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(Co)variance components, genetic parameters and trends for body weight traits in Muzaffarnagari sheep of India

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Abstract
The aim of present investigation was to estimate variance and covariance components, genetic parameters and genetic, phenotypic and environmental trends for body weight traits at different ages of Muzaffarnagari sheep for a period of 27 years (1991-2017). Phenotypic data was collected from Central Institute for Research on Goats, Makhdoom. The traits analyzed under present study were birth weight (BWT), weaning weight (WWT), 6 months weight (6WT), 9 months weight (9WT) and 12 months weight (12WT). Sex, season, year of lambing, parity and type of birth were included as fixed effects for mixed model analysis. Six animal models with different combinations of direct and maternal genetic effects were fitted by restricted maximum likelihood method using Wombat software. Bayesian information criterion was utilized for determining best model for all traits. Model 3 was obtained as the best model for all traits. Direct heritability estimates of BWT, WWT, 6WT, 9WT and 12WT are 0.29, 0.37, 0.47, 0.34 and 0.41 respectively and their respective maternal heritabilities were 0.31, 0.12, 0.19, 0.13 and 0.13. Negative covariance was observed between direct and maternal effects for all traits. The genetic and phenotypic correlation among the traits ranged from 0.23 (BWT-12WT) to 0.91 (9WT-12WT); 0.28 (BWT-9WT) to 0.84 (6WT-9WT and 9WT-12WT) respectively. Overall genetic and phenotypic and trends for all the traits were in desired direction. Negative estimates were observed for environmental trends. Desired genetic improvement obtained through selection is hampered by environmental interaction. Importance of maternal effect in influencing the traits was found in the investigation.

Keywords: Animal model, (Co)variance; growth, maternal effects, muzaffarnagari sheep, trends

Introduction

India being basically agriculture based country, income of farmers were based on the agriculture along with animal husbandry. Among which animal rearing plays an important and indispensible place in the livelihood security of them. Sheep population with about 12.71% (http://dahd.nic.in/sites) of total livestock population stands in an important place in the income generation for small and marginal farmers. Present Breed of discussion, Muzaffarnagari, sometimes referred as Bulandshahri, with about 0.18 million population, has about 0.30% (http://dahd.nic.in/sites) of total sheep population. Being the heaviest among sheep breeds of India, it is believed to be the most promising breed for meat and carpet wool production The breeding tract of breed includes Saharanpur, Muzaffarnagar, Meerut, Bulandshahr and Bijnor of Uttar Pradesh and Dehradun of Uttarakhand, distributed widely in the areas of semi-arid western Uttar Pradesh. (http://14.139.252.116/agris/bridDescription). It is believed to possess less-known unique genotype with better adaptability and slightly more prolific than other sheep breeds (Mandal *et al*. 2003) [36]. Because of its heaviness and scope for improvement in meat production, the breed is facing increased interest from the shepherd community for improving the body weight nowadays.

Formulation of a breeding strategy optimally is a very essential step for improving the production efficiency of sheep. Genetic parameters estimation and analysis of the relationship among them at different ages is important for formulating breeding programme successfully.

Several researchers found that the growth traits were influenced by both additive and maternal genetic effects and models which included both gave unbiased and precise estimates. (Hanford *et al*. 2002; Abegaz *et al*. 2002; Hanford *et al*. 2002; Assan *et al*. 2002; Abegaz *et al*. 2005; Hanford *et al*. 2006; Kushwaha *et al*. 2009; Cloete *et al*. 2009; Gamasaee *et al*. 2010; Prince *et al*. 2010; Baneh *et al*. 2009; Hossein-Zadeh and Ardalan 2010; Shokrollahi and Baneh. 2012; Supakorn *et al*. 2013; Jafaroghli *et al*. 2013; Jafari and Hashemi. 2014, Singh *et al*. 2016; Boujenane *et al*. 2015; Mandal *et al*. 2015; Shahdadi and Saghi. 2016; Aksoy *et al*. 2016; Latifi *et al*. 2018) [19, 1, 19, 6, 2, 20, 13, 16, 43, 22, 26, 25, 12, 37, 46, 4, 32].

Accurate prediction of breeding value of animals is one of the best tools available to maximise the response to selection programs. Success of a breeding program can be assessed by actual change in breeding value expressed as a proportion of expected theoretical change of the breeding value mean for the trait under selection (Jurado *et al*. 1994) [29]. For finding the efficiency of selection programme and for predicting the response to selection in the future, accurate prediction of breeding value and estimation of trends are of atmost importance. Trends estimates for various body weight traits at different ages were given by various authors. (Hanford *et al*. 2006; Gizaw *et al*. 2007; Cloete *et al*. 2009; Arora *et al*. 2010; Mokhtari and Rashidi 2010; Mohammadi *et al*. 2011; Khojastehkey and Aslaminejad 2013; Supakorn *et al*. 2013; Jeichitra *et al*. 2014; Ahmadpanah *et al*. 2016; Yeganehpour *et al*. 2015; Eteqadi *et al*. 2016; Hossein-Zadeh and Ghahremani 2018; Latifi and Mohammadi 2018; Yadav *et al*. 2018) [20, 18, 13, 5, 40, 39, 30, 50, 52, 14, 17, 32, 51] Information on genetic, phenotypic and environmental trends for body weight traits of Muzaffarnagari sheep is not available.

Hence to structure a meaningful and profitable breeding programme, knowledge regarding genetic parameters, relationship among them and consideration of both additive and maternal genetic effects are required. Present investigation is aimed at estimating the genetic parameters along with trends analysis for birth weight (BWT), weaning weight or 3 months body weight (WWT), weight at 6 months (6WT), 9 months (9WT) and 12 months (12WT) in Muzaffaranagari sheep.

Materials and Methods

Phenotypic data was collected from the Muzaffarnagari flock maintained by the Animal Genetics and Breeding Division of the Central Institute for Research on Goats (CIRG), Makhdoom, Mathura, Uttar Pradesh, India. The records on body weight from birth to 12 months of age of Muzaffarganari sheep spread over a period of 27 years (1991-2017) were collected for the present study. The detailed characteristic structure of data of present investigation is given in the table 1.

The Institute consists of about 300 ha and maintains purebred Muzaffarnagari flock. It is positioned between Agra and Mathura at 27°10'N and 78°02'E, 169 m above sea level. The land is undulating, with a difference of about 5-6 m between the lower and higher levels, and forms part of the Jamuna alluvial. The climate is almost semi-arid. The temperature ranges from 0 °C to over 45 °C, with annual precipitation of about 750mm, mainly during the monsoon from July to September.

Animals were kept under two systems of feeding management i.e. intensive and semi-intensive at farm condition. The sheep at different stages of production *viz*. pregnant, dry, lactating were kept in separate sheds. Newly born lambs were allowed to be with dams in lactating pens for 4-5 days and then shifted to lamb nursery.

All the lambs were weaned at 3 months age. In order to study growth potential and carcass characteristics of the breed, each year 15-20 male lambs were put under the intensive system of feeding and reared up to 6 months of age. In this period, lambs were given *ad libitum* growth ration, constituting of about 72% TDN and 16% DCP. Ration formulation consists of maize/rice polish (15%), barley (20%), groundnut cake (35%), wheat bran (20%), molasses (7%), mineral mixture (1.5%) and salt (1.5%). Lambs were also given dry and green fodders *ad libitum* and were not allowed to graze. The remaining animals were maintained under the semi-intensive system of feeding under which they were provided 100-400 g of growth ration at various ages, dry and green fodders, and allowed for 6 hrs of grazing. Ewes at 100 days of their pregnancy and during lactation were provided supplementary feeding, whereas dry ewes were fed only on maintenance ration. Green fodder was supplied by the farm section of the institute throughout the year as per availability in different seasons. The dry fodder like gram or pegion pea straw were also fed to the animals. The grazing area of the institute is undulating ravine of sandy land with low organic C and available N and dominated with K.

Controlled breeding was practiced wherein which breeding seasons were restricted in such a way that the lambing takes place in an optimum environmental period of the year and as such two breeding seasons namely (1) May-June and (2) October-November, were practiced with lambing in October-November and March-April months of the year. Moreover, most of the ewes (70-80%) exhibited estrous in the above mentioned seasons.

Initially, data were analyzed for finding the fixed effects for including in the model by least-square analysis of variance (SPSS 2010). Fixed effects such as sex of the lamb (two levels), season of lambing (two levels), period of lambing (7 levels) with 4 years in each period, parity of dam (5 levels) and type of birth of lambs (2 levels). Dam's weight at lambing is taken as a covariate. (Co)variance components and genetic parameters were estimated by restricted maximum likelihood (REML) procedures using wombat software (Meyer, 2013) [38].

Only significant effects ($p \leq 0.05$) were included in the models which were subsequently used for genetic analysis. The Convergence of the restricted maximum likelihood (REML) solutions was assumed when the variance of function values ($-2 \log L$) in the simplex was less than 10^{-8}. To ensure that a global maximum was reached, the analysis was restarted. When estimates did not change up to two decimals, convergence was confirmed. Six models which accounted for the direct and maternal effects were fitted and are as follows:

$$Y = X\beta + Z_a a + \varepsilon$$

$$Y = X\beta + Z_a a + Z_m m + \varepsilon, \text{ with } Cov\,(a_m,m_o) = 0$$

$$Y = X\beta + Z_a a + Z_m m + \varepsilon, \text{ with } Cov\,(a_m,m_o) = A\sigma_{am}$$

$$Y = X\beta + Z_a a + Z_c c + \varepsilon, \text{ with } Cov\,(a_m m_o) = 0$$

$$Y = X\beta + Z_a a + Z_m m + Z_c c + \varepsilon, \text{ with } Cov\,(a_m,m_o) = 0$$

$$Y = X\beta + Z_a a + Z_m m + Z_c c + \varepsilon, \text{ with } Cov\,(a_m,m_o) = A\sigma_{am}$$

Where Y is the vector of record, β, a, m, c, and ε are the vectors of fixed, direct additive genetic, maternal genetic, permanent environmental effects of the dam and residual effects, respectively. X, Z_a, Z_m, and Z_c are the incidence matrices that relate these effects to records, A is the numerator relationship matrix between animals and σ_{am} is the covariance between additive direct and maternal genetic effects. Assumptions for variance (V) and covariance (Cov) matrices involving random effects were

$V(a) = A\,\sigma^2_a$, $V(m) = A\,\sigma^2_m$, $V(c) = I\,\sigma^2_c$, $V(\varepsilon) = I\,\sigma^2_e$ and $Cov(a,m) = A\sigma_{am}$

Where I represents identity matrix; σ^2_a, σ^2_m, σ^2_c, and σ^2_e are additive genetic, additive maternal, maternal permanent environmental and residual variances respectively. The direct-maternal correlation (r_{am}) was calculated for all the traits under study. Bayesian information criteria (BIC) was used to choose the best fit model among all the models (Schwarz, 1978) [45]. The model yielding lowest BIC explains the better variation in the trait and will be considered as the best one.

The phenotypic trend can be estimated as the regression of population performance on time. The genetic trend was estimated by Henderson's principle (Henderson, 1973) [21] which consisted of regression of the weighted average transmitting abilities of the sires for each period on time (period). The Expected Breeding Values (EBV) of each sire was obtained by the formula given by Lush (1935) [34].

$$EBV = \frac{0.5nh^2}{1+(n-1)t}\,(LSC)$$

Where EBV indicates the expected breeding value, h^2 is heritability, t is intra class correlation (0.25 h^2 for the half sib progeny), n is number of half sib progeny and LSC is the least squares constant which can be obtained from the wombat analysis. The expected transmitting abilities were obtained by dividing the respective EBVs by 2. Then the weighted transmitting abilities of sires for period, were then regressed on period. The regression value, thus obtained, was multiplied by 7 (as there were 7 periods) to get the total genetic change and then divided by 27 (as there were 27 years in 7 periods) to get the annual genetic change. The environmental trends were obtained by subtracting the genetic trend from the phenotypic trend. (Balasubramaniam *et al.*, 2013) [9].

Results and Discussion

Number of observations along with mean, standard deviations and coefficients of variation are given in the table 1. The coefficients of variation for the present studies traits varied from 19.51 to 26.55. This is in agreement with the findings of Mandal *et al*. 2015 [37] in Muzaffarnagari sheep and Abegaz *et al*. 2002; Kushwaha *et al*. 2009; Mokhtari and Rashidi 2010; Gamasaee *et al*. 2010 [16]; Shahdadi and Saghi 2016; Ahmadpanah *et al*. 2016; Boujenane *et al*. 2015 [12]; Eteqadi *et al*. (2016) [14] and Jawasreh *et al*. (2018) [27] in other sheep breeds. The entire pedigree information and dataset were spread over the period of 27 years and the magnitude and intensity of data set spread is sufficient enough to obtain reliable estimates of genetic parameters and trends. The least square means along with standard errors for various fixed effects were indicated in the table 2. The least square means for BWT, WWT, 6WT, 9WT and 12WT were 3.41±0.02, 15.13±0.17, 22.91±0.22, 27.25±0.23 and 31.33±0.24 respectively. Higher estimates than the present study was arrived at by Sinha and Singh 1997 and lower estimates than the present study was derived by Mandal *et al*. 2003 [36] and Mandal *et al*. 2015 [37] in Muzaffarnagari sheep. Whereas in other breeds of sheep, lower estimates were reported by several authors. (Abegaz *et al*. 2002; Assan *et al*. 2002; Abegaz *et al*. 2005; Behzadi *et al*. 2007; Gizaw *et al*. 2007; Kushwaha *et al*. 2009; Mokhtari and Rashidi 2010; Arora *et al*. 2010; Prince *et al*. 2010; Balasubramanyam *et al*. 2012; Singh *et al*. 2016; Boujenane *et al*. 2015; Eteqadi *et al*. 2016 and Mallick *et al*. 2016) [6, 2, 7, 18, 5, 43, 8, 12, 14, 35] and higher estimates were given by some researchers (Hanford *et al*. 2002, 2006; Cloete *et al*. 2009; Labo *et al*. 2009; Baneh *et al*. 2009; Gamasaee *et al*. 2010; Hossein-Zadeh and Ardalan 2010; Shahdadi and Saghi 2016; Shokrallahi and Baneh 2012; Jafaroghli *et al*. 2013; Khojastehkey and Aslaminejad 2013; Ahmadpanah *et al*. 2016; Jawasreh *et al*. 2018 and Latifi and Mohammadi 2018) [13, 19, 33, 16, 22, 26, 30, 27, 32] in other breeds of sheep.

Sex, year of birth and type of birth had significant effect on all the above studies traits. Season had significant effect on all the traits except for 12WT and parity have significance over BWT and WWT but not on other traits. Male animals had shown increased growth rate than female animals and it is because of differences in their endocrine system. In females, estrogen production restricts the development of long bones, whereas in case of males, testosterone had positive impact on development of bones and acts like growth hormone for males (Fourie *et al*. 1970) [15]. Difference observed in body weights of animals in various ages at different seasons might be due to the differences in the fodder available to sheep during grazing, differences in environmental and managemental conditions that prevailed in different seasons. Availability of berseem and lucerne increases from December onwards, providing good ration during gestation, which may be the reason for higher BWT in S-1 born lambs. Lambs born to ewes in their fourth parity was heavier than the younger and older ewes except for birth weight in which lambs born for fifth parity ewe was heaviest. Single born lambs (83.3%) were heavier and different from twins (16.4%). The overall effect of these fixed factors upon the present studied traits were in congruence with the results of Sinha and Singh 1997; Mandal *et al*. 2003 [36] in Muzaffarnagari sheep and also coincides with the results obtained in various other breeds. (Hanford *et al*. 2002; Abegaz *et al*. 2005; Hanford *et al*. 2006; Behzadi *et al*. 2007; Gamasaee *et al*. 2010; Shahdadi and Saghi 2016; Balasubramanyam *et al*. 2012; Shokrallahi and Baneh 2012; Khojastehkey and Aslaminejad 2013; Jafari and Hashemi 2014; Boujenane at al. 2015; Nimase *et al*. 2017; Jawasreh *et al*. 2018 and Latifi and Mohammadi 2018) [19, 2, 20, 7, 16, 8, 30, 25, 12, 41, 27, 32].

Estimates of (co)variance components and genetic parameters obtained from different models are presented in table 3 (3.1-3.4) highlighting the best model for different traits. Generally, model 1 by including animal additive genetic effects alone provides biased results, whereas model 2 consisting of both animal and maternal genetic effects may give better estimates of direct heritability. But in our study, we found that model 3 gives lowest BIC values for all the traits and considered to be the best model in explaining variability for all the traits. This model includes both animal and dam genetic effects along with the covariance between the effects. Model 4 includes only maternal permanent environment, model 5 includes both dam genetic and environmental effects, and since model 6 provides all the effects along with the covariance between the effects, can also be the best model, but based on the lowest

BIC values, model 3 is chosen as the best model.

The direct heritability estimates of body weights ranged from 0.29 to 0.47 with the least value observed for birth weight and increasing trend in heritability estimates observed with increase in age. This can be because of increased influence of maternal and environmental factors on the birth weight than on the weights measured at later ages of life. This confirms the findings of Mandal *et al*. 2003 [36] in this breed. Low heritability estimates than the present investigation was reported by several workers (Mandal *et al*. 2003 and 2015 in Muzaffarnagari sheep; Hanford *et al*. 2002 in Columbia sheep; Abegaz *et al*. 2005 in Horro sheep; Hanford *et al*. 2006 in Polypay sheep; Behzadi *et al*. 2007 in Kermani sheep; Kushwaha *et al*. 2009 in Chokla sheep; Baneh *et al*. 2009 in Ghezel sheep; Shahdadi and Saghi 2016 in Kourdi sheep; Balasubramanyam *et al*. 2012 in Madras Red sheep; Prakash *et al*. 2012 in Malpura sheep; Singh *et al*. 2016 in Marwari sheep and Boujenane *et al*. 2015 in D'man sheep) [36, 37, 19, 2, 20, 7, 8, 42, 12]. Higher estimates than the results of this study were given by Sinha and Singh 1997 in Muzaffarnagari sheep, Gizaw *et al*. 2007 [18] in Menz sheep, Lobo *et al*. 2009 [33] in multibreed meat population of Brazil and Gamasaee *et al*. (2010) [16] in Mehrabun sheep.

The maternal heritability estimates varied from 0.12 to 0.31. Maximum maternal heritability estimate could be observed for BWT (0.31) and after which it decreases with age with slight increase observed in 6WT (0.19). This is in congruence with the observation of Robinson 1981 who stated that the maternal effects in mammals are substantial in young animals and diminishes with increase in age, however some adult traits will always contain this source of variation. This increased maternal variance for BWT might explain the variation attributed by the dam by gestation and lactation on the lamb, the effect of which reduces with age. Lower maternal heritability estimates comparing to our findings were given Assan *et al*. 2002 [6] in Sabi sheep, Hanford *et al*. 2002 [19] in Columbia sheep, Hanford *et al*. 2006 [20] in Polypay sheep, Kushwaha *et al*., 2009 in Chokla sheep, Hossein-Zadeh and Ardalan 2010 [22] in Moghani sheep, Shokrallahi and Baneh 2012 in Arabi sheep, Jafaroghli *et al*. 2013 [26] in Baluchi sheep, Singh *et al*., 2016 in Marwari sheep Boujenane *et al*. 2015 [12] in D'man sheep and Latifi and Mohammadi 2018 [32] in Iranian Afshari sheep. Higher maternal heritability estimate than the present study was obtained by Behzadi *et al*. 2007 [7] in Kermani sheep and Shahdadi and Saghi 2016 in Kourdi sheep. Clear and high negative covariance exists between direct and maternal effects suggesting utilizing both the effects at the same time is challenging in the selection programme. Antogonisity between them should be considered for selection programme planning and it is a part of natural selection in which the intermediate optimum will be mostly favoured and these results confirm the findings of Abegaz *et al*. 2005 [2] in Horro sheep, Shokrallahi and Baneh 2012 in Arabi sheep and Latifi and Mohammad 2018 [32] in Iraninan Afshari sheep and contrary to the result of Assan *et al*. 2002 [6] in Sabi sheep and Hanford *et al*. 2006 [20] in Polypay sheep who obtained positive covariance between direct and maternal effects for BWT and WWT. Hossein-Zadeh and Ardalan 2010 [22] in Moghani sheep derived positive direct and maternal effect for BWT but negative results for other body weight traits.

The total heritability estimates are the reflection of the expected response to phenotypic selection for the traits. In the current investigation, the total heritability estimates were lower in magnitude (0.15-0.22) and lower than the findings of several researcher in various breeds of sheep (Jafaroghli *et al*. 2013; Kushwaha *et al*. 2009; Behzadi *et al*. 2007; Prakash *et al*. 2012; Shahdadi and Saghi 2016; Singh *et al*. 2016; Gamasaee *et al*. 2010; Assan *et al*. 2002) but higher than the values obtained by Abegaz at al. 2005, Baneh *et al*. 2009, Boujenane *et al*. 2015 [26, 7, 42, 16, 6, 2, 12] and Latifi and Mohammadi 2018 [32].

The genetic and phenotypic correlation among various body weight traits were given in the table 4. The genetic correlation among the studied traits ranged from 0.23 (BWT-12WT) to 0.91 (9WT-12WT) and the phenotypic correlation varied from 0.28 (BWT-9WT) to 0.84 (6WT- 9WT and 9WT-12WT). It can be noted that the correlation of BWT with other traits are less in comparison to the correlation between traits exhibited at later ages of life, showing that selection for BWT will lead to reduced body weights in later ages. But selection for the traits expressed at later stages will increase the age of selection indirectly increasing the cost of maintanence, space and time. Hence selection should be at the age, such that it takes into consideration all the above discussed facts. In our study WWT has high correlation with all the body weight traits and if selected for, it can increase the overall weight gain of animals. Therefore selection for WWT will be beneficial. Similar positive genetic and phenotypic correlation among the body weight traits were given by several published literatures. (Sinha and Singh 1997 and Mandal *et al*. 2015 [37] in Muzaffarnagari sheep; Abegaz *et al*. 2002; Hanford *et al*. 2002 and 2006; Gizaw *et al*. 2007; Shokrallahi and Baneh 2012; Singh *et al*. 2016; Boujenane *et al*. 2015 and Jawasreh *et al*. 2018) [37, 19-20, 18, 12, 27]. Comparing to our results, increased genetic correlation of BWT with other body weight traits were observed in few literatures. (Behzadi *et al*. 2007; Lobo *et al*. 2009; Shahdadi and Saghi 2016; Prakash *et al*. 2012 and Jafaroghli *et al*. 2013) [7, 33, 42, 26]

Information regarding the genetic, phenotypic and environmental trends for Muzaffarnagari sheep is very scarce and not published yet. The genetic, phenotypic and environmental trends estimated for BWT, WWT, 6WT, 9WT and 12WT were given in the table 5. Figure 1 to 5 shows the genetic and phenotypic trends for different body weight traits. Evaluation of genetic trends gives an idea about the direction of breeding as well as the rate of genetic improvement since the start of the concerned breeding programme (Bosso *et al*. 2007) [11]. Genetic trends obtained for all the studied traits were positive ranging from 0.001 (BWT) to 0.06 (6WT and 12WT). It can be inferred that selection plan used in this programme gave more importance for mature weight traits than young age traits. Positive genetic trends for all the studied traits shows the significance of ongoing breeding programme in the desired and right direction obtaining positive response to selection and these results were in congruence with the findings of Gizaw *et al*. 2007 [18] in Menz sheep, Mokhtari and Rashidi 2010 in Kermani sheep, Khojastehkey and Aslaminejad 2013 [30] in Zandi sheep, Ahmadpanah *et al*. 2016 in Iran Black sheep, Jeichitra *et al*. 2015 [28] Mecheri sheep, Yeganehpour *et al*. 2015 [52] in Lori sheep, Eteqadi *et al*. 2016 [14] in sheep population at Guilan province of Iran, Mallick *et al*. 2016 [35] in Bharat Merino Sheep and Latifi and Mohammadi 2018 [32] in Iranian Afshari sheep. Mohammadi *et al*. 2011 [39] obtained positive genetic trends for all post weaning body weight traits. Positive genetic trend for BWT was observed by Sukaporn *et al*. 2013 in sheep population of Thailand. Cloete *et al*. 2009 [13] resulted in positive genetic trend in high line lambs and negative genetic trend in low line lambs of Merino sheep.

Phenotypic trends estimated was high and negative for WWT (-0.14) and 6WT (-0.21) and low and positive for other traits studied. The environmental trends estimates for all the studies traits were high in magnitude and negative in direction. This indicates that inspite of favourable selection programme implementation, the desired results were somewhat hampered by the environmental influences such as climatic fluctuations, feed and fodder availability and managemental differences. Environmental interactions should be minimized to the level possible for obtaining maximum response to selection. In confirmation with the present result, Arora *et al.* (2010) [5] found positive genetic trends for all the body weight traits, negative trends for few phenotypic traits and low and negative environmental trends for all the body weight traits in Malpura sheep. In contrary to the result of the present investigation, Yadav *et al.* 2018 [51] obtained negative genetic and phenotypic trends for all the body weight traits studied in Munjal sheep.

Table 1: Characteristics of data structure of Muzaffarnagari sheep

TRAIT	BWT	WWT	6WT	9WT	12WT
Number of records	4525	4185	3743	3322	2929
Mean	3.41	15.14	22.91	27.25	31.33
Standard deviation	0.70	4.19	5.48	5.74	6.24
CV (%)	19.51	26.55	23.34	20.87	19.88
Number of sires with progeny record	215	214	208	204	200
Number of dams with progeny records	1623	1566	1474	1406	1307

BWT birth weight; WWT weaning weight; 6WT body weight at 6 months of age; 9WT body weight at 9 months of age; 12WT body weight at 12 months of age; CV Coefficient of variation.

Table 2: Least square means along with standard error for body weight traits in Muzaffarnagari sheep.

	BWT		WWT		6WT		9WT		12WT	
	N	MEAN ± SE	N	MEAN ±SE	N	MEAN ±SE	N	MEAN ±SE	N	MEAN ±SE
Overall mean	4525	3.41±0.02	4185	15.13±0.17	3743	22.91±0.22	3322	27.25±0.23	2929	31.33±0.24
Sex	**		**		**		**		**	
Male	2183	3.48^{a}±0.23	1999	15.66^{a}±0.18	1730	24.52^{a}±0.24	1420	29.57^{a}±0.25	1143	34.32^{a}±0.27
Female	2342	3.34^{b}±0.23	2186	14.62^{b}±0.17	2013	21.29^{b}±0.23	1902	24.93^{b}±0.24	1786	28.33^{b}±0.25
Season	**		*		*		**		NS	
1	2116	3.46^{a}±0.24	1966	15.28^{a}±0.18	1778	22.70^{a}±0.24	1555	26.62^{a}±0.25	1422	31.15±0.26
2	2409	3.36^{b}±0.23	2219	14.99^{b}±0.18	1965	23.11^{b}±0.24	1767	27.87^{b}±0.25	1507	31.50±0.26
Period	**		**		**		**		**	
1(1991-94)	579	3.45^{b}±0.08	533	18.09^{c}±0.55	424	27.71^{c}±0.74	352	29.47^{b}±0.83	305	32.89^{b}±0.98
2(1995-98)	544	3.86^{d}±0.06	480	15.48^{ab}±0.40	415	23.75^{b}±0.52	350	26.81^{a}±0.55	253	29.83^{a}±0.65
3(1999-02)	685	3.11^{a}±0.05	619	15.29^{b}±0.35	570	22.28^{b}±0.46	470	25.88^{b}±0.49	419	31.51^{d}±0.54
4(2003-06)	875	2.99^{a}±0.05	787	14.05^{ab}±0.32	696	21.27^{b}±0.43	643	25.58^{b}±0.45	564	30.47^{d}±0.51
5(2007-10)	423	3.34^{b}±0.06	413	13.99^{a}±0.38	393	21.86^{a}±0.48	349	26.57^{a}±0.51	327	31.13^{c}±0.56
6(2011-14)	874	3.51^{c}±0.05	842	15.58^{c}±0.36	762	23.60^{d}±0.47	723	28.21^{c}±0.50	680	31.18^{e}±0.55
7(2015-17)	545	3.58^{c}±0.07	511	13.49^{c}±0.49	483	19.86^{e}±0.65	435	28.21^{d}±0.68	381	32.27^{f}±0.74
Parity	**		*		NS		NS		NS	
1	1604	3.28^{a}±0.03	1475	14.97^{a}±0.19	1287	22.70±0.25	1154	26.97±0.26	998	30.75±0.28
2	1123	3.41^{b}±0.03	1029	15.29^{b}±0.20	904	22.96±0.26	794	27.24±0.27	714	31.44±0.23
3	744	3.45^{b}±0.03	699	15.31^{b}±0.21	636	23.01±0.28	559	27.40±0.29	501	31.54±0.31
4	502	3.43^{b}±0.03	467	15.33^{b}±0.23	431	23.35±0.30	380	27.70±0.32	341	31.67±0.34
5	552	3.47^{b}±0.03	515	14.79^{b}±0.23	485	22.50±0.30	435	26.93±0.37	375	31.23±0.33
Type of Birth	**		**		**		**		**	
1	3784	3.78^{a}±0.02	3496	16.61^{a}±0.16	3124	24.13^{a}±0.22	2776	28.41^{a}±0.22	2440	32.44^{a}±0.23
2	741	3.04^{b}±0.03	689	13.67^{b}±0.21	619	21.68^{b}±0.27	546	26.09^{b}±0.29	489	30.21^{b}±0.30

BWT birth weight; WWT weaning weight; 6WT body weight at 6 months of age; 9WT body weight at 9 months of age; 12WT body weight at 12 months of age; *P<0.05; **P<0.01; NS non-significant (P>0.05); N number of observations; TOB type of birth; Means without superscript do not differ significantly.

Table 3.1: Variance components and genetic parameters for body weight traits in Muzaffarnagari sheep

Trait:	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
BWT						
σ^2_a	0.09	0.05	0.1	0.05	0.05	0.1
σ^2_m	-	0.05	0.11	-	0.03	0.08
σ_{am}	-	-	-0.07	-	-	-0.07

σ^2_c	-	-	-	0.05	0.03	0.03
σ^2_e	0.24	0.24	0.21	0.24	0.24	0.21
σ^2_p	0.34	0.34	0.34	0.34	0.34	0.34
h^2	0.28±0.031	0.15±0.03	0.29±0.05	0.15±0.029	0.15±0.03	0.29±0.05
m^2	-	0.16±0.019	0.31±0.03	-	0.08±0.02	0.23±0.01
r_{am}	-	-	0.14	-	-	0.1
c^2	-	-	-	0.16±0.02	0.08±0.002	0.08 ± 0.04
h^2_t	-	-	-0.31	-	-	-0.31
WWT	-	-		-	-	-
σ^2_a	6.48	3.92	5.33	3.92	3.92	5.33
σ^2_m	-	0.5	1.69	-	0.25	1.25
σ_{am}	-	-	-2.08	-	-	-2.08
σ^2_c	-	-	-	0.5	0.25	0.44
σ^2_e	10.06	10.25	9.59	10.25	10.25	9.59
σ^2_p	16.54	14.66	14.53	14.66	0.017±0.000	14.53
h^2	0.39±0.04	0.27± 0.04	0.37±0.06	0.27±0.04	0.27±0.04	0.37±0.06
m^2	-	0.03±0.02	0.12±0.03	-	0.02± 0.02	0.09±0.03
r_{am}	-	-	-0.69	-	-	-0.81
c^2	-	-	-	0.03± 0.02	0.02±0.00	0.03± 0.001
h^2_t	-	-	0.22	-	-	0.21
BIC	15456.39	15081.69	15071.3	15081.69	15090.02	15079.63

Bold values denote estimates derived from the best model based on BIC values;
σ^2_a, σ^2_m, σ^2_c, σ^2_e and σ^2_p are additive genetic, additive maternal, maternal permanent environmental residual and phenotypic variances respectively; σ_{am} is the covariance between additive direct and maternal genetic effects; h^2 direct heritability; m^2 maternal heritability; r_{am} direct-maternal genetic correlation; c^2 maternal permanent environment variance as a proportion of phenotypic variance; h^2_t total heritability; BIC Bayesian information criteria
BWT birth weight; WWT weaning weight; 6WT body weight at 6 months of age; 9WT body weight at 9 months of age; 12WT body weight at 12 months of age.

Table 3.2: Variance components and genetic parameters for body weight traits in Muzaffarnagari sheep

Trait: 6WT	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	7.76	5.29	11.09	5.28	5.29	11.09
σ^2_m	-	0.69	4.41	-	0.34	3.86
σ_{am}	-	-	-6.06	-	-	-6.06
σ^2_c	-	-	--	0.69	0.34	0.55
σ^2_e	17.68	17.35	14.04	17.35	17.35	14.04
σ^2_p	25.44	23.32	23.47	23.32	23.32	23.47
h^2	0.31±0.03	0.23± 0.03	0.47± 0.06	0.23± 0.03	0.23± 0.03	0.47± 0.06
m^2	-	0.03±0.02	0.19±0.03	-	0.02±0.02	0.16± 0.03
r_{am}	-	-	-0.87	-	-	-0.93
c^2	-	-	-	0.03±0.02	0.02± 0.00	0.02±0.001
h^2_t	-	-	0.18	-	-	0.17
BIC	15541.7	15260.2	15199.15	15260.2	15268.41	15207.36
9WT						
σ^2_a	6.68	4.02	7.45	4.02	4.02	7.45
σ^2_m	-	0.41	2.81	-	0.21	2.33
σ_{am}	-	-	-3.72	-	-	-3.72
σ^2_c	-	-	-	0.41	0.21	0.48
σ^2_e	17.31	17.52	15.48	17.52	17.52	15.49
σ^2_p	24	21.95	22.02	21.95	21.95	22.02
h^2	0.28±0.04	0.18±0.03	0.34±0.06	0.18± 0.03	0.18±0.03	0.34±0.06
m^2	-	0.02±0.02	0.13±0.03	-	0.01±0.00	0.11±0.03
r_{am}	-	-	-0.81	-	-	-0.89
c^2	-	-	-	0.02±0.02	0.01±0.02	0.02±0.001
h^2_t	-	-	0.15	-	-	0.14
BIC	13638.44	13405.19	13380.34	13405.19	13413.29	13388.44

Bold values denote estimates derived from the best model based on BIC values;
σ^2_a, σ^2_m, σ^2_c, σ^2_e and σ^2_p are additive genetic, additive maternal, maternal permanent environmental residual and phenotypic variances respectively; σ_{am} is the covariance between additive direct and maternal genetic effects; h^2 direct heritability; m^2 maternal heritability; r_{am} direct-maternal genetic correlation; c^2 maternal permanent environment variance as a proportion of phenotypic variance; h^2_t total heritability; BIC Bayesian information criteria.
BWT birth weight; WWT weaning weight; 6WT body weight at 6 months of age; 9WT body weight at 9 months of age; 12WT body weight at 12 months of age.

Table 3.3: Variance components and genetic parameters for 12WT trait in Muzaffarnagari sheep.

Trait: 12WT	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	8.46	5.11	9.44	5.1	-	9.44
σ^2_m	-	0.46	3	-	0.23	2.44
σ_{am}	-	-	-4.21	-	-	-4.21
σ^2_c	-	-	-	0.46	0.23	0.56
σ^2_e	16.59	17.13	14.6	17.13	17.13	14.6
σ^2_p	25.05	22.7	22.83	22.7	22.7	22.83
h^2	0.34±0.04	0.23±0.04	0.41±0.06	0.23±0.04	0.23±0.04	0.41±0.06
m^2	-	0.02±0.02	0.13± 0.04	-	0.01±0.02	0.11±0.04
r_{am}	-	-	-0.79	-	-	-0.88
c^2	-	-		0.02± 0.02	0.01±0.00	0.03± 0.001
h^2_t	-	-	0.2	-	-	0.19
BIC	12091.37	11876.76	11852.42	11876.76	11884.73	11860.39

Bold values denote estimates derived from the best model based on BIC values;
σ^2_a, σ^2_m, σ^2_c, σ^2_e and σ^2_p are additive genetic, additive maternal, maternal permanent environmental residual and phenotypic variances respectively; σ_{am} is the covariance between additive direct and maternal genetic effects; h^2 direct heritability; m^2 maternal heritability; r_{am} direct-maternal genetic correlation; c^2 maternal permanent environment variance as a proportion of phenotypic variance; h^2_t total heritability; BIC Bayesian information criteria
BWT birth weight; WWT weaning weight; 6WT body weight at 6 months of age; 9WT body weight at 9 months of age; 12WT body weight at 12 months of age.

Table 3.4: Variance components and genetic parameters for average daily gain traits of Muzaffarnagari sheep from best models

Trait	BWT	WWT	6WT	9WT	12WT
Best model	3	3	3	3	3
σ^2_a	0.1	5.33	11.09	7.45	9.44
σ^2_m	0.11	1.69	4.41	2.81	3
σ_{am}	-0.07	-2.08	-6.06	-3.72	-4.21
σ^2_e	0.21	9.59	14.04	15.48	14.6
σ^2_p	0.34	14.53	23.47	22.02	22.83
h^2	0.29±0.05	0.37±0.06	0.47± 0.06	0.34±0.06	0.41±0.06
m^2	0.31±0.03	0.12±0.03	0.19±0.03	0.13±0.03	0.13± 0.04
r_{am}	0.14	-0.69	-0.87	-0.81	-0.79
h^2_t	0.15	0.22	0.18	0.15	0.2
BIC	-589.69	15071.3	15199.15	13380.34	11852.42

Bold values denote estimates derived from the best model based on BIC values;
σ^2_a, σ^2_m, σ^2_c, σ^2_e and σ^2_p are additive genetic, additive maternal, maternal permanent environmental residual and phenotypic variances respectively; σ_{am} is the covariance between additive direct and maternal genetic effects; h^2 direct heritability; m^2 maternal heritability; r_{am} direct-maternal genetic correlation; c^2 maternal permanent environment variance as a proportion of phenotypic variance; h^2_t total heritability; BIC Bayesian information criteria
BWT birth weight; WWT weaning weight; 6WT body weight at 6 months of age; 9WT body weight at 9 months of age; 12WT body weight at 12 months of age.

Table 4: Genetic (above diagonal) correlation and phenotypic (below diagonal) correlation estimates among traits from bivariate analysis in Muzaffarnagari sheep

	Wt0	Wt3	Wt6	Wt9	Wt12
Wt0		0.41 ± 0.08	0.31 ± 0.09	0.39 ± 0.09	0.23 ± 0.02
Wt3	0.33 ± 0.02		0.88 ± 0.03	0.77 ± 0.05	0.70 ± 0.06
Wt6	0.29 ± 0.02	0.80 ± 0.01		0.90 ± 0.02	0.73 ± 0.05
Wt9	0.28 ± 0.02	0.68 ± 0.01	0.84 ± 0.01		0.91 ± 0.03
Wt12	0.33 ± 0.09	0.58 ± 0.01	0.70 ± 0.01	0.84 ± 0.01	

BWT birth weight; WWT weaning weight; 6WT body weight at 6 months of age; 9WT body weight at 9 months of age; 12WT body weight at 12 months of age.

Table 5: Genetic, phenotypic and environmental trends per year for body weight traits in Muzaffarnagari sheep

Traits	Genetic trend	Phenotypic trend	Environmental trend
BWT	0.001	0.0005	-0.0008
WWT	0.05	-0.14	-0.19
6WT	0.06	-0.21	-0.28
9WT	0.03	0.008	-0.02
12WT	0.06	0.02	-0.04

BWT birth weight; WWT weaning weight; 6WT body weight at 6 months of age; 9WT body weight at 9 months of age; 12WT body weight at 12 months of age.

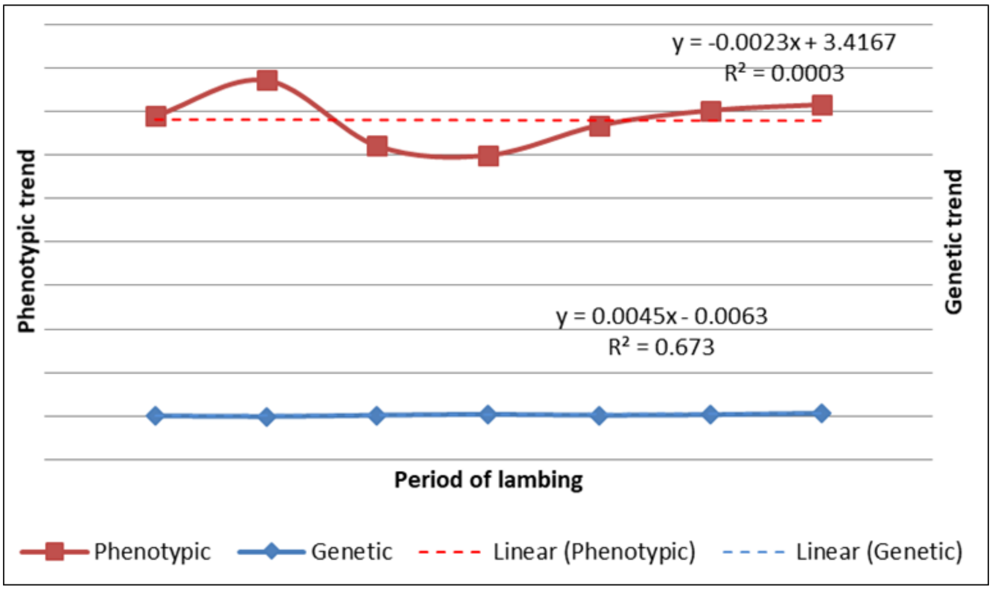

Fig 1: Period wise genetic and phenotypic trends of birth weight; R2 coefficient of determination; y dependent variable; x independent variable.

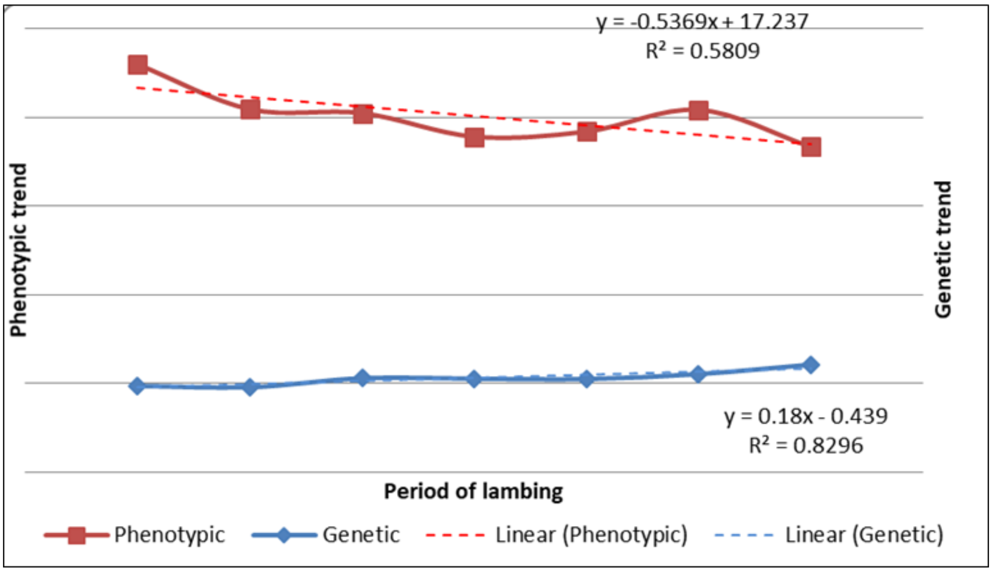

Fig 2: Period wise genetic and phenotypic trends of weaning weight; R2 coefficient of determination; y dependent variable; x independent variable.

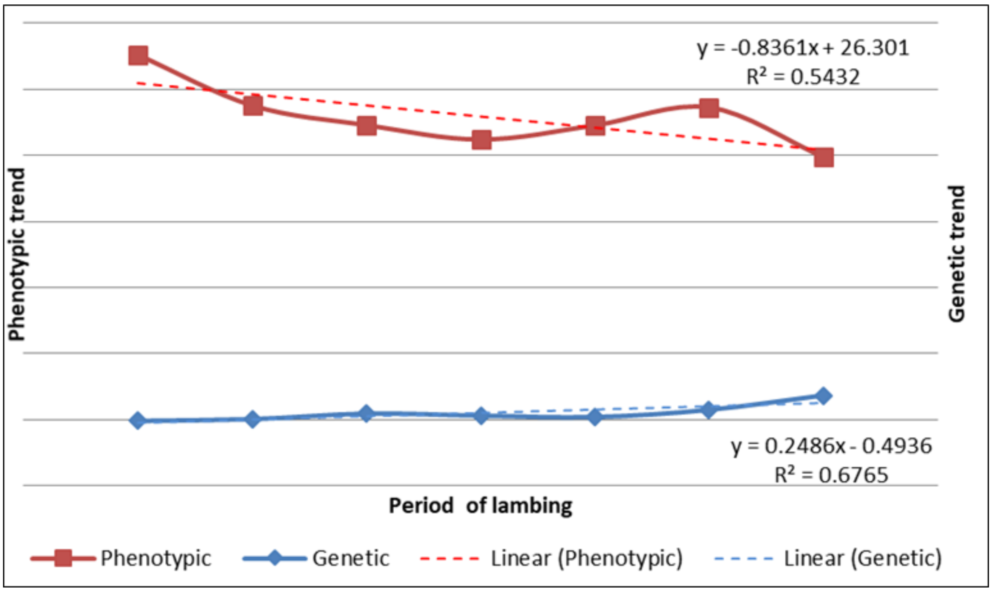

Fig 3 Period wise genetic and phenotypic trends of 6 months body weight; R2 coefficient of determination; y dependent variable; x independent variable.

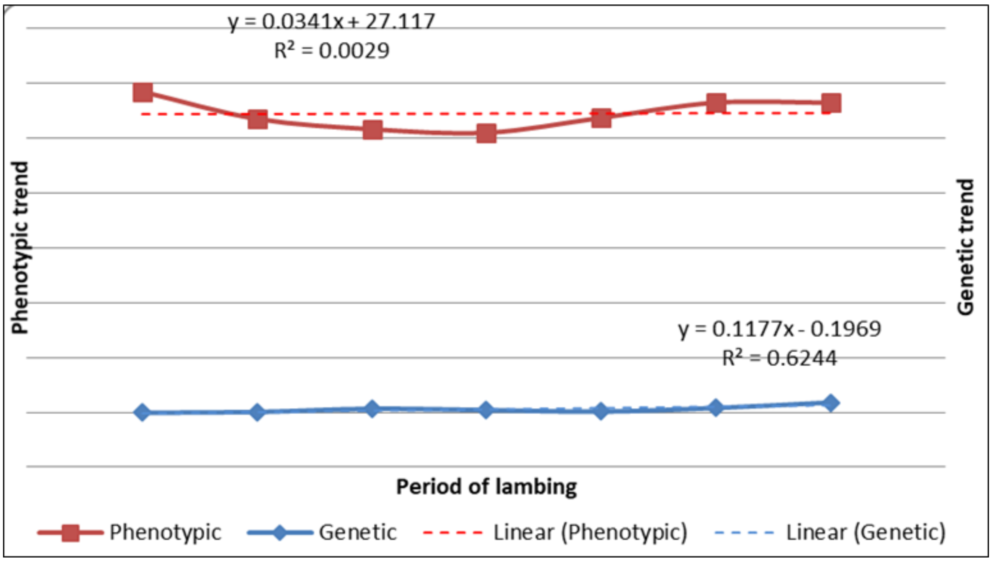

Fig 4: Period wise genetic and phenotypic trends of 9 months body weight; R2 coefficient of determination; y dependent variable; x independent variable.

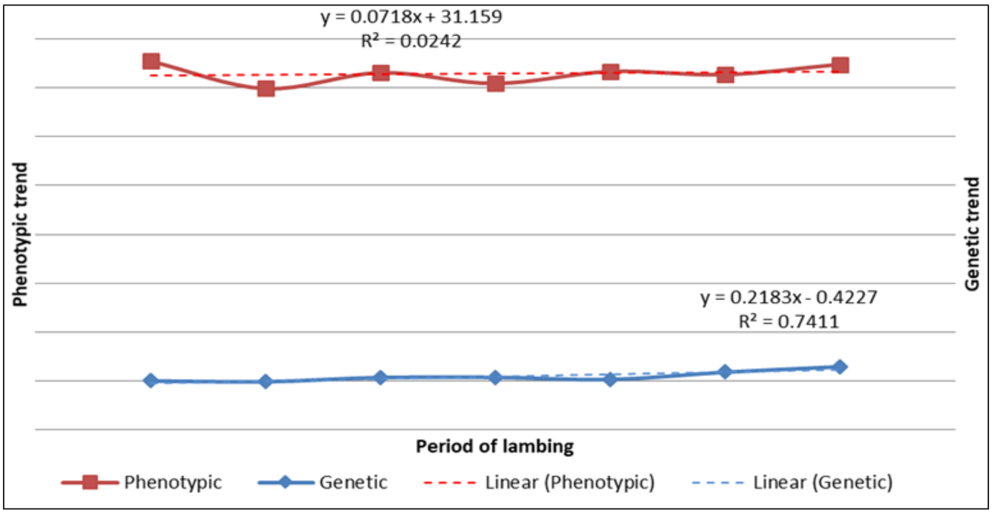

Fig 5: Period wise genetic and phenotypic trends of 9 months body weight; R2 coefficient of determination; y dependent variable; x independent variable.

Conclusion

The effects of fixed factors discussed here for Muzaffarngari sheep is in agreement with the findings of many authors in the same breed various other breeds also. The genetic parameters estimates obtained in this study can be used as a better guide for selection in this breed and it is important for planning efficient breeding programme. As per the results obtained, ignoring maternal effects will lead to overestimation of heritability. Hence along with the additive genetic effects, maternal effects should also be considered while evaluating genetic parameters for body weight traits in Muzaffarnagari sheep. Since WWT has high and positive correlation with other traits, when selected at an early age, increase in body weight at later ages could be obtained. Positive genetic trends for all the studied traits imply that, though selection was for phenotype, still genetic improvement have been obtained on the studies traits with the ongoing breeding programme. Since no literature is available for trends estimates for this breed, the results achieved in the present study can be used as a reliable estimate for analyzing genetic, phenotypic and environmental trends in this breed.

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