be a significant factor in determining milk production (Sabuncuoglu and Coban, 2007). Wilmink (1996) also recommended that udder conformation traits should be considered, over and above milk performance in dairy cattle selection. The relationship between udder characteristics and milk yield can be a key tool for selecting dairy animals (Mingoas et al. 2017). A positive significant genetic and phenotypic correlation between udder type traits and milk yield was reported both in zebu (Tapki and Guzey, 2013; Dubey et al. 2014; Khan and Khan, 2016) as well as in crossbred cows (Waghmore and Siddiqui, 2000; Singh et al. 2010; Patel et al. 2016). In high yielding dairy cows, the most prevalent (90%) and challenging disease is mastitis which imposes enormous economic losses in dairy herds of developing and developed countries causing $35 billion annual economic losses worldwide (Varshney and Mukherjee, 2002; Donovan et al. 2005; Sharma and Sindhu, 2007). Over and above the pathological reasons, udder biometric traits of dairy cow add to the occurrence of mastitis (Chrystal et al. 2001; Amin et al. 2002).

Karan Fries, a synthetic strain of cattle (Tharparkar X Holstein Friesian), was evolved at National Dairy Research Institute, Karnal

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during 1982. Karan Fries cattle were evolved to have high milk yield and to maintain heat tolerance, disease resistance characters of indigenous cattle (Gurnani et al. 1986).

Principal component analysis (PCA), a statistical procedure, transforms a set of possibly correlated variables into a set of linearly uncorrelated variables (principal components), which retain most of the original variability (Hotelling, 1933; Lukibisi et al. 2008; Hair, 2009). Principal component analysis (PCA) has been used as a tool to evaluate the body morphometric traits of an animal (Salako, 2006; Sadak et al. 2006). Thus, morphological classification by means of PCA will support selection for multiple economic traits and also improve the management of animals (Yunusa et al. 2013).

The literature on inclusive study of all the vital udder conformation traits of Karan Fries cattle along with their dimension reduction is scarce. Furthermore, scanty reports are available to demonstrate associations between various udder biometric traits and the occurrence of mastitis in crossbred dairy cattle (Singh et al. 2014; Danish et al. 2018). Hence, present investigation was undertaken to study the different udder biometric traits, relationships among the traits, develop un-observable components (latent) to define which of these traits best represent udder conformation in Karan fries cows and to explore their relation with milk production, composition and clinical mastitis.

Materials and methods

Animals

The study was conducted on 254 lactating Karan Fries (Bos taurus X Bos indicus) cows maintained at Livestock Research Centre, ICAR-National Dairy Research Institute, Karnal, Haryana, India during 2016-2018.

The farm is situated in the north eastern semi-arid areas of Haryana (between 30° and 31°N and 76°50' to 77°30'E), having mean maximum temperature ranges from 37°C to 47°C and minimum temperature ranges from 3°C to 25°C. The farm experiences more than 800 mm of annual rainfall. Animals under this study were maintained in a loose housing system inside the farm. Paddock for the animals was large, open and brick paved with herring bone system containing drainage in between covered and open space having adequate slope for better drainage. The animals were machine milked, three times a day (morning 4 a.m., 12 noon and evening 4 p.m.) followed by the recording of milk yield. The average per day milk production of Karan Fries cows was 13.07 kg. Limited concentrates and ad libitum green fodders were offered to meet the nutrient requirement of the lactating animals. The feeding management practices and feed ingredients (ICAR 2013) were similar for all lactating animals in the herd.

Udder and teat morphometric traits

The data on nine udder morphometric traits and seven teat morphometric traits were recorded. The animals were summoned one hour before the routine milking for recording of the traits. The traits included udder morphometric traits such as rear udder height (RUH), rear udder width (RUW), udder width (UW), fore udder attachment (FUA), udder circumference (UC), udder balance (UB), central ligament (CL), udder depth (UD), udder length (UL) and teat morphometric traits such as fore and rear teat length (FTL and RTL), teat diameter (TD), distance between fore and rear teat (DFR), distance between right and left teat (DLR), shortest distance from fore teat end to floor (SDF), shortest distance from rear teat end to floor (SDR) (Table 1). Udder and teat measurements were done by using meter long measuring tape whereas, teat diameter was measured using vernier caliper. The udder and teat measurements of the animals under the study were carried out during December, 2016 to June, 2018. Norms relating to the ethical treatment of animals throughout the whole operation were strictly followed. The udder measurements were recorded by a qualified veterinarian. All the measurements were recorded once in straight animal standing on a level ground and by the same person to avoid between-recorder effects.

The data on 305-days milk yield, 305-days milk-fat yield, 305-days milk-protein yield and 305-days solids not fat yield of each animal were collected from Livestock Record Unit of Institute.

Mastitis data

Incidences of clinical mastitis among the lactating Karan Fries cattle were recorded from treatment register of the Animal Health Complex of Livestock Research Centre, ICAR-NDRI, Karnal. Animals were regularly screened by rapid California Mastitis Test (CMT), and results were recorded. The data on clinical mastitis was of a binomial distribution since the scoring of clinical mastitis was dichotomous (either healthy or infected). If a cow got infected with mastitis at least once in the studied lactation, a response of "1" was attributed to the record. A healthy record with a response of "0" was created for a cow that was never treated for the disease.

To improve consistency of the structure of database and subsequent analysis, the records of cows without pedigree, dates of birth, end of lactation and without production records were removed from the data. For cows with more than one classification over the productive life, only the first was considered. The udder and teat morphometric traits were adjusted for the significant effect of parity, season and stage of lactation. Further analysis was done with the data adjusted for these non-genetic factors.

The principal component analysis incorporated 16 linear type traits using the correlation matrix between the traits to make sure that all traits are standardized in the analysis (Vucasinovick et al. 1997). The matrix of partial correlations, Kaiser statistic for sampling adequacy (MSA) with a lower limit of 0.50, and Bartlett's sphericity test were used to determine the degree of interrelations between variables and adequacy for use in the principal component analysis. Bartlett test (Bartlett, 1950) was performed to check whether the data set of 254 animals with 16 traits could be factored or not. Maxwell (1959) suggested that the test should be used prior to the application of principal component analysis. The following formula was used to compute Bartlett's test of sphericity:

$\chi^2 = [(n–1)1/6(2p + 5) \log_e$ œ#R œ#]

where, n, sample size; p, number of variables; œ#Rœ#, determinant of correlation matrix. It follows χ^2 distribution with [p (p–1)/2] degree of freedom.

Components were selected on the basis of values greater than one and scree test (graph) (Cattell, 1966). The point where the graph begins to turn into horizontal is considered indicative of the maximum number of components to be extracted (Hair, 2009). Varimax rotation was used for rotation of principal components through the transformation of the components to almost a simple structure. Components were rotated via varimax rotation to assist interpretation because of the reduction of ambiguities in non-rotated solutions (Hair, 2009). The value of 0.50 was used to conclude a significant correlation between traits and components.

The statistical analyses were performed by means of the SPSS (2001) statistical package by the maximum likelihood method to decrease the dimensionality and lessen the information in a group of p original variables Z_1, Z_2... Z_p, to a new group of variables $Y_1(F_1)$, $Y_2(F_2)$...$Y_p(F_p)$. In this analysis few of the first components hold greater part of the variability of the original variables (Cruz and Regazzi, 1997).

Relationship of these principal components with milk production traits were analyzed using general linear model in the GLM procedure of SPSS (2001):

Effect of the principal components on incidence of clinical mastitis were analyzed through binomial logistic regression model with the SPSS software statistical package (Version 23). The following dichotomous logistic model was used:

$$\text{logit}(p) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots\ldots + \beta_{16}X_{16}$$

Where,

logit(p)βo = Log[p/ (1-p)] = Odds of occurring clinical mastitis in the animalsInterception at y-axis
β1…16 = Partial regression coefficients
X1...16 = Predictor variables i.e., udder and teat type traits

The multivariate analysis for binomial logistic regression considered incidence of clinical mastitis as a categorical response variable, expressed on a scale of 1 and 0. The model included continuous traits (linear udder and teat morphometric traits). The data were analyzed by logistic regression procedure as well as odds ratios (ORs) with a 95% confidence interval. The reference category was set according to preference. Differences were interpreted as significant if P d" 0.05.

Results and Discussion

The means of linear udder type trait measurements varied between 1.00 cm for udder balance and 142.85 cm for udder circumference (Table 1). Whereas, the means of teat type trait measurements varied between 2.23 cm for teat diameter and 47.01 cm for shortest distance from front teat end to floor (Table 1). The descriptive statistics for all the udder and teat conformation traits are given in Table 1. The means of udder and teat conformation traits showed that Karan Fries cows were having intermediate udder and teat measurements.

The phenotypic correlations among different udder and teat conformation traits are presented in Table 2. The magnitude of correlation coefficient ranges between -0.491 (SDR, shortest distance from rear teat end to the floor and UW, udder width) to 0.879 (SDR, shortest distance from rear teat end to the floor and SDF, Shortest distance from fore teat end to the floor). Among the total 78 correlations (in all combinations), 44 were significant, of which 21 were positive correlations (Table 2).

Rear udder height had significant negative correlations with udder length, udder width, udder circumference and distance between fore and rear teats. Udder depth had significant negative correlations with udder length, udder width, udder circumference, central ligament, distance between front and rear teat, distance between rear teats and significant positive correlations with shortest distance from fore teat end to the floor and shortest distance from rear teat end to floor. Udder length had significant positive correlations with udder width, udder circumference,

Table1. Descriptive statistics of udder biometric traits in Karan Fries cows

Trait	Mean
1.Udder type traits	
Rear udder height (cm)	23.47±0.33
Udder depth (cm)	53.73±0.36
Udder balance (cm)	1.00±0.35
Udder length (cm)	60.20±0.46
Udder width (cm)	71.06±0.53
Udder circumference (cm)	142.85±1.59
Central ligament (cm)	3.12±0.09
2.Teat type traits	
Fore teat length (cm)	5.30±0.09
Distance between front and rear teats (cm)	6.70±0.27
Distance between rear teats (cm)	8.84±0.31
Shortest distance from front teat end to floor (cm)	47.01±0.35
Shortest distance from rear teat end to floor (cm)	46.96±0.35
Teat diameter (cm)	2.23±0.02

distance between front and rear teat, distance between rear teats, teat diameter, and significant negative correlations with shortest distance from fore teat end to the floor and shortest distance from rear teat end to floor. Udder width had significant positive correlations with udder circumference, fore teat length, distance between front and rear teats, distance between rear teats, teat diameter and significant negative correlation with shortest distance from fore teat end to the floor and shortest distance from rear teat end to floor. Udder circumference had significant positive correlations with distance between front and rear teat and distance between rear teats; significant negative correlation with shortest distance from fore teat end to the floor and shortest distance from rear teat end to floor. A significant positive correlation was observed between central ligament and fore teat length and significant negative correlation with shortest distance from fore teat end to the floor and shortest distance from rear teat end to floor. Fore teat length had significant positive correlations with distance between front and rear teat, distance between rear teats, teat diameter and significant negative correlation with shortest distance from front teat end to floor. Distance between fore and rear teat had significant positive correlations with the distance between rear teats; significant negative correlation with the shortest distance from fore teat end to the floor and the shortest distance from rear teat end to the floor. Distance between rear teats had a significant negative correlation with shortest distance from fore teat end to the floor and shortest distance from rear teat end to the floor. Shortest distance from fore teat end to the floor also had significant positive correlations with the shortest distance from rear teat end to the floor.

The PCA analysis was applied to 16 udder and teat conformation traits in Karan Fries cows. The general mean value of KMO test gave measure of sampling adequacy (MSA) as 0.695, a level pointing to the existence of significant correlations between linear type traits and the existence of true factors. The estimate of KMO also indicates suitability of the data for PCA analysis. The KMO analysis excluded 3 traits (fore udder attachment, rear udder width, rear teat length) with KMO lesser than 0.5. KMO-MSA score greater than 0.5 is essential for suitable PCA analysis to continue (Kaiser, 1974; Hair, 2009). The estimate of KMO-MSA revealed proportion of the variance in different udder biometric traits caused by underlying components (Kaiser, 1958). Bartlett's test of sphericity was used to test overall significance of the correlation matrix for the udder type traits. Chi-square value for the test was estimated as 1222.095, which was highly significant (P<0.001). As the correlation matrix was found to be non identity matrix, it signified the validity of the PCA analysis of udder biometric traits data.

Five principal components were extracted out of the total 13 principal components by means of Kaiser Rule criterion (Johnson and Wichern, 1982) which finds out the number of components having eigen values greater than 1 (Table 3). Principal components were also chosen based on scree test (graph) (Cattell, 1966). In the scree plot, the point where the graph begins to become horizontal is considered indicative of the maximum number of components to be extracted (Hair, 2009), components having eigen values up to the point "bent of elbow" are usually considered (Fig. 1). The scree plot also indicated extraction of five components (Fig. 1). The identified five components could explain 70.11% of the cumulative variance between the linear udder type traits (Table 3). PCA determines the variability of individual traits and how these traits contribute towards the total morpho structural variance of animal (Mavule et al. 2013). The first principal

Table 2. Phenotypic Correlation among 13 different udder biometric traits in Karan Fries cows

	RUH	UD	UB	UL	UW	UC	CL	FTL	DFR	DRT	SDF	SDR	TD
RUH	1												
UD	.047	1											
UB	-.007	.089	1										
UL	-.165**	-.286**	-.010	1									
UW	-.192**	-.398**	.018	.563**	1								
UC	-.341**	-.160*	.015	.273**	.300**	1							
CL	-.002	-.195**	-.099	-.041	.081	.114	1						
FTL	-.030	-.022	.040	.007	.164**	-.001	.163**	1					
DFR	-.157*	-.155*	.065	.206**	.264**	.167**	-.016	.150*	1				
DRT	-.053	-.201**	.019	.275**	.411**	.141*	.045	.143*	.749**	1			
SDF	.001	.687**	.026	-.298**	-.369**	-.187**	-.317**	-.194**	-.179**	-.192**	1		
SDR	.059	.710**	.039	-.434**	-.491**	-.225**	-.242**	-.093	-.224**	-.307**	.879**	1	
TD	-.020	.003	.144*	.155*	.194**	.041	-.070	.355**	.070	.107	-.105	-.060	1

The lower triangle shows the phenotypic correlation among the different udder type traits with superscripts showing their respective level of significance i.e. ** means p<0.01 and * means p<0.05 respectively. FTL, Fore teat length; SDF, Shortest distance from front teat end to floor; RUH, Rear udder height;SDR, Shortest distance from rear teat end to floor; DFR, Distance between front and rear teat; TD,Teat diameter; DRT, Distance between rear teats; UD, Udder depth; CL, Central ligament; UW,Udder width; UC, Udder circumference; UB, Udder balance; UL, Udder length

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

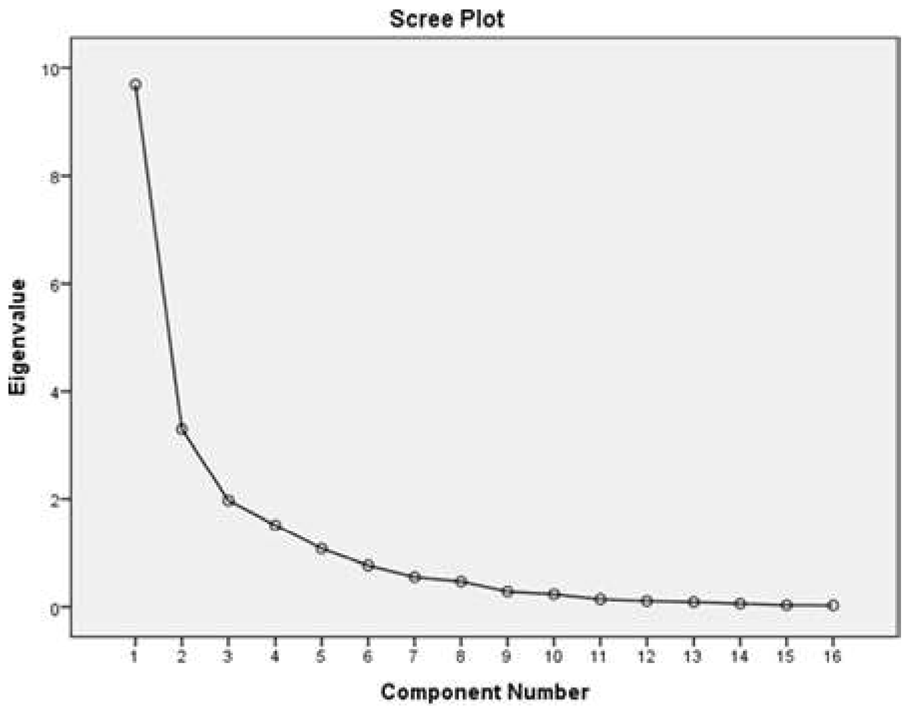

Table 3. Total variance explained by different components in Karan Fries cows

Component	Initial eigen values			Extraction sums of squared loadings			Rotation sums of Squared loadings
	Total	% of variance	Cumulative%	Total	% of variance	Cumulative%	Total
1	3.702	28.475	28.475	3.702	28.475	28.475	3.053
2	1.708	13.140	41.615	1.708	13.140	41.615	1.837
3	1.368	10.521	52.135	1.368	10.521	52.135	1.539
4	1.235	9.499	61.635	1.235	9.499	61.635	1.445
5	1.102	8.475	70.110	1.102	8.475	70.110	1.241
6	.937	7.208	77.318				
7	.723	5.562	82.880				
8	.626	4.818	87.698				
9	.542	4.167	91.864				
10	.438	3.370	95.234				
11	.313	2.410	97.645				
12	.216	1.664	99.309				
13	.090	.691	100.000				

n, number of Karan Fries cows

component (PC1) accounted for 28.475% of the variation (Table 3). It was represented by significant positive high loading of udder depth, shortest distance from front teat end to floor and shortest distance from rear teat end to floor (Table 5). The first principal component seemed to be explaining the maximum of udder and teat conformation traits in Karan Fries cows.

The second principal component (PC2) explained 13.14% of total variance (Table 3) with a high loading of distance between front and rear teats and distance between rear teats (Table 5). The third principal component (PC3) explained 10.521% of the variance (Table 3) and showed high component loading for rear udder height (Table 5). The fourth principal component (PC4) accounted for 9.499% of total variability (Table 3) with comparatively higher loading for fore teat length and teat diameter (Table 5). The fifth principal component (PC5) accounted for 8.475% of total variability (Table 3) with comparatively higher loading for central ligament (Table 5).

The PC1 gave different weights with positive sign to all the biometric traits except to udder length, udder width, fore teat length, distance between front and rear teat, distance between rear teats and teat diameter. The PC2 gave negative coefficient value for udder depth, udder balance, udder circumference,

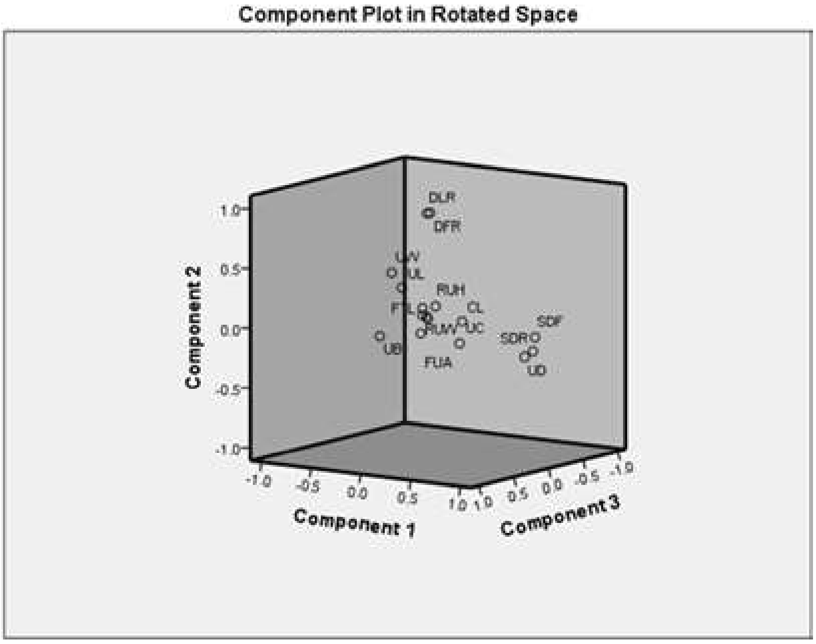

Fig. 2. Component plot in rotated space.

FUA, Fore udder attachment; FTL, Fore teat length; SDF, Shortest distance from front teat end to floor; RUH, Rear udder height; RUW, Rear udder width; RTL, Rear teat length; SDR, Shortest distance from rear teat end to floor; DFR, Distance between front and rear teat; TD, Teat diameter; DRT, Distance between rear teats; UD, Udder depth; CL, Central ligament; UW, Udder width; UC, Udder circumference; UB, Udder balance; UL, Udder length.

Table 4. Communalities and unique factor of various udder biometric traits in Karan Fries cows

Trait	Communalities	UniqueFactor
Rear udder height	0.666	0.334
Udder depth	0.719	0.281
Udder balance	0.277	0.723
Udder length	0.627	0.373
Udder width	0.621	0.379
Udder circumference	0.622	0.378
Central ligament	0.680	0.32
Fore teat length	0.742	0.258
Distance between front and rear teats	0.860	0.14
Distance between rear teats	0.879	0.121
Shortest distance from front teat end to floor	0.846	0.154
Shortest distance from rear teat end to floor	0.876	0.124
Teat diameter	0.700	0.3

shortest distance from front teat end to floor, shortest distance from rear teat end to floor and teat diameter. The PC3 gave negative coefficient value for udder depth, udder balance, udder circumference, central ligament, fore teat length and shortest distance from rear teat end to floor. The PC4 gave negative coefficient value for central ligament, shortest distance from front teat end to floor and shortest distance from rear teat end to floor. The PC5 gave negative coefficient value for rear udder height and fore teat length (Table 5).

The communality ranged from 0.277 (udder balance) to 0.879 (distance between rear teats) and unique factors ranged from 0.121 (distance between rear teats) to 0.723 (udder balance) for all these 13 different udder type traits (Table 4). The lower estimates of communality of udder balance inferring that this trait is less effective in explaining variation shared with the other traits. Distance between rear teats and shortest distance from rear teat end to floor had the highest communalities, confirming its equilibrium position between udder and teat conformation traits.

Varimax rotation was applied to find the squared correlations between variables and components as it maximizes sum of the variances of the squared loadings (Fernandez, 2002). Coefficients of the PCA of rotated component matrix of the five extracted principal components are presented in Table 5. Correlation between a principal component and the original traits correspond to the weight of each trait. The trait with a higher weight represents the corresponding principal component more efficiently. Each principal component can be interpreted physiologically or biologically based on the sign and magnitude of the component weight of each trait (Vukasinovic et al. 1997).

Among all the PCs, the component weights varied from -0.763 to 0.918 for udder circumference and shortest distance from rear teat end to floor, respectively (Table 5). The higher significant weights in the first component were for udder depth, shortest distance from front teat end to floor and shortest distance from rear teat end to floor. All these traits were related to the mammary system so this component was called mammary system. The component weights for PC1 varied from -0.568 to 0.918 for the udder width and shortest distance from rear teat end to floor, respectively (Table 5).

The component weights for PC2 varied from -0.138 to 0.916 for the shortest distance from rear teat end to floor and distance between front and rear teat, respectively (Table 5). This principal component was called teat morphometry system as the higher significant component weights in second component were for the distance between front and rear teats and distance between rear teats which are a part of teat morphometric traits (Table 5). The component weights varied from -0.763 (Udder circumference) to 0.810 (Rear udder height) for the third component (Table 5). The higher significant component weight in the third principal component was for rear udder height related to the rear udder (Table 5).

The component weights varied from -0.116 (shortest distance from front teat end to floor) to 0.807 (teat diameter) for principal component 4 (Table 5). The higher significant component weights in principal component 4 were for fore teat length and teat diameter related to teat morphometric traits (Table 5).

For principal component 5, the component weights varied from -0.363 (fore teat length) to 0.785 (central ligament) (Table 5). The higher significant component weight in principal component 5 was for central ligament which is related to the rear udder (Table 5).

In general, three well-defined factors were formed (Fig. 2). Principal component 1, 2 and 3 had 28.475%, 13.140% and 10.521% of the

Table 5. Estimates of component weights for udder biometric traits using varimax rotation

Trait	Principal component				
	1	2	3	4	5
Rear udder height	0.067	0.050	0.810	0.006	-0.042
Udder depth	0.832	-0.063	-0.008	0.100	0.114
Udder balance	0.052	-0.001	-0.038	0.364	0.374
Udder length	-0.531	0.161	0.369	0.062	0.423
Udder width	-0.568	0.284	0.368	0.199	0.208
Udder circumference	0.181	-0.061	-0.763	0.013	0.057
Central ligament	0.229	0.023	-0.089	-0.053	0.785
Fore teat length	-0.029	0.156	-0.002	0.765	-0.363
Distance between front and rear teat	-0.086	0.916	0.104	0.046	0.004
Distance between rear teats	-0.195	0.913	0.045	0.061	0.029
Shortest distance from front teat end to floor	0.877	-0.051	0.020	-0.116	0.245
Shortest distance from rear teat end to floor	0.918	-0.138	-0.061	-0.016	0.102
Teat diameter	-0.081	-0.002	0.039	0.807	0.201

Table 6. Extracted component and their respective descriptions obtained from linear udder type traits in Sahiwal cows

Factor	Name	Characterization of the component
1	Mammary System	Deeper udder with optimum distance from front and rearTeat end to floor
2	Teat morphometricTraits	Optimum distance between front-rear teat and rear teats
3	Rear udder	Optimum rear udder height

Table 7. Linear regression coefficients (b) of components and their respective standard error on milk production traits

Phenotypic measure	Linear regression coefficients (b)				
	Component 1	Component 2	Component 3	Component 4	Component 5
305 DMY	1.017±0.010*	-0.001±0.002	0.003±0.001	-0.001±0.002	0.003±0.002
305 DF	-2.646±1.041	1.335±0.813	1.155±0.149	1.090±0.351	-1.737±0.948
305 DP	1.939±0.986	0.882±0.772	-1.179±0.097	-1.513±0.035	-1.074±0.900
305 DSNF	2.941±0.862	-1.972±0.139	-1.764±0.620	1.365±0.528	1.436±0.330

305 DMY = 305-day milk yield, 305 DF = 305-day milk-fat yield, 305 DP = 305-day milk protein yield, 305 DSNF = 305-day Solids not fat yield

common variance respectively, explaining 52.135% of the total variance between the linear udder morphometric traits.

If the traits of principal component 1 are included in the selection programme (Table 6), cows are expected to have a deep and voluminous udder, with optimal distance from front and rear teat end to floor which is vital for superior milk production as well as better udder health. Animals with deeper udder will have additional area for mammary tissue within the udder. As the mammary tissues are the primary source to synthesize milk, thus the animals with deeper udders are expected to produce higher quantity of milk.

When principal component 2 is used for selection (Table 6), the cows should have optimum distance between front and rear teats as well as optimum distance between rear teats. The teats should not be too close or too far from each other as they create in compatibilities for machine milking and handling. Including the traits of principal component 3 in selection decisions (Table 6), cows are expected to have an optimum rear udder height. This will prevent broken/very pendulous suspension of udder and in turn less susceptible to udder damage.

The relation between principal component 1 and 305-day milk yield was positive and significant with a non-significant effect of 305-day milk-fat (305 DF), milk-protein (305 DP) and Solids not fat yield (305 DSNF) (Table 7). The principal component 1 was also found to have a significant effect on incidence of clinical mastitis (Table 8). Cows with deep and voluminous udder, with optimum distance from front and rear teat end to floor are associated with higher milk production and lesser incidence of clinical mastitis. It means that selection for this combination of udder and teat type traits could bring associated increase in 305-day milk yield as well as lesser incidence of clinical mastitis.

The present investigation was focused to study the different udder biometric traits, relationships among the traits, develop unobservable components (latent) to define which of these traits best represent udder conformation in Karan fries cows and to explore their relation with milk production, composition and clinical mastitis. The means of rear udder height, udder circumference, udder depth, udder balance and central ligament of Karan Fries cattle in this study were in accordance with Dubey et al. 2014 and Deng et al. (2012). The mean of udder width and udder length were in agreement with Patel et al. (2016). Among the teat type traits studied, the means of fore teat length, teat diameter, distance between front-rear teats, distance between rear teats, shortest distance from front teat end to floor and shortest distance from rear teat end to floor are in concurrence with Singh et al. (2014) who studied the same in Holstein Friesian × Sahiwal crossbred dairy cows.

Rear udder height had significant negative correlations with udder length, udder width, udder circumference and distance between fore-rear teats. These findings are in agreement with Dubey et al. 2014 and Mingoas et al. (2017) in zebu cows. The positive genetic correlation between udder depth, udder cleft (central ligament) and front teat distance reported in the present study were in accordance with Sorensen et al. (2000). Khan and Khan (2016) reported positive genetic correlation between udder depth, length, width and circumference which is in agreement with the present study. Udder balance had significant positive correlations with teat diameter which is also supported by Dubey et al. 2014. Udder length had significant positive correlations with udder width, udder circumference, distance between front and rear teat, distance between rear teats, teat diameter, and significant negative correlations with shortest distance from fore teat end to the floor and shortest distance from rear teat end to floor which is in accordance with Sezenler et al. (2016) and Mingoas et al. (2017). Udder width had significant positive correlations with udder circumference, fore teat length, distance between front and rear teats, distance between rear teats, teat diameter and significant negative correlation with shortest distance from fore teat end to the floor and shortest distance from rear teat end to floor. The current findings are supported by Ahlawat et al. (2008); Singhai et al. (2013) and Sezenler et al. (2016). A significant positive correlation was observed between central ligament and fore teat length which is in concurrence with Sorensen et al. (2000). Central ligament also had significant negative correlation with shortest distance from fore teat end to the floor and shortest distance from rear teat end to floor. These findings are supported by Nakov et al. (2014). Distance between fore and rear teat had significant positive correlations with the distance between rear teats; significant negative correlation with the shortest distance from fore teat end to the floor and the shortest distance from rear teat end to the floor. Distance between rear teats had a significant

Table 8. Effect of principal components on incidence of clinical mastitis in Karan Fries cattle (Healthy animals=64.5% and Mastitic animals= 35.5%)

S.No.	Components	Wald $\chi2$	Exp(B)	95% C.I.	
				Lower	Upper
1	Principal Component 1	6.088*	1.018	0.994	1.042
2	Principal Component 2	3.009	1.015	0.968	1.064
3	Principal Component 3	0.013	0.994	0.903	1.095
4	Principal Component 4	2.114	0.900	0.828	0.979
5	Principal Component 5	0.364	0.935	0.867	1.009

negative correlation with shortest distance from fore teat end to the floor and shortest distance from rear teat end to the floor. Shortest distance from fore teat end to the floor also had significant positive correlations with the shortest distance from rear teat end to the floor. All these findings are in concordance with Nakov et al. (2014).

KMO-MSA score greater than 0.5 is essential for suitable PCA analysis to continue (Kaiser, 1974; Hair, 2009). The general mean value of KMO test gave measure of sampling adequacy (MSA) as 0.695, which revealed that proportion of the variance in different udder biometric traits caused by underlying components (Kaiser, 1958). The present finding is supported by Corrales et al. (2011) and Kern et al. (2014) who accounted sampling adequacy of 0.75 and 0.79 for linear type traits in Holstein Cattle, respectively.

Five principal components were extracted out of the total 13 principal components by means of Kaiser Rule criterion (Johnson and Wichern, 1982) which find out the number of components having eigen values greater than 1. In a study of linear type traits in Brazilian Holstein cattle, four factors were extracted using factor analysis by (Kern et al. 2014). In Holstein cows of Colombia (Corrales et al. 2011) seven factors were identified with auto values greater than one. Previous studies using principal components established higher number of factors to be extracted for linear type traits. The different number of extracted factors in those studies might be due to differences in the statistical methods, as well as populations.

A relation between principal component 1 and 305-day milk yield was positive and significant with a non-significant effect of 305-day milk-fat (305 DF), milk-protein (305 DP) and Solids not fat yield (305 DSNF). The principal component 1 was also found to have a significant effect on incidence of clinical mastitis. The genetic correlations showed that higher yielding cows have relatively deeper udders in Holstein dairy cattle (Bohlouli et al. 2015). Positive and highly significant correlations were observed between udder depth and 305-day milk yield in zebu cows (Mingoas et al. 2017) as well as in Holstein cows (Zwertvaegher et al. 2012; Corrales et al. 2011). Deeper udders showed the highest somatic cell count in Holstein cows (Nemcova et al. 2007). Whereas, in Holstein Friesian × Sahiwal crossbred dairy cows, deeper udder showed higher susceptibility to mastitis (Singh et al. 2014). The deeper udders may hamper easy movement of the cow and raise the risks of udder and teat lesions (Mein et al. 2004). The deeper udders also has higher predisposition to become soiled and, thus, being contaminated with environmental pathogens (Lopez-Benavides et al. 2005). Consequently, deeper udders were observed to have more risk of developing mastitis. Bhutto et al. (2010) and Bardakcioglu et al. (2011) accounted elevated predisposition to intra mammary infection and higher milk SCC with the teats placed closer to the floor. An increasing proportion of teat lesions were observed alongside decreasing teat tip to floor distance which results in higher occurrence of mastitis in Holstein Friesian (Breen et al. 2009) and Holstein Friesian × Sahiwal crossbred dairy cows (Singh et al. 2014).

Furthermore, lower udders with the teats placed closer to floor had additional liner slips and required longer milking time. The liner slips give rise to a sudden and rapid loss of vacuum that might move the pathogens located at the teat opening or inside the streak canal into the teat cistern and bring about new infections (Mein et al. 2004). The longer milking time due to lesser teat end to floor distance causes roughness of the teat end which consecutively results in higher probability of new intra mammary infections (Neijenhuis et al. 2000, 2001).

Principal component 1 including the mammary system traits may be more important for milk production compared to other factors such as those of teat morphometric traits as well as rear udder.

Conclusion

A positive and significant correlation was observed among different linear udder and teat type traits suggesting high predictability among these traits, and also making them acquiescent for analysis through PCA. The principal component analysis has resulted in the reduction in dimensionality of the group of linear type traits studied, forming three orthogonal synthetic variables which could be used in explaining the whole udder and teat conformation in Karan Fries cattle. The communalities estimate specified the fact that udder balance could not put in effectively to explain udder conformation, at the same time the remaining traits contribute effectively, thus these traits could be considered to explain the udder conformation of the Karan Fries cows. The Component 1, that included udder depth, shortest distance from front teat end to floor and shortest distance from rear teat end to floor, had a positive association with 305-day milk yield and incidence of clinical mastitis, signifying that this component can be used in breeding programme for phenotypic selection of females to get better milk production together with lesser incidence of clinical mastitis.

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References

Ahlawat K, Dang AK, Singh C (2008) Relationship of teat and udder shape with milk SCC in primiparous and multiparous Sahiwal cows. Indian J Dairy Sci 61:152–156

Amin AA, Gere T, Kishk WH (2002) Genetic and environmental relationship among udder conformation traits and mastitis incidence in Holstein Friesian into two different environments. Archiv Tierzucht Dummerstorf 45:129–138

Bardakcioglu HE, Sekkin S, Oral Toplu HD (2011) Relationship between some teat and body measurements of Holstein cows and subclinical mastitis and milk yield. J Anim Vet Adv 10:1735–1737

Bartlett MS (1950) Tests of significance in factor analysis. Br J Psychol 3:77–85

Bhutto AL, Murray RD, Woldehiwet Z (2010) Udder shape and teat-end lesions as potential risk factors for high somatic cell counts and intramammary infections in dairy cows. Vet J 183:63–67

Bohlouli M, Alijani S, Varposhti MR (2015) Genetic relationships among linear type traits and milk production traits of Holstein dairy cattle. Ann Anim Sci 15:903–917

Breen JE, Green MJ, Bradley AJ (2009) Quarter and cow risk factors associated with the occurrence of clinical mastitis in dairy cows in the United Kingdom. J Dairy Sci 92: 2551–2561

Cattell RB (1966) The scree test for the number of factors. Multivar Behav Res 1:245-276

Chrystal MA, Seykora AJ, Hansen LB, Freeman AE, Kelley DH, Healey MH (2001) Heritability of teat-end shape and the relationship of teat-end shape with somatic cell score for an experimental herd of cows. J Dairy Sci 84:2549–2554

Corrales JA, Ceron-Munoz M, Canas JA, Herrera CR, Calvo SC (2011) Relationship between type traits and milk production in Holstein cows from Antioquia, Colombia. Rev MVZ Cordoba 16:2507-2513

Cruz CD, Regazzi AJ (1997) Biometric Models Applied to Genetic Improvement. 2nd. Ed, Vicosa, Federal University of Vicosa, pp 390

Danish Z, Bhakat M, Paray AR, Ahmad S, Lone AR, Mohanty TK, Sinha R (2018) Udder and teat morphology and their relation with incidence of sub-clinical and clinical mastitis in Sahiwal, Karan Fries cows and Murrah buffaloes. J. Entomol. Zool Stud 6 :2138-2141

Deng MP, Badri TM, Atta M, Hamad ME (2012) Relationship between udder dimensions and milk yield of Kenana × Friesian crossbred cows. Research Opinions in Animal and Vet Sci 2:49-54

Donovan DM, Kerr DE, Wall RJ (2005) Engineering disease resistant cattle. Transgenic Res. 14:563-567

Dubey A, Mishra S, Khune V (2014) Appraisal of linear type traits in Sahiwal cattle. Indian J Anim Res 48: 258-261

Fernandez G (2002) Data Mining Using SAS Application. Chapman & Hall/ CRC press, USA. pp 367

Gurnani M, Sethi RK, Nagarcenkar R (1986) Development of Karan Fries cattle at NDRI, Karnal. Dairy Information Bulletin No. 111.9, National Dairy Research Institute, Karnal, India: pp 1-2

Hair JRJF (2009) Multivariate data analysis. 6th ed. Bookman, Porto Alegre, pp 679

Hotelling H (1933) Analysis of the complex of statistical variables into principal components. J Educ Psychol 24:417–41

ICAR (2013) Nutrient Requirements of Cattle and Buffaloes. Indian council of Agricultural Research, Krishi Bhavan, New Delhi, India. ISBN 978-81-7164-145-2

Johnson RA, Wichern DW (1982) Applied Multivariate Statistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ, USA

Kaiser HF (1958) The varimax criterion for analytic rotation in factor analysis. Psychometrika 23:187–200.

Kaiser HF (1974) Index to factorial simplicity. Psychometrika 39:31–36

Kern EL, Cobuci JA, Costa CN, Pimentel CMM (2014) Factor analysis of linear type traits and their relation with longevity in Brazilian Holstein cattle. Asian-australas. J Anim. Sci. 27 (6):784

Khan MA, Khan MS (2016) Genetic parameters of udder traits and their relationship with milk yield in Sahiwal cows of Pakistan. J Anim Plant Sci 26:880-886

Lopez-Benavides MG, Williamson JH, Cursons RT, Lacy-Hulbert SJ, Woolford MW (2005) Streptococcus uberis population dynamics in the New Zealand pastoral dairy farm. In: Hogeveen H, (editor), Proceedings of the 4th IDF International Mastitis Conference, Maastricht, (Wageningen Academic Publishers), pp 649–655

Lukibisi FB, Muhuyi WB, Muia JMK, Ole Sinkeet SN, Wekesa WF (2008) Statistical use and interpretation of principal component analysis in applied research. Egerton University's 3rd Annual Research Week and International Conference

Mavule BS, Bezuidenhout CC, Muchenje V, Kunene NW (2013) Morphological structure of Zulu sheep based on principal component analysis of body measurements. Small Ruminant Res 111:23–30

Maxwell AF (1959) Statistical methods in factor analysis. Psychol Bull 56:228–235

Mein GA, Reinemann DJ, Schuring N, Ohnstad I (2004) Milking machines and mastitis risk: A storm in a teat-cup. In Proceedings of the 43rd Annual Meeting of the National Mastitis Council, USA

Mingoas KJP, Awah Ndukum J, Dakyang H, Zoli PA (2017) Effects of body conformation and udder morphology on milk yield of zebu cows in North region of Cameroon. Vet. World 10:901-905

Nakov D, Hristov S, Andonov S, Trajchev M (2014) Udder-related risk factors for clinical mastitis in dairy cows. Vet Arh 84:111–127

Neijenhuis F, Barkema HW, Hogeveen H, Noordhuizen JPTM (2000) Classification and longitudinal examination of callused teat ends in dairy cows. J Dairy Sci 83: 2795-2804

Neijenhuis F, Barkema HW, Hogeveen H, Noordhuizen JPTM (2001) Relationship between teat-end callosity and occurrence of clinical mastitis. J Dairy Sci 84: 2664-2672

Nemcova E, Stipkova M, Zavadilova L, Bouska J, Vacek M (2007) The relationship between somatic cell count, milk production and six linearly scored type traits in Holstein cows. Czech J Anim Sci 52:437–446

Patel YG, Trivedi MM, Rajapura RM, Savaliya FP, Parmar M (2016) Udder and Teat Measurements and Their Relation with Milk Production in Crossbred Cows. Int J Sci Environ Technol 5:3048-3054

Posadas MV, Valdenegro HHM, Lopez FJR (2008) Genetic parameters for conformation traits, stayability and milk yield for Holstein dairy cattle in Mexico. Técnica pecuariaen México 46:235-248

Sabuncuoglu N, Coban O (2007) Relationship between udder and teat conformation and milk yield performance in dairy cows pre- and post-milking. Can J Anim Sci 87: 285–289

Sadak MH, Al-Aboud AZ, Ashmaway AA (2006) Factor analysis of body measurements in Arabian horses. J Anim Breed Genet 123: 369–377

Salako AE (2006) Principal component factor analysis of the morpho structure of immature Uda sheep. Int J Morphol 24:571–574

Sezenler A, Ceyhan A, Yuksel MA, Taner OA, Yildirir M (2016) Effect of parity and type of lambing on performance and udder traits of Bandirma ewes. Indian J Anim Sci 86 :572–577

Sharma A, Sindhu N (2007) Occurrence of clinical and subclinical mastitis in buffaloes in the State of Haryana (India). Ital J Anim Sci 6:965-967

Singh RR, Dutt T, Singh M, Kumar A (2010) Association of udder and teat dimensions with production traits in Vrindavani cattle. Indian J Dairy Sci 63:455-458

Singh RS, Bansal BK, Gupta DK (2014) Udder health in relation to udder and teat morphometry in Holstein Friesian X Sahiwal crossbred dairy cows. Trop Anim Health Prod 46:93–98

Singhai SK, Ravikala K, Murthy KS, Gajbhiye PU, Vataliya PH, Savsani HH (2013) Udder teat morphology and body measurements and their relationship with milk yield and milking traits in Gir cows. Indian Society of Animal Production and Management 29:5-11

Sorensen MK, Jensen J, Christensen LG (2000) Udder conformation and mastitis resistance in Danish first lactation cows: heritabilities, genetic and environmental correlations. Acta Agric Scand. - A: Anim Sci 50:72-82

SPSS (2001) Statistical Package for Social Sciences. SPSS Inc., 444 Michigan Avenue, Chicago, IL, USA

Stamschror J (2000) Judging Dairy Cattle. https:// www.aphis.usda.gov/ animal_health/ emerging issues/ compensation/ downloads/ judgingdairycattle.pdf. Accessed 15 May 2020

Tapki I, Guzey YZ (2013) Genetic and phenotypic correlations between linear type traits and milk production yields of Turkish Holstein dairy cows. Greener J. Agric. Sci. 3(11):755-761

Varshney JP, Mukherjee R (2002) Recent advances in management of bovine mastitis. Intas Polivet 1:62-65

Vukasinovic N, Moll J, Kunzi N (1997) Factor analysis for evaluating relationships between herd life and type traits in Swiss Brown cattle. Livest. Prod. Sci.49:227-234

Waghmore P, Siddiqui MF (2000) Studies on correlation of different udder and teat measurements with lactation milk yield in case of Holde crossbred cows, Karnataka. J Agric Sci. 13(3):802-804

Wilmink JBM (1996) Indices for super traits versus total merit index: Theoretical considerations and practical benefits. Proceedings of the Open Session of the Interbull Annual Meeting, Veldhoven, the Netherlands, Jun. 23–24, pp 88–90, Interbull Bulletin 14:88-90 (in Sweden)

Yunusa AJ, Salako AE, Oladejo OA (2013) Principal component analysis of the morphostructure of Uda and Balami sheep of Nigeria. Int J Agric Sci 1:45–51

Zwertvaegher I, Van Weyenberg S, Piepers S, Baert J, De Vliegher S (2012) Variance components of teat dimensions in dairy cows and associated factors. J Dairy Sci 95:4978-4988