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GENETIC AND PHENOTYPIC CORRELATIONS BETWEEN LINEAR TYPE TRAITS AND MILK YIELD IN SAHIWAL COWS

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The traits of economic importance in farm animals are mostly controlled by many gene pairs and hence show correlations. The knowledge of such correlations is very much needed while making multiple traits selection in farm animals. The present study was planned with the objectives to find out genetic and phenotypic correlations between linear type traits and milk yield in Sahiwal cows. Freshly calved 310 cows were scaled and scored for traits on a linear scale of 1-9 following the guide lines of International Committee on Animal Recording. The variance and covariance components were estimated using residuals or restricted maximum likelihood (REML) procedures. The linear mixed model was fitted for estimation of variance. Bivariate animal model analysis was performed for estimation of genetic and phenotypic correlations. Stature, angularity, rear udder height, fore teat length, dewlap width, foot angle, udder depth and rear udder width were significant sources of variation for score-day milk yield ($P<0.05$-$P<0.001$). The 305-day milk yield was influenced by linear type traits of rump angle, rump width, central ligament and rear udder width ($P<.05$-$P<.001$). Highest positive genetic correlations were for rear udder width with score-day milk yield (0.43±0.00) and 305 days milk yield (0.40±0.00). The highest negative genetic correlation (-0.27±0.00 and -0.23±0.00) was found of udder depth with score-day milk yield and 305-day milk yield. The phenotypic correlations ranged from -0.23±0.06 between udder depth and score-day milk yield to 0.54±0.04 between rear udder width and score-day milk yield. The genetic and phenotypic correlations will help to short list the type traits and put focus on those that are more important. The linear scoring in Sahiwal cattle should be initiated at public and private farms.
Keywords: Genetic traits, genetic correlation, milk yield, cattle breeds.

INTRODUCTION

Dairymen, extension workers and researchers have long been debating on the issue of relative importance of milk yield and type traits. Fact remains that milk yield of cow is still a trait of primary importance. At the same time, it is accepted that good looking animals are not only a source of pride for the framers but also linked to higher lifetime profitability. The type or conformation of cow therefore cannot be overlooked. Moreover, the intensive systems of production compelled cows to produce more for a longer time. Longer stay of cows in the herd will increase profitability due to reduced cost of replacement (White, 1974).

The linear type traits have an influence on milk yield. Fifteen linear type traits have been declared as primary or standard traits (ICAR, 2002). The traits having heritability more than 0.10 and known economic importance are called primary traits while those having undetermined economic importance are called secondary. The later might be recorded as research trait and can be included in the list of primary traits if it has economic worth and heritability of desired magnitude (Lawstuen *et al*., 1987; Short *et al*., 1991). A research trait is therefore assumed to provide information dissimilar from other traits with different biological explanations.

Many researchers have studied various aspects of correlation of linear type traits with milk yield of cows from different cattle breeds. Genetic correlations between lactation milk yield and linear type traits of Holstein Friesian, Jersey and Guernsey breeds have been reported (Brotherstone, 1994; Visscher and Goddard, 1995; Cruickshank *et al.*, 2002; DeGroot *et al.*, 2002). Phenotypic correlations between linear type traits and first lactation yield of Guernsey and Friesian Holstein cows were reported (Meyer *et al.*, 1987; Cruickshank *et al.*, 2002). A few other studies have reported phenotypic and genetic correlations between linear type traits and fluid milk, lifetime milk yield, fat corrected milk and herd mate deviation milk (Foster *et al.*, 1988; Funk *et al.*, 1991; Klassen *et al.*, 1992; Harris *et al.*, 1992; Weigel *et al.*, 1997). The Sahiwal cattle breed has few very peculiar physical attributes. Such features are considered by the farmers while selecting animals and are also taken into account while marketing. Such attributes are also believed to have relation with milk yield of cows. Written account on the subject may be difficult to find out yet, farmers do have ideals which add to the beauty of their breeding stock. Some of the recent studies have focused on the issue and reported information on various aspects of linear score system in Sahiwal cattle. The heritability estimates for linear type traits of Sahiwal cattle and influence of non-genetic factors on such traits has been reported for the first time in Pakistan (Khan and Khan, 2015a; Khan and Khan, 2016). The linear score system for Sahiwal cattle has been developed (Khan and Khan, 2015b). The genetic and phenotypic correlations among linear type traits for Sahiwal cattle have been reported (Khan *et al*., 2008). The present study was planned with the objectives to study effect of primary and secondary linear type traits on milk yield and estimation of genetic and phenotypic correlations between type traits and milk yield in Sahiwal cattle. Such estimates are necessary for devising any breeding program.

MATERIALS AND METHODS

***Data collection*:** Freshly calved cows up to 5^{th} parity were selected from Livestock Experiment Station, Bahadurnagar, District Okara, Livestock Experiment Station, Jahangirabad, District Khanewal and Livestock Experiment Station, Khizerabad, District Sargodha Punjab (Pakistan). The linear scoring was made following the guidelines of International Committee on Animal Recording (ICAR, 2002). Seventeen primary and 3 secondary traits were scaled and scored on a scale of 1-9 at three stages of lactation (15-45 days, 90-120 days and 165-195 days postpartum). The definitions of linear type traits are presented in Table 1. For assigning linear score to dewlap surface area, the impression of moistened dewlap was obtained on a plane paper. The area of this plane paper was measured with the help of leaf area meter. In this way dewlap area of individual animal was used for linear scoring of said trait of animal. The average of three days yield (a day before day of scoring, on the day of scoring and after day of scoring) was treated as score-day milk yield. Whereas 305-day parity yield was calculated from weekly records routinely maintained at three farms. The data on animal ID, date of birth, date of classification, sire, dam and parity were also collected.

***Data analyses*:** For studying the influence of linear type traits on milk yield, a fixed effect model was fitted. The fixed effects included were herd, parity, stage of lactation and linear score for individual type trait. The cows were grouped into first parity and second and later parity cows. The stage of lactation was omitted while analyzing 305-day milk. The linear and quadratic effects of age of cow at classification were included as covariate in the model. There were 790 records available for analysis of average of three days milk yield of 310 cows. For studying the effect of linear type traits on 305-day milk yield, linear type traits records obtained on first stage of lactation were included in analysis after checks of consistency. The full statistical model for milk yield analysis assumed the following form:

$$Y_{ijklm} = \mu + H_i + P_j + S_k + L_l + e_{ijklm}$$

Table 1. **Definitions of linear type traits.**

Traits	**Score**		
	1-3	**4-6**	**7-9**
1. Stature	Short	Intermediate	Tall
2. Chest Width	Narrow	Intermediate	Wide
3. Body Depth	Shallow	Intermediate	Deep
4. Angularity	Lacks angularity	Intermediate	Very angular
5. Rump Angle	High pins	Intermediate	Extreme slope
6. Rump Width	Narrow	Intermediate	Wide
7. Rear Legs Set	Straight	Intermediate	Sickle
8. Rear Legs Rear View	Extreme toe out	Intermediate	Parallel feet
9. Foot Angle	Very low angle	Intermediate	Very steep
10. Fore Udder Attachment	Weak and loose	Intermediate	Extremely strong and tight
11. Rear Udder Height	Very low	Intermediate	High
12. Central Ligament	Convex to flat udder floor	Slight definition	Deep definition
13. Udder Depth	Below hock	Intermediate	Shallow
14.Teat Placement Rear view	Outside of quarter	Middle of quarter	Inside of quarter
15. Fore Teat Length	Short	Intermediate	Long
16. Rear Udder Width	Narrow	Intermediate	Wide
17. Thurl Width	Narrow	Intermediate	Wide
Secondary type traits			
18. Naval Length	Short	Intermediate	Long
19. Dewlap Width	Narrow	Intermediate	Wide
20. Dewlap Surface Area	Low	Intermediate	High
21. Dewlap Visual Score†	Light folds	Intermediate folds	Heavy folds

Trait 1-17 scored on a scale of 1-9 (ICAR, 2002) † = Score on a scale of 1-3.

Where Y_{ijklm} = milk yield record of animal, μ = overall mean, H_i = effect of i^{th} herd (1-3), P_j = effect of j^{th} parity (1-2), S_k = effect of k^{th} stage of lactation, L_l = effect of l^{th} linear type trait score, e_{ijklm} = random error

For estimation of genetic and phenotypic correlations between linear type traits and milk yield, bivariate animal model analysis was performed. The linear type trait scores and milk yield recorded at first stage of lactation were utilized for this analysis. For said purpose several runs were required to have estimates of variances and co-variances. The variance and covariance components were estimated using residuals or restricted maximum likelihood (REML) procedures developed by Patterson and Thompson (1971). The ASReml (Version 2.0) was the statistical package used (Gilmour *et al.*, 2007). The linear mixed model for estimation of variance components and genetic and phenotypic correlations between linear type traits and milk yield assumed the following form:

$$Y_{ijkl} = \mu + H_i + P_j + A_k + b_1(a_{ijkl}) + b_2\,(a_{ijkl})^2 + e_{ijklm}$$

Where Y_{ijklm} = combination of traits (linear type trait and milk yield) in bivariate form, μ = overall mean, H_i = effect of i^{th} herd (1-3), P_j = effect of j^{th} parity (1-2), A_k = random animal effect with mean zero and variance σ^2A, a_{ijkl} = age at classification, b_1 and b_2 = the linear and quadratic regression coefficients of age at classification, e_{ijklm} = random error

RESULTS

The analysis of milk yield traits including score-day milk yield and 305-day yield is presented in Table 2. Stature, angularity, rear udder height and fore teat length were significant source of variation for score-day milk yield (P<0.05). Dewlap width was a significant source of variation for score-day milk yield (P<0.01). Foot angle, udder depth and rear udder width were affecting score-day milk yield significantly (P<0.001). The linear type traits including chest width, body depth, rump angle, rump width, rear legs set, rear legs rear view, fore udder attachment, central ligament, teat placement rear view, thurl width, naval length, dewlap surface area and dewlap visual score were not significant source of variation for score-day milk yield (P<0.05). There was an increase observed in score-day milk yield with increase in linear score for stature, angularity, rear udder height, fore teat length and rear udder width. Score-day milk yield showed a decreasing trend with increase in linear score for foot angle, udder depth and dewlap width (Fig. 1). The 305-day milk yield was influenced by linear type traits of rump angle, rump width and central ligament (P<0.05). Rear udder width was a significant source of variation for 305-day milk yield (P<0.001). All other traits were not a significant source of variation for 305-day milk yield (P<0.05). Milk yield for 305-days showed an increasing trend with increase in linear score for rump angle and rear udder width. There was a decreasing trend for 305-day milk yield with increase in linear score for rump width (Fig. 2). Although, central ligament was statistically significant source of variation, yet, trend for predicted 305-days milk yield was not very clear.

Table 2. Analysis of variance for milk yield traits†.

Traits	Milk yield	
	Score-day yield	305-day yield
1. Stature	*	NS
2. Chest width	NS	NS
3. Body depth	NS	NS
4. Angularity	*	NS
5. Rump angle	NS	*
6. Rump width	NS	*
7. Rear legs set	NS	NS
8. Rear legs rear view	NS	NS
9. Foot angle	***	NS
10. Fore udder attachment	NS	NS
11. Rear udder height	*	NS
12. Central ligament	NS	*
13. Udder depth	***	NS
14. Teat placement rear view	NS	NS
15. Fore teat length	*	NS
16. Rear udder width	***	***
17. Thurl width	NS	NS
18. Naval length	NS	NS
19. Dewlap width	**	NS
20. Dewlap surface area	NS	NS
21. Dewlap visual score††	NS	NS

† * = Significant at (P<.05), ** = Significant at P<.01), *** = Significant at (P<.001), NS = Non-significant.

The genetic and phenotypic correlations between linear type traits and milk yield traits are presented in Table 3. In general, the genetic and phenotypic correlations were in lower range. Most of the genetic and phenotypic correlations were less than 0.20. The highest positive genetic correlations were for rear udder width with score-day milk yield and 305-day milk yield. The highest negative genetic correlation was found of udder depth with score-day milk yield and 305-day milk yield. The positive genetic correlations of considerable magnitude were of stature, body depth, fore teat length and thurl width with score-day milk yield. The secondary type traits have very low correlations with score-day milk yield and 305-day milk yield.

The phenotypic correlations between milk yield traits and linear type traits were in the same range as for genetic correlations. Positive phenotypic correlation in medium range was between rear udder width and 305-day milk yield. Phenotypic correlation with reasonable magnitude of rear udder height with score-day milk yield and 305-day milk yield were important.

Table 3. Genetic and phenotypic correlations between linear type traits and milk yield.

Traits	Phenotypic correlations		Genetic correlations	
	Score-day yield	**305-day yield**	**Score-day yield**	**305-day yield**
1. Stature	0.22±0.06	0.17±0.06	0.25±0.00	0.19±0.00
2. Chest Width	-0.17±0.06	-0.10±0.06	0.12±0.00	0.11±0.00.
3. Body Depth	0.10±0.06	0.01±0.06	0.23±0.00	0.15±0.00
4. Angularity	0.07±0.06	0.05±0.06	0.07±0.00	0.06±0.00
5. Rump Angle	0.01±0.06	0.06±0.06	-0.07±0.00	-0.03±0.00
6. Rump Width	-0.04±0.06	0.05±0.06	0.01±0.00	0.04±0.00
7. Rear Legs Set	-0.01±0.06	0.07±0.06	-0.05±0.00	-0.010±.00
8. Rear Legs Rear View	0.03±0.06	0.01±0.06	0.08±0.00	-0.06±0.00
9. Foot Angle	-0.20±0.06	-0.20±0.06	-0.18±0.00	-0.18±0.00
10. Fore Udder Attachment	-0.01±0.06	-0.07±0.06	-0.02±0.08	-0.06±0.00
11. Rear Udder Height	0.23±0.06	0.24±0.06	-0.05±0.00	-0.00±0.00
12. Central Ligament	-0.01±0.06	0.15±0.06	0.12±0.00	0.17±0.00
13. Udder Depth	-0.23±0.06	-0.16±0.06	-0.27±0.00	-0.23±0.00
14. Teat Placement Rear View	-0.06±0.06	-0.03±0.06	-0.03±0.00	-0.03±0.00
15. Fore Teat Length	0.09±0.06	-0.02±0.06	0.22±0.00	0.15±0.00
16. Rear Udder Width	0.54±0.04	0.50±0.05	0.43±0.00	0.40±0.00
17. Thurl Width	0.09±0.06	0.07±0.06	0.22±0.00	0.17±0.00
18. Naval Length	0.15±0.06	0.11±0.06	0.09±0.00	0.07±0.00
19. Dewlap Width	0.06±0.06	-0.04±0.06	0.11±0.00	0.04±0.00
20. Dewlap Surface Area	0.12±0.06	0.07±0.06	0.15±0.00	0.10±0.00
21. Dewlap Visual Score	0.12±0.06	-0.02±0.06	0.14±0.00	0.05±0.00

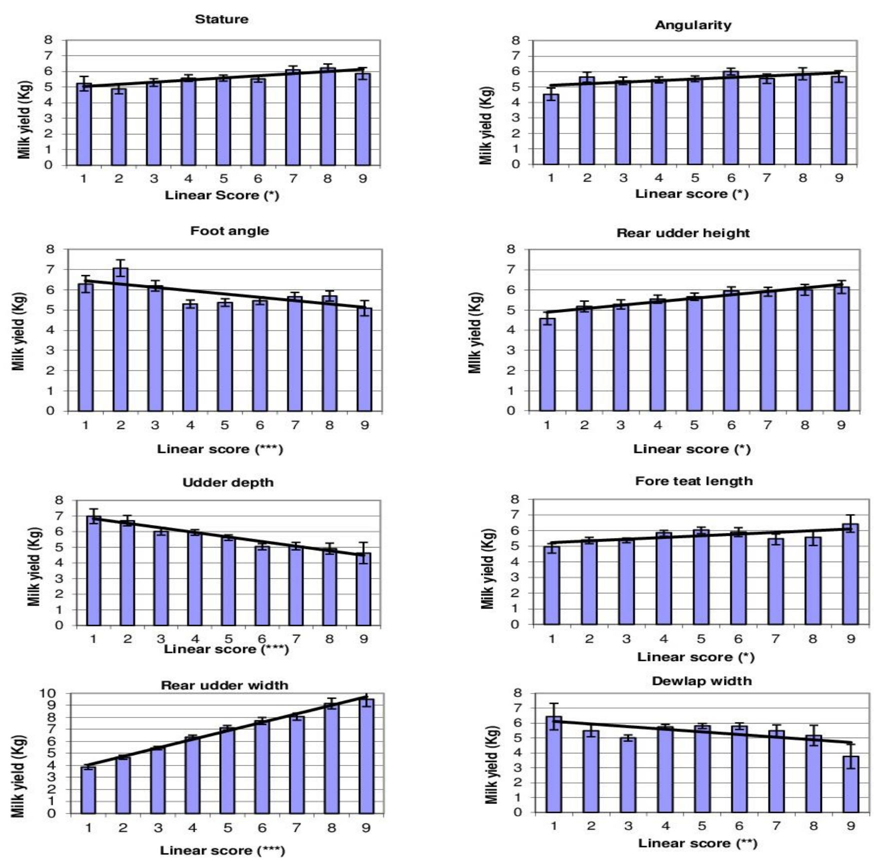

Figure 1. Effect of linear type traits on score-day milk yield.

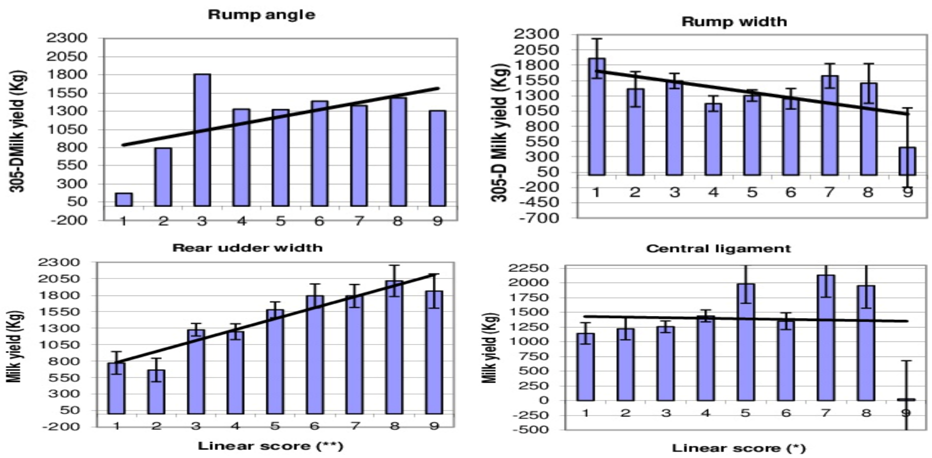

Figure 2. Effect of linear type traits on 305-days milk yield.

Negative phenotypic correlations of foot angle with score-day milk yield and 305-day milk yield were considerable. Many of other phenotypic correlations between linear type traits and milk yield were of low magnitude and negligible.

DISCUSSION

High producing cows inclined to have lower udders, similar to findings of (Burnside *et al.,* 1963). Decrease in 305-day milk yield with increase in linear score for teat length in the present study was contrary to the findings of (Hickman, 1964) in Holsteins and Ayrshires, where cows with short front teats produced significantly more milk up to 180 days of lactation. The breed differences could be the reason for such dissimilar findings. Secondly most of the farms adopt practice of machine milking in advance countries where as in Pakistan cows are milked manually. This difference of practice could affect teat length and hence different research findings. Current findings of association of more milk on the day of measurement with cows taller at hip and possessing deeper than average udders were in consensus to the results of (Shanks and Spahr, 1982) and as for this study; milk production was negatively associated with udder depth. The udder depth is assigned linear score with reference to floor of the udder and hock position. The intermediate score is given to cows having udder floor balanced with hock. The magnitude of the score above hock increases and below hock decreases. Increase in linear score for udder depth results shallow udder. As a result milk is decreased. As the linear score decreases udder becomes deeper and milk is increased. But cows with deeper udder become more prone to mastitis and injury (Rogers, 1993). So while selecting cows one should keep in mind the balance between two ideals. As for present study, high yielding Caucasian cows were taller as compared to low yielding cows (Khachatryan, 1989). The height of the animal has some relation with body weight and hence with production. The bigger cows produce more milk as compared to smaller cows. Non-significant effect of angularity on 305-day milk yield was not in consensus to the findings of (Foster *et al.,*1989) in a study on Holsteins. The linear score to angularity is assigned visually. The visual judgments may vary widely resulting in dissimilar results for different studies. Association of rump width with 305-day milk yield was not different from findings of (Patel and Tomer, 1990) for crossbred heifers. Rump width is also bone and structure associated trait that depicts the size of the cow. Wider rump could provide better roof for udder development and hence more milk yield.

With a few exceptions, most of the correlations between milk yield traits and linear type traits indicated that different genes were controlling these traits. Indirect selection for milk yield on the basis of linear type traits will not be very effective. The positive genetic and phenotypic correlations in medium range between rear udder width and milk yield traits indicated that selection for wider rear udder will result in increased milk yield. Keeping in view the genetic correlations with reasonable magnitude of linear type traits including stature, body depth, fore teat length and thurl width and score-day yield, selection for these traits will result a correlated response in milk. The negative genetic correlation between udder depth and milk yield showed that milk yield increased as udder became deeper. Cows with deeper udders have more chances of udder injury and mastitis (Rogers, 1993). So selection for increased milk yield can be practiced with care to avoid such problems. Positive genetic correlations with magnitude more than 0.20 of linear type traits and milk yield were desirable and can result in correlated response in milk yield.

The general behavior of genetic correlations between linear type traits and milk yield in the present study were not very different from other studies. Genetic correlation between stature and 305-day milk yield was not very different from 0.22 for Holstein Friesian (Brotherstone, 1994) and Guernsey (Cruickshank *et al.*, 2002) and 0.21 for Holsteins (DeGroot *et al.*, 2002). However, genetic correlation (0.30) higher than present study was reported between stature and 305-day milk yield of Guernsey cows (Harris *et al.*, 1992). Negative genetic correlation between udder depth and 305-day milk yield in the present study was in consensus to many other studies. The genetic correlation between udder depth and 305-day milk yield in present study was higher than -0.16 (Vollema and Groen, 1997), -0.12 (Foster *et al.*, 1988) and lower than -0.65±0.31 (DeGroot *et al.*, 2002), -0.52 (Meyer *et al.*, 1987), -0.51 (Cruickshank *et al.*, 2002), -0.50 (Funk *et al.*, 1991), -0.48 (Brotherstone, 1994) and -0.44 (Misztal *et al.*, 1992; Harris *et al.*, 1992). The genetic correlation in medium range with positive signs between udder depth and milk was reported for Holsteins in Turkey (Tapki and Guezy, 2013). This was the only correlation reported with positive signs between udder depth and milk yield. The difference might be because of difference in traits definition. It is pointed out that almost all of the studies have reported negative genetic correlation between udder depth and milk yield traits. The negative genetic correlations found between the udder depth and milk yield suggest that the maintenance of the present emphasis of selection of animals for milk yield result, as a correlated response, in deep udders. in other words, udder below the line of the hock, which could lead to health problems in the cow, such as accidental loss of a teat by stepping on it or through mastitis leading to increased premature and involuntary disposal. According to (Rupp and Boichard, 1999) Holstein cows with deep udders are commonly culled from French herds as they suffer from problems related to udder health. In linear scoring system the desirability of the trait does not move with the magnitude of the score. The high magnitude or low magnitude of the score does not depict the desirability or undesirability of the trait. Same is the case with udder depth in which medium score is ideal. Genetic correlation between rear udder width and 305-day milk yield in current study was higher than 0.31 reported for Holsteins (Misztal *et al.*, 1992) and lower than 0.65 (Cruickshank *et al.*, 2002) and 0.60 (Harris *et al.*, 1992) for Guernsey cows. It indicates that the genes responsible for high milk production also have some genetic control on rear udder with. It means making selection for rear udder width will result an associated increase in milk production. The genetic correlations of milk yield with stature, chest width, body depth and angularity higher than current study has been reported for dairy cows (Berry *et al*., 2004). Higher than current study genetic correlation >0.29 between angularity and milk yield has been reported for Holstein cows in Brazil (Raefal *et al*., 2015). Higher than current study genetic correlation between angularity and milk yield 0.48 has been reported for primiparous dairy cows (Berry *et al*., 2004). The difference in the magnitude of the correlation could also be due to trait definition procedures. Mostly the Angularity is assigned a score visually. Visual scoring might put personal variation while assigning the score. Breed differences could also affect the linear scores and genetic correlations might have dissimilar values.

The phenotypic correlation between rear udder width and 305-day milk yield in present study was higher than (0.22) reported for Holsteins by Misztal *et al.* (1992), 0.16 by Funk *et al.* (1991) and 0.11 by Foster *et al.* (1988). It was comparable to 0.40 by Harris *et al.* (1992) and 0.44 by Cruickshank *et al.* (2002). The phenotypic correlations between rear udder height and 305-day milk yield in present study was higher than (0.17) reported for Holsteins (Misztal *et al.*, 1992), 0.13 for Canadian Holsteins (Klassen *et al.*, 1992) and was not very different from 0.30 (Harris *et al.*, 1992) and 0.33 (Cruickshank *et al.*, 2002) for Guernsey cows. The phenotypic correlations indicate that all the traits were experiencing same type of environment effects. The phenotypic correlations between rear udder height and score-day milk yield and 305-day yield >.20 is also important and it verifies the thinking of the breeders and farmers that cows with high rear udder could yield more milk. The phenotypic correlation of milk yield with rump width was less than 0.10 for Brown Swiss and Red and White cattle as for this study (De Haas *et al*., 2007). From the current study it could be deduced that rump with in Sahiwal has no direct link with milk production. However, more data should be generated to draw more meaningful conclusions.

***Conclusion*:** The primary type traits including stature, rear udder height, and udder depth and rear udder width need attention while selecting animals for milk yield. Indirect selection for milk yield by selecting for wider rear udder will result in improvement in milk yield. Selection just for increased milk production will result deterioration in fore udder attachment and udder depth. The taller and more angular cows, with high and wide rear udder and deeper udders and longer fore teats will produce more milk.

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REFERENCES

Berry, D.P., F. Buckley, P. Dillon, R.D. Evans and R.F. Veerkamp. 2004. Genetic relationships among linear type traits, milk yield, body weight, fertility and somatic cell count in primiparous dairy cows. Irish J. Agric. Food Res. 43:161-176.

Brotherstone, S. 1994. Genetic and phenotypic correlations between linear type traits and production traits in Holstein-Friesian dairy cattle. Anim. Prod. 59:183-187.

Burnside, E.B. B.T. McDaniel and J.E. Legates. 1963. Relationships among udder height, age and milk production. J. Dairy Sci. 46:157-158.

Cruickshank, J., K.A. Weigel, M.R. Dentine and B.W. Kirkpatrick. 2002. Indirect prediction of herd life in Guernsey dairy cattle. J. Dairy Sci. 85:1307-1313.

DeGroot, B.J. J.F. Keown, L.D. Van Vleck and E.L. Marotz. 2002. Genetic parameters and responses of linear type, yield traits and somatic cell scores to divergent selection for predicted transmitting ability for type in Holsteins. J. Dairy Sci. 85:1578-1585.

De Haas, Y., L.L.G. Janss and H.N. Kadarmideen. 2007. Genetic and phenotypic parameters for conformation and yield traits in three Swiss dairy cattle breeds. J. Anim. Breed. Genet. 124:12-19.

Foster, W.W., A.E. Freeman, P.J. Berger and A. Kuck. 1988. Linear type trait analysis with genetic parameter estimation. J. Dairy Sci. 71:223-231.

Foster, W.W., A.E. Freeman, P.J. Berger and A. Kuck. 1989. Association of type traits scored linearly with production and herd life of Holsteins. J. Dairy Sci. 72:2651-2664.

Funk, D.C., L.B. Hansen and D.A. Funk. 1991. Inheritance of cow durability for linear type traits. J. Dairy Sci. 74:1753-1759.

Gilmour, A.R., B.J. Gogel, B.R. Cullis, S.J. Welham and R. Thompson. 2007. ASReml User Guide (Version 2.0), VSN International Ltd, Hemel Hempstead, HP11ES, UK.

Harris, B.L., A.E. Freeman and E. Metzger. 1992. Genetic and phenotypic parameters for type and production in Guernsey dairy cows. J. Dairy Sci. 75:1147-1153.

Hickman, C.G. 1964. Teat shape and size in relation to production characteristics and mastitis in dairy cattle. J. Dairy Sci. 47:777-782.

ICAR. 2002. P73-79. International Agreement of Recording Practices, approved on 30 May, 2002.

Khachatryan, M.S. 1989. External characteristics of Caucasian Brown cows in relation to age and milk yield. Dairy Sci. Abst. 51:4, 1989.

Khan, M.A., M.S. Khan and A. Iqbal. 2008. Genetic and phenotypic correlations among linear type traits in Sahiwal cows. Pak. J. Agri. Sci. 45:268-274.

Khan, M.A. and M.S. Khan. 2015a. Non Genetic factors affecting linear type traits in Sahiwal cattle. J. Anim. Plant Sci. 25:29-36.

Khan, M.A. and M.S. Khan. 2015b. Development of linear score system for Sahiwal cows in Pakistan. J Anim. Health Prod. 3:59-63.

Khan, M.A and M.S. Khan. 2016. The heritability estimates of linear type traits in Sahiwal. J. Anim. Plant Sci. 26:25-33.

Klassen, D.J., H.G. Monardes, l. Jairath, R.I. Cue and J.F. Hayes. 1992. Genetic correlations between lifetime production and linearized type in Canadian Holsteins. J. Dairy Sci. 75:2272-2282.

Lawstuen, D.A., L.B. Hansen and L.P. Johnson. 1987. Genetic basis of secondary type traits for Holsteins. J. Dairy Sci. 70:1633-1645.

Meyer, K., S. Brotherstone, W.G. Hill and M.R. Edwards. 1987. Inheritance of linear type traits in dairy cattle and correlations with milk production. Anim. Prod. 44:1-10.

Misztal, I., T.J. Lawlor, T.H. Short and P.M. VanRaden. 1992. Multiple-trait estimation of variance components of yield and type traits using an animal model. J. Dairy Sci. 75:544-551.

Patel, A.K. and O.S. Tomer. 1990. Prediction of production performance based on pre-partum body measurement in crossbred heifers. Ind. J. Dairy Sci. 43:35-39.

Patterson, L.D. and R. Thompson. 1971. Recovery of inter-block information when block sizes are unequal. Biometrica 58:545-554.

Rafael, V.C., J.A. Cobuci, E.L. Kern, C.N. Costa and C.M. McManus. 2015. Genetic Parameters for linear type traits and milk, fat, and protein production in Holstein Cows in Brazil. Asian Australas. J. Anim. Sci. 28:476–484.

Rogers, G.W. 1993. Index selection using milk yield, somatic cell score, udder depth, teat placement and foot angle. J. Dairy Sci. 76:664-670.

Rupp, R. and D. Boichard. 1999. Genetic parameters for clinical mastitis, somatic cell, score, production, udder, type traits, and milking ease in first lactation Holsteins. J. Dairy Sci. 82:2198-2204.

Shanks, R.D. and S.L. Spahr. 1982. Relationship among udder depth, hip height, hip width and daily milk production in Holstein cows. J. Dairy Sci. 65:1771-1775.

Short, T.H., T.J. Lawlor and K.L. Lee. 1991. Genetic parameters for three experimental linear type traits. J. Dairy Sci. 74:2020-2025.

Tapki, S. and Y.Z. Guzey. 2013. Genetic and phenotypic correlations between linear type traits and milk production yields of Turkish Holstein dairy cows. Greener J. Agri. Sci. 3:755-761.

Visscher, P.M. and M.E. Goddard. 1995. Genetic parameters for milk yield, survival, workability and type traits for Australian dairy cattle. J. Dairy Sci. 78:205-220.

Vollema, A.R. and A.B.F. Groen. 1997. Genetic correlations between longevity and conformation traits in an upgrading dairy cattle population. J. Dairy Sci. 80:3006-3014.

Weigel, D.J., B.G. Cassel and R.E. Pearson. 1997. Prediction of transmitting abilities for productive life and lifetime profitability, somatic cell count and type traits in milk markets for fluid milk and cheese. J. Dairy Sci. 80:1398-1405.

White, J.M. 1974. Role of conformational and managemmental traits in dairy cattle breeding. J. Dairy Sci. 57:1267-1278.