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Factor analysis for udder and teat type traits in Sahiwal and Karan Fries cows

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ABSTRACT

Selecting female cows for productivity based on udder and teat traits is essential in field due to lack of available records. The objective of the present study was to reduce the dimensionality of the 17 udder and teat traits and to analyse their impact on milk productivity. The data on 256 cattle comprising 133 Sahiwal and 123 Karan Fries cows were used in this study over the years 2017-2019 from Livestock Research Centre (LRC) of ICAR-National Dairy Research Institute, Karnal. The 17 udder and teat traits were fore udder attachment (FUA), rear udder width (RUW), rear udder height (RUH), udder balance (UB), udder depth (UD), udder length (UL), udder width (UW), udder circumference (UC), central ligament/udder cleft (CL), teat circumference (TC), fore teat length (FTL), rear teat length (RTL), distance between fore and rear teat (DFR), distance between left and right teat (DLR), shortest distance from floor to fore teat (SDFT), shortest distance from floor to rear teat (SDRT) and teat diameter (TD). In the factor analysis, first five latent factors accounted for 62.22% of total variance in udder and teat measurements for Sahiwal cows and 65.67% in Karan Fries (KF) cows, respectively. In Sahiwal cows F1 represented better udder support and wideness (wide udders, udders were supported by strong suspensory ligament), whereas in KF cows, first factor reflected better udder dimension and distance between teats (longer length, width of udder and well placed teats). Factor analysis could reduce the multicollinearity of the data. It can be concluded that inclusion of udder and teat measurements in selection index can be a reliable criteria for selecting cows for higher milk yield.

Keywords: Factor analysis, Karan Fries, Sahiwal

India has 192.49 million cattle, which includes 142.11 million indigenous cattle and 50.42 million crossbred cattle (http://dadf.gov.in). In spite of the huge livestock diversity, the productivity is 4.07 kg of milk per day for indigenous cows and 8.32 kg for crossbred cattle (DAHDF 2023), which is low in comparison with the productivity of exotic improved cattle. There are several reasons for low averages like low selection intensity, inadequate coverage of genetic improvement programs, inadequate nutrition supply, poor reproductive health services, harsh climatic conditions, etc. (Gowane *et al*. 2019). One important factor is unavailability of data and pedigree records in the field due to which selection of superior animals is difficult and mostly eyeball selection takes place, which lacks accuracy. Recently, there is availability of improved semen doses from government and private labs in India, however, selecting within the available female stock is a challenge. Alternate approaches for selecting better females, even with minimum data records availability is the need of the hour. Traits which are usually of biometrical measurements on the body can support this cause of indirect selection. The durability component included longevity, body size, overall udder, feet and legs, final score, other conformation traits, milking temperament, and meat quality.

Until recently, in India, the sole selection criteria for any improvement program has been focused on increasing milk production. Realising huge diversity among Indian breeds and the importance of type traits, National Dairy Development Board (NDDB) started recording type traits in 2014 for incorporating it in selection criteria (NDDB 2017).

In present research 17 udder and teat traits in Sahiwal and KF cows was studied by realising their importance for milk productivity. The aim was also to reduce the dimensionality for 17 traits' using factor analysis. The study investigated the use of obtained factors for explaining the variance in milk yield in these two genetic groups.

MATERIALS AND METHODS

Traits measured: Data on 17 traits for 133 Sahiwal and 123 KF cows were collected between years 2017 to 2019 from Livestock Research Centre, ICAR-National Dairy Research Institute, Karnal, Haryana. The 16 udder and teat measurements were in centimeters except for udder attachment which was in degrees (the soundness of attachment of fore udder to abdominal wall). Rear

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udder width (RUW), rear udder height (RUH) and central ligament/udder cleft (CL) were measured as per NDDB 2017 guidelines. The udder balance (UB): measured as the level of the rear udder was assessed in relation to the depth of the front udder; udder depth (UD): measured as the distance from the hock to the lowest part of the udder floor by a line drawn imaginary. The udder length (UL): measured from the rear attachment of the udder close by the escutcheon to the front of the udder where it combines evenly with the body. The udder width (UW): measured as a distance linking two lateral lines of attachment of the udder to abdominal wall, below the flank. Front and rear teat length (FTL and RTL): measured from the higher part of the teat, where it dangles perpendicularly from the quarter to the tip of teat. The distance between fore and rear teat (DFR), distance between left and right teat (DLR): measured as the distance linking teats at midpoint of the teat length. Mean of distance from pair of the front teat ends to floor was taken as the shortest distance from floor to fore teat (SDFT) and from rear teats was shortest distance from floor to rear teat (SDRT). Teat diameter (TD) was measured at the mid-point length by Vernier Calliper and Teat circumference was measured with a measuring tape at the midpoint of teat length.

Analysis: The data for udder and teat traits were corrected for the non-genetic factors prior to start of principal components and factor analysis. The sources of variation were stage of lactation which was divided into 4 stages, i.e. 0-90 days, 90-180 days, 180-270 days and >270 days; parity (1-5 or >5); season of calving Summer: April–June, Rainy: July–August, Autumn: September–November, Winter: December–March. Udder and teat measurements were done by metal tape before afternoon milking.

The factor analysis was performed using SPSS (22) on the 17 udder and teat conformation traits in Sahiwal and KF cows. SPSS was used to extract 17 factors as there are 17 variables. In an exploratory analysis, the eigenvalue was calculated for each factor extracted from the analysis and it was used to determine the number of factors to be extracted. A cut off value of one is generally used to determine factors based on eigenvalues.

The exploratory factor analysis is run and used for understanding their biological meaning and in what extent each one of them explain part of one of the original traits. The statistical procedure involves, selecting udder and teat traits with statistical hypothesis testing of the factor loading in exploratory factor analysis and drawing inferences about the significant udder and teat traits. Correlation matrix was used to ensure that traits were weighted equally in the exploratory factor analysis. Out of 17 factors, only those were retained whose eigenvalues were greater than 1. The sphericity test of Bartlett's (1950) was used for significance testing.

Where, n, sample size; p, number of variables; , determinant of the correlation matrix. It follows χ^2 distribution with $[1/2\,(p^2\text{-}p)]$ degree of freedom. Eigenvalues greater than 1 represented the minimum number of factors which explained relationships among the udder and teat traits conformation data. After the decision was made on how many principal factors to extract and retain from the original set of variables, exploratory factor analysis with the varimax rotation as described by Kaiser (1958) was carried out to obtain factors such that each factor had only the minimum number of traits with large absolute values of loadings. The process was implemented with the Statistical Package for the Social Sciences (IBM SPSS Statistics 22) software.

The data on 305-d lactation yield were obtained for the Sahiwal and KF cows maintained at Livestock Research Center, National Dairy Research Institute over period from 2017-2019. Facilities for food were similar for all cows included in this study. The normal lactation was considered as the period of milk production by a cow for at least 200-d. Data were adjusted for significant non genetic factors. The association of 17 traits was studied separately with the 305d milk yield in Sahiwal as well as KF using multiple regression analysis. One trait per time was regressed and then performed a multiple testing correction using Bonferroni adjustment. If a significance threshold of α is used, but n separate tests are performed, then the Bonferroni adjustment deems a score significant only if the corresponding P-value is $\leq\alpha/n$. Regression of each of the 17 traits separately was done for dependent variable and the P-value was subjected to Bonferroni correction.

RESULTS AND DISCUSSION

Morphometric of udder and teat traits in Sahiwal and Karan Fries cows: The descriptive statistics of the udder and teat traits in Sahiwal and KF cows are presented in Table 1. From results it can be inferred that the breed wise differences existed for average values of all the traits, with higher dimensions in KF over Sahiwal. As compared to Karan Fries cows, Sahiwal cows had smaller and narrower rear udder, however the teat length was higher in Sahiwal as compared to KF. The higher milking potential of the KF resulted in higher dimensionality over Sahiwal.

High coefficient of variation for most of the traits in both the genetic groups in present study suggests that previously selection was not practiced for udder and teat traits in KF and Sahiwal. This occurs as the main focus of animal breeders towards increasing milk production irrespective of biometrical measurements. Strong fore udder attachment is of great importance in dairy cows for selection by animal breeders and preferred over intermediate and loose attachment, since it indicates the integrity and support of the udder which must be well adhered to abdomen of cow and a strong median suspensory ligament essential for udder conformation. Fernandes *et al*. (2019) reported that poor fore udder attachment leads to impaired longevity of the mammary glands of high-yield cows. Rear udder width is indicator of udder capacity in cows and intermediate RUW should be preferred over other groups because it can lead to less susceptibility for predisposition to mastitis. The high rear udder height depicts increasing capacity for

Table 1. Descriptive statistics of udder and teat type traits in Sahiwal and Karan Fries cows

Trait	Sahiwal			Karan Fries		
	Mean±SE	Standard deviation	CV(%)	Mean±SE	Standard deviation	CV(%)
FUA (degree)	116.10±1.18	13.61	11.72	123.00±1.27	14.12	11.47
RUW (cm)	6.29±0.91	2.23	35.45	9.31±0.22	2.473	26.53
RUH (cm)	19.30±0.39	4.59	23.78	25.70±0.35	3.98	15.4
UB (cm)	-1.34±0.30	3.56	-2.65	-0.63±0.46	5.125	-8.12
UD (cm)	28.07±0.79	9.22	32.84	36.63±0.76	8.504	23.20
UL (cm)	53.92±0.68	7.95	14.74	61.63±0.71	7.918	12.83
UW (cm)	56.84±0.95	10.99	19.33	69.83±0.92	10.28	14.72
UC (cm)	122.84±1.35	15.60	12.69	129.61±1.65	18.372	14.17
CL (cm)	4.27±0.21	2.50	58.54	4.30±0.16	1.845	42.79
TC (cm)	9.13±0.17	2.06	22.56	7.602±0.08	0.904	11.84
RTL (cm)	6.11±0.18	2.13	34.86	4.703±0.11	1.283	27.23
FTL (cm)	6.27±0.18	2.17	34.60	5.292±0.11	1.401	26.46
DFR (cm)	4.97±0.20	2.36	47.48	7.934±0.23	2.627	33.03
DLR (cm)	5.08±0.17	2.06	40.55	7.295±0.27	2.99	41.01
SDF (cm)	40.16±0.50	5.84	14.54	48.56±0.59	6.585	13.55
SDR (cm)	38.12±0.50	5.82	15.2	48.554±0.60	6.6545	13.69
TD (cm)	1.81±0.06	0.71	39.22	1.50±0.04	0.4698	30.66

Fore udder attachment (FUA), rear udder width (RUW), rear udder height (RUH), udder balance (UB), udder depth (UD), udder length (UL), udder width (UW), udder circumference (UC), central ligament/udder cleft (CL), teat circumference (TC), fore teat length (FTL), rear teat length (RTL), distance between fore and rear teat (DFR), distance between left and right teat (DLR), shortest distance from floor to fore teat (SDF), shortest distance from floor to rear teat (SDR), teat diameter (TD).

storage of milk and is preferred over other groups because this will prevent sagging of the udder and prevent it from environmental trauma that includes contact of udder with floor by shortening distance of udder from the floor in the animal. Comparatively higher values for RUH were reported by Oshin (2019) and Kumari (2019) in Sahiwal Cows. Intermediate udder depth should be in practice for selection because appropriate depth of udder helps to prevent from mastitis and injury.

In the present study most of the animals are with intermediate udder width in both breeds but a higher udder width have the advantage in productive life due to high milk production and reduced risk of injury. In present study, most of the animals are with intermediate cleft in both the breeds but a stronger cleft can lead to minimisation of the potential for injuries and maximizing milking management by keeping the teats in place and udder elevated and can have a longer stay in the herd.

The highest frequency for teat circumference was observed in intermediate group followed by short group in both Sahiwal and Karan Fries cows. An intermediate to thin teat circumference is the most desirable measure for better udder health. Over thick teats is considered as undesirable trait which can impair the milking process.

Pearson correlation and communalities for udder and teat traits in Sahiwal and Karan Fries cows: In the present study, the estimate of Pearson correlation between udder and teat traits are presented in Table 2 and 3 in Sahiwal and KF. The non-significant correlation was found for UD with TL and significant ($P<0.01$) for UD with TD, indicating increasing udder diameter will result in increase in teat diameter in Sahiwal as well as KF.

High correlation between FTL and RTL, RUH and RUW in Sahiwal cows, indicates that breeding programme can be successful by keeping only one trait in the case if they are highly correlated, thereby reducing number of traits assessed on each animal (Boholouli *et al*. 2015). Positive and significant correlations suggests higher predictability among traits (Vohra *et al*. 2015). Similar results have been reported by Sinha *et al*. (2020). Based on the correlation estimates, prediction can be done breed wise, whether increasing one trait will have positive or negative impact on the other trait or not. The genetic differences between the breeds reflected on the correlation between the traits. Many traits which are positively associated with each other in Sahiwal were not so in KF and vice-versa. However, the data size in this study is small; therefore conclusions are not encouraged from the present correlation estimates.

The communality ranged from 0.06 (UB) to 0.93 (RUW) in Sahiwal cows and in Karan Fries cows, ranged from 0.20 (RUH) to 0.76 (FTL) for all these 17 different udder and teat traits (Supplementary Table 5).

Dimensionality reduction for udder and teat traits using factor analysis in Sahiwal and Karan Fries cows: In the present study, factor analysis was applied to 17 udder and teat conformation traits in Sahiwal and KF cows separately. The results along with eigenvalues and the proportion of the phenotypic variation explained by each factor are depicted in Supplementary Table 1 and 2. Five latent factors had an eigenvalue ≥1. The general mean of Kaiser Meyer Olkin (KMO) measure of sampling adequacy (MSA) was obtained as 0.682 and 0.697 in Sahiwal and

Table 2. Pearson correlation among udder and teat type traits in Sahiwal cows

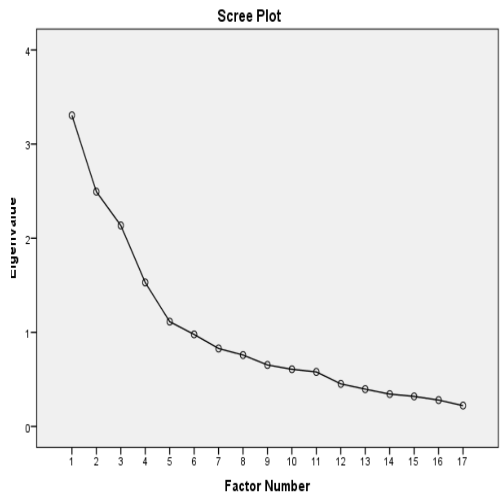
Trait	FUA	RUH	RUW	UL	UW	UC	UD	UB	CL	TT	FTL	RTL	DFR	DLR	SDF	SDR	TD
FUA	1.000																
RUH	0.170	1.000															
RUW	0.193*	0.610**	1.000														
UL	-0.112	-0.038	-0.071	1.000													
UW	-0.134	-0.019	-0.043	0.660**	1.000												
UC	-0.040	0.010	0.094	0.081	0.107	1.000											
UD	0.084	0.051	0.374**	-0.428**	-0.362**	0.334**	1.000										
UB	0.066	-0.005	-0.072	0.021	-0.018	-0.113	-0.024	1.000									
CL	-0.147	-0.014	-0.041	0.485**	0.490**	-0.119	-0.381**	0.107	1.000								
TT	0.008	-0.104	-0.114	0.041	0.040	0.182*	0.015	0.079	0.054	1.000							
FTL	0.123	0.005	0.046	0.282**	0.192*	0.209*	-0.148	0.076	0.267**	0.315**	1.000						
RTL	0.015	-0.140	-0.106	0.102	0.027	0.068	-0.141	0.209*	0.208*	0.296**	0.594**	1.000					
DFR	0.127	0.101	0.093	0.310**	0.303**	0.156	-0.012	-0.035	0.035	0.067	0.063	-0.098	1.000				
DLR	0.038	0.082	0.168	-0.010	0.096	0.310**	0.291**	-0.120	-0.130	0.025	-0.117	-0.199*	0.335**	1.000			
SDF	0.024	-0.124	-0.079	-0.383**	-0.356**	-0.234**	0.198*	0.003	-0.369**	-0.201*	-0.382**	-0.286**	-0.146	-0.211*	1.000		
SDR	0.093	-0.010	0.032	-0.171*	-0.191*	-0.175*	0.011	-0.098	-0.216*	-0.173*	-0.285**	-0.293**	-0.070	-0.121	0.388**	1.000	
TD	0.064	-0.015	0.144	-0.298**	-0.257**	0.368**	0.370**	0.044	-0.060	0.436**	0.286**	0.233**	-0.160	-0.009	-0.083	-0.169	1.000

* Significant at 5% level of significance, ** Significant at 1% level of significance.

KF cows indicating the existence of significant correlations between udder and teat conformation traits. This estimate provided enough evidence for the suitability of the data for factor analysis, as KMO-MSA should be greater than 0.5 for satisfactory factor analysis (Hair *et al*. 2009). Similar values for KMO were reported by Sinha *et al*. (2020) in indigenous Sahiwal cattle. The overall significance of the correlation matrix using Bartlett's test of sphericity for the udder and teat traits was significant ($P<0.001$) which means correlation matrix is not an identity matrix and provided enough support for the validity of the factor analysis of data.

There could be more than one criterion to decide how many components can be used which can explain the sizable variance. The scree plot can also help in depicting the various components which can be used to decide the actual number of the components to be included for analysis, components having eigenvalues up to "bent of elbow" are usually considered. The scree plot in this study depicted extraction of five components in both breeds (Fig. 1).

A



B

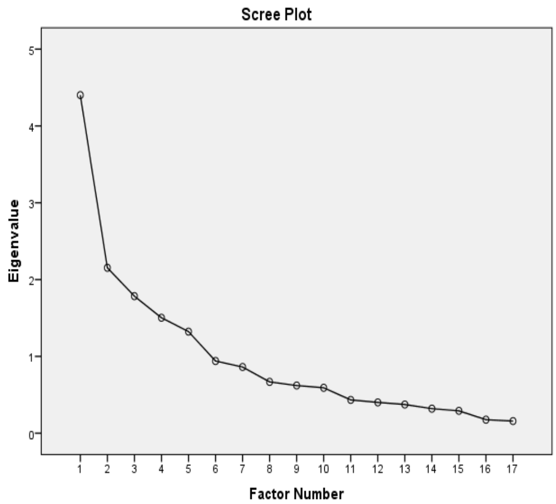


Fig. 1. Scree plot showing factor number with eigenvalues in Sahiwal and Karan Fries cows.

Table 3. Pearson correlation among udder and teat type traits in Karan Fries cows

Trait	FUA	RUH	RUW	UL	UW	UC	UD	UB	CL	TT	FTL	RTL	DFR	DLR	SDF	SDR	TD
FUA	1.000																
RUH	-0.088	1.000															
RUW	-0.019	-0.017	1.000														
UL	-0.003	-0.224**	0.088	1.000													
UW	-0.031	-0.252**	0.021	0.491**	1.000												
UC	0.319**	-0.246**	0.222*	0.318**	0.282**	1.000											
UD	0.004	-0.152	0.275**	-0.275**	0.012	0.042	1.000										
UB	0.008	-0.029	-0.029	-0.085	0.017	-0.195*	0.237**	1.000									
CL	-0.042	0.084	-0.207*	0.110	0.242**	-0.116	-0.089	0.218*	1.000								
TT	-0.239**	-0.039	0.173	0.430**	0.450**	0.197*	-0.121	0.027	0.248**	1.000							
FTL	-0.070	0.080	0.102	0.286**	0.176	0.217	-0.159	-0.062	0.154	0.479**	1.000						
RTL	-0.057	0.048	0.030	0.303**	0.257**	0.097	-0.114	0.098	0.174	0.477**	0.767**	1.000					
DFR	-0.024	0.028	-0.150	0.329**	0.476**	-0.061	-0.123	0.186*	0.264**	0.209*	0.069	0.100	1.000				
DLR	-0.141	-0.270**	0.210*	0.378**	0.422**	0.145	0.040	-0.139	-0.111	0.255**	0.030	0.032	0.173	1.000			
SDF	-0.036	0.154	0.013	-0.268**	-0.583**	-0.287**	0.080	-0.024	-0.369**	-0.445**	-0.334**	-0.296**	-0.149	-0.303	1.000		
SDR	0.056	0.196*	-0.069	-0.431**	-0.609**	-0.156	-0.079	-0.197*	-0.324**	-0.475**	-0.275**	-0.335**	-0.351	-0.417	0.677**	1.000	
TD	-0.175	-0.175	0.388**	0.153	0.274**	0.373**	0.148	-0.067	-0.203*	0.499**	0.315**	0.343**	-0.152	0.329	-0.250**	-0.300**	1.000

* Significant at 5% level of significance, ** Significant at 1% level of significance.

The five factors after varimax rotation also explained 62.22% and 65.67% of the total variation among the 17 udder and teat conformation traits but with differences in terms of magnitude of each eigenvalue and the proportion of variance explained by each factor in Sahiwal and Karan Fries cows, respectively. The pattern coefficients using varimax rotation and communalities for both breeds are shown in Supplementary Table 3, 4 and 5. Only loading coefficients ≥|0.35| (Chu *et al*. 2002) were reported for each udder and teat measurements. High correlation between the traits in the present study, suggests that the multivariate techniques are more efficient than the measured phenotypes in implementing aggregate selection index for breeding purpose (Olasege *et al*. 2019). Olasege *et al*. (2019) also reported 60.37% vaiation in Chinese Holstein cattle by retaining 7 components for PCA as well as factor analysis. Sinha *et al*. (2020) accounted for 75.77% variance using 6 components for 17 linear udder traits in indigenous Sahiwal cows by PCA. Mazza *et al*. (2016) selected 6 common latent factors which explained 63% of the total variance in Rendena and 58% in Aosta Red Pied cattle for 20 and 22 type traits, respectively.

In the present study, the factor 1 (F1) was heavily loaded for UL (0.73), UW (0.68) and CL (0.63) in Sahiwal cows whereas in KF cows, with UL (0.58), UW (0.81), TC (0.47), DFR (0.47) and DLR (0.57). In Sahiwal cows F1 represented better udder support and wideness (wide udders, udders were supported by strong suspensory ligament). In Karan Fries cows, first factor reflected better udder dimension and distance between teats (longer length and width of udder and well placed teats). In Karan Fries and Sahiwal cows, factor 1 included with higher loading for udder and teat conformation traits which indicates scope in improvement in milk production as well as persistency by including in selection index, since there is high genetic correlation between type traits and persistency, persistency of animals is important as more persistent lactations bring longer high-production periods (Sharma *et al*. 2018). By including the traits of F1 in selection index and decisions, both breeds are expected to have increasing teat-end-to-floor distance which is preferred because decreasing teat-end-to-floor distance serve as risk factors for clinical mastitis and periparturient udder edema. The factor 2 (F2) with 14.67% variability had higher loadings on FTL (0.43), RUW (0.47), UC (0.51) and UD (0.51) in Sahiwal cows, whereas in KF cows it had loadings on FTL (0.86), RTL (0.80) and TC (0.54) with 12.66% variability. By including factor 2 in selection index, Sahiwal and KF cows are expected to have intermediate teats placement and is preferred because long teats are more easily damaged due to increased susceptibility to injury, whereas short teats are favored for milking machine systems.

Udder and teat traits defines milk yield potential of cows: The association of 17 'udder and teat' traits was studied separately with the 305-d milk yield in Sahiwal as well as KF using multiple regression analysis. The bonferroni significance threshold was 0.0029 for P-value. None of present P-value cross that mark for Sahiwal and Karan Fries cows, respectively (Supplementary Table 6 and 7). This indicated that trait wise association for prediction of milk yield was futile. The regression of 17 udder and teat traits with the 305-d milk yield obtained no encouraging results mostly due to small data size in the present study. However this does not suggests that the teat and udder traits do not have association with milk yield per se. Further studies with more data on udder and teat traits and milk yield records are warranted before reaching a conclusion. Kern *et al*. (2014) obtained high linear regression coefficients for prediction of milk yield for 305-d of first lactation and longevity and Noskova *et al*. (2019) for prediction of milk yield by using linear type traits, highlighting the importance of type traits as indirect measure of production.

In India, the breed improvement programs are still not covering most of the population and works on simple principle of increasing milk yield through selection. To increase the economic value of animals, profitability of farm need to be increased by focusing on durability (udder and teat type traits), production and reproduction traits by creating selection index. Using biometrical measurements in combination with production traits can help to achieve increased longevity, persistency and herd life of animals. It is also possible to select cows for their strength, mastitis resistance, production and reproductive efficiency and look for morphometric markers in udder and teat traits which can define overall genetic merit of the cow. However, at the same time reduction in multicollinearity must also be taken in to consideration. The best way for properly selecting for durability is to know the genetic correlations existing among the traits of interest (production and functionality including longevity) and to use this information for properly assigning the economic weights to the selection index. Further study can be planned in future with addition of more data and information from genomic and pedigree sources to look for the impact of type traits in overall dairy cattle productivity.

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