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(Co)variance components, genetic parameters and trends for average daily gain 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 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 average daily gain from birth to 3 months of age (ADG1), average daily gain from 3 to 6 months of age (ADG2), average daily gain from 6 to 9 months of age (ADG3), average daily gain from 9 to 12 months of age (ADG4) and average daily gain from 3 to 12 months of age (ADG5). 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 ADG1, ADG2, ADG3, ADG4 and ADG5 are 0.37, 0.45, 0.25, 0.26 and 0.41 respectively and their respective maternal heritablilities were 0.08, 0.15, 0.09, 0.07 and 0.16. Negative covariance was observed between direct and maternal effects for all traits. The genetic and phenotypic correlation among the traits ranged from -0.59 (ADG1-ADG3) to 0.52 (ADG2-ADG5); -1 (ADG2-ADG4) to 0.50 (ADG2-ADG5) respectively. Overall genetic, phenotypic and environmental trends for all the traits were in desired direction with few negative estimates. Although desired genetic improvement has been obtained through selection, it can be further hastened, if hampering effect of environment is taken care of. Results shows the importance of maternal effects in influencing the traits studied.

Keywords: Animal model, heritability, correlations, trends, maternal effects, growth rate, sheep

Introduction

India, with rich biodiversity, being endowed with 43 registered sheep breeds (NBAGR 2018) comprising of about 12.71% (http://dahd.nic.in/sites) of total livestock population stands in an important place in the income generation for shepherd community, small and marginal farmers. The Muzaffarnagari, sometimes referred as Bulandshahri, is one of the heaviest and largest mutton breeds of India and is widely distributed in the semi-arid region of western Uttar Pradesh, comprising districts of Meerut, Muzaffarnagar, Saharanpur, Bijnor and in some parts of Delhi and Haryana. With a population of about 0.18 million, it accounts for about 0.30% of India's total sheep population (DAHD, 2013) [5]. The breed has a better potential for meat and carpet wool production than other Indian sheep breeds (Mandal *et al*. 2003) [17].

Sheep farming has been an important source of income for farmers of arid and semi-arid regions of India as it provides a valuable and persistent source of income throughout the year. The Muzaffarnagari is one of the heaviest and largest mutton breeds of India and is widely distributed in the semi-arid region of western Uttar Pradesh, comprising districts of Meerut, Muzaffarnagar, Saharanpur, Bijnor and in some parts of Delhi and Haryana. With a population of about 0.18 million, it accounts for about 0.30% of India's total sheep population (DAHD, 2013) [5]. This breed is considered as a less-known unique genotype exhibiting better growth, very good adaptability, and a somewhat higher prolificacy than other Indian sheep breeds.

The breed has a better potential for meat and carpet wool production than other Indian sheep breeds (Mandal *et al*. 2003) [17]. Due to the heaviness of this breed and scope for meat production there is an increasing interest in improving the animals for body weight traits nowadays. Improvement in the daily gain of animals is an important criterion in improving the overall growth of the animal. Genetic evaluation of the average daily gain of animals can be a guide for improving the meat production in Muzaffarnagari sheep. In addition, the study of genetic and phenotypic trends, can help one to see the direction of response to selection procedures visually and can be a valuable guide for minimizing the possible mistakes in the selection process. Follow-up and the interpretation of genetic trend estimates allow monitoring the efficiency of improvement strategies and assure that the selection pressure is directed towards traits of economic importance (Hudson and Kennedy, 1985) [12]. Such reports on trend estimates were of scarce or lacking for Muzaffarnagari sheep.

Several pieces of research have been conducted on genetic analysis of Muzaffarnagari sheep for various parameters (Bhadula and Bhat, 1980., Sinha and Singh, 1997 [29], Mandal 2002, 2003, 2007, 2015) [17, 19, 16] but there is no information regarding the trend estimates for average daily gain at different ages in this breed. Therefore the present investigation was conducted to analyze the genetic parameters of average daily gain and their trends in Muzaffarnagari sheep maintained at CIRG, Makhdoom, Mathura.

Materials and Methods

Source of Data

Phenotypic data was collected from the Muzaffarnagari flock maintained at the Genetics and Breeding Division of the Central Institute for Research on Goats (CIRG), Makhdoom, Mathura, Uttar Pradesh, India. The records on daily weight gain from birth to 12 months of age at different intervals in Muzaffarganari sheep spread over a period of 27 years (1991-2017) were collected for the present study.

Study area

The Institute occupies an area of about 300 ha and maintains purebred Muzaffarnagari flock. It is situated between Agra and Mathura at 27º10’N and 78º02’E, 169 m above sea level. It is located in the south-western plains, categorized under agro climatic zone V of the country. 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.

Managemental Practises

At CIRG the animals were maintained 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 kept with their 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. During this period, lambs were given *ad libitum* growth ration, which consists 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 pigeon pea straw was 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. 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 respectively. Moreover, most of the ewes (70-80%) exhibited estrous in the above mentioned seasons.

Traits under study

Different economic traits used for the analysis were average daily gain from birth to 3 months (ADG1), 3 to 6 months (ADG2), 6 to 9 months (ADG3), 9 to 12 months (ADG4) and 3 to 12 months (ADG5). The data were classified according to sex, season, period, parity and type of birth of lamb.

Statistical Analysis

Initially, data were analyzed for finding the fixed effects for including in the model by least-square analysis of variance (SPSS 2010). Fixed effects namely 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) were included in the analysis. Dam’s weight at lambing was taken as a covariate. (Co)variance components and genetic parameters were estimated by restricted maximum likelihood (REML) procedure using wombat software (Meyer, 2013). Only significant effects ($p \leq 0.05$) were included in the models which were subsequently used for genetic analysis. The Convergence of the REML solutions was assumed when the variance of function values (-2 log L) in the simplex was less than 10^{-8}. This analysis was repeated until a global maximum was reached. 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:

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

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 criterion (BIC) was used to choose the best fit model among all the models (Schwarz, 1978) [26]. The model yielding lowest BIC, best explains the variation in the trait and was 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) according to which, trend estimation was done as, 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) [15].

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

Where EBV indicates the expected breeding value, h^2 is heritability, t is intra class correlation (0.25 h2 for the half sib progeny), n is number of half sib progeny and LSC is the least squares constant which were 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) in order to get the annual genetic change. The environmental trends were obtained by subtracting the genetic trend from the phenotypic trend. (Balasubramaniam *et al.*, 2013) [30].

Results

The data structure and number of records along with mean, standard deviation, coefficient of variation, number of sires and dams for analyzing the data are presented in the table 1. The entire pedigree information was spread over the period of 27 years and intensity of distribution was fair enough to obtain reliable estimates of genetic parameters for the traits under study. The least square means along with standard error for average daily gains were specified in the table 2. Statistical analysis revealed that, sex and period were highly significant over all the studied traits. Parity and type of birth have significant effect on pre weaning daily gain.

Estimates of (co)variance components and genetic parameters obtained from different models are presented in table 3 highlighting the best model for different traits. Generally, model 1 by includes only animal additive genetic effects alone, whereas model 2 consists of both animal and maternal genetic effects. 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 ADG1, ADG2, ADG3, ADG4 and ADG5 obtained from the best model were 0.37±0.06, 0.45±0.07, 0.25±0.06, 0.26±0.06 and 0.41±0.07 respectively and the maternal heritability estimates for all the above traits were 0.08±0.03, 0.15±0.03, 0.09±0.03, 0.07±0.03 and 0.16±0.04 respectively. Strong negative correlation can be visualized between animal and maternal genetic effects for all the studied traits and it ranged from -0.74 to -1.00. Estimates of genetic and phenotypic correlations among all the traits from the bivariate analysis were mentioned in the table 4. Genetic correlations among all the studied traits were mostly positive, and the magnitude varied from low to high ranging from -0.59 (ADG1-ADG3) to 0.76 (ADG1-ADG5) and phenotypic correlations were mostly negative ranging from -0.24 (ADG1-ADG3) to 0.50 (ADG2-ADG5).

The genetic, phenotypic and environmental trends for all the studied parameters are given in the table 5 and graphical representations of trends for all the traits were represented from fig 1 to 5. The genetic trends for the traits under study were mostly positive with only exception of ADG3 and magnitude ranged from -0.09 (ADG3) to 1.78 (ADG1).

Discussion

The overall least square means estimated in the present study were lower than the estimates of Sinha and Singh (1997) [29] in Muzaffarnagari sheep and Qureshi *et al*. (2010) [23] in Kajli sheep. Present values however were higher than the values of Mandal *et al*. (2003) [17] in Muzaffarnagari sheep and Thiruvenkadan *et al*. (2011) [32], Ganesan *et al*. (2013) [6], Gowane *et al*. (2015) [10], Aguirre *et al*. (2016) [1], Kumar *et al*. (2017) [14], Illa *et al*. (2019) [13], and Arthy *et al*. (2018) in various other breeds of sheep. Sex and year of lambing had significant effect (p<0.01) on all the studied traits. Season had significant effect (p<0.05) on post weaning growth rate and this is in contrary to the findings of Thiruvenkadan *et al* (2011) [32]. Parity and type of birth had significant effect on pre weaning daily gain. Male lambs had expressed increased growth rate than females and it can be attributed to the differences in their endocrine system. In females estrogen hormone restricts the growth of long bones, whereas the testosterone had positive impact on growth rate and it acts like growth hormone in males. Difference observed in growth rate at different seasons might be due to the availability of fodder to sheep during grazing, environmental and manage mental conditions that prevailed in different seasons. Differences that prevailed in different phases of growth could be due to changes in nutrition, management, agro climatic variations and breeding strategies followed during different periods. Pre weaning average daily gain were inversely proportional to type of birth. Single born lambs were heavier and slightly different from twins and almost similar results were produced by Mandal *et al*. (2003) [17] in Muzaffarnagari sheep. Findings of present study related to effect of fixed factors almost coincides with the results of Qureshi *et al*. (2010) [23] in Kajli sheep, Ganesan *et al*. (2013) [6] in Madras Red sheep, in Baluchi sheep, Gowane *et al*. (2015) [10] in Malpura sheep, Reddy *et al*. (2017) [24] in Nellore Brown sheep, Kumar *et al*. (2017) [14] in Deccani sheep, Gholizadeh and Ghafouri-Kesbi (2017) [8] in Baluchi sheep and Illa *et al*. (2019) [13] in Nellore sheep.

The direct heritability estimate in the present study is moderate (0.37) for pre weaning daily gain (ADG1) and it is in congruence with the estimates obtained by Illa *et al*. (2019) [13] in Nellore sheep (0.37) and higher than the estimates of Mandal *et al*. (2003) [17] in muzaffarangari sheep (0.19), Gowane *et al*. (2010) [9] in Garole x Malpura crossbred sheep (0.17), Qureshi *et al*. (2010) [23] in Kajli sheep (0.10), Sarghale *et al*. (2014) [25] in Baluchi sheep (0.08), Singh *et al*. (2016) in Marwari sheep (0.26), Reddy *et al*. (2017) [24] in Nellore Brown sheep (0.04), Gholizadeh and Ghafouri-Kesbi (2017) [8] in Baluchi sheep and Arthy *et al*. (2018) in Madras red sheep (0.31). However heritability estimates were lower than the values obtained by Sinha and Singh (1997) [29] in Muzaffarnagari sheep (0.44), Ganesan *et al*. (2013) [6] in Madras red sheep (0.47), Gowane *et al*. (2015) [10] in Malpura sheep (0.43), and Aguirre *et al*. (2016) [1] in Santa Ines sheep (0.38). In the present analysis, the direct heritability estimate for post weaning daily gain (ADG5) was 0.41 which is higher than the estimates of Mandal *et al*. (2003) [17] in Muzaffarnagari sheep (0.20), Gowane *et al*. (2010) [9] in Garole x Malpura crossbred sheep (0.17), Sarghale *et al*. (2014) [25] in Baluchi sheep (0.10) and Qureshi *et al*. (2010) [23] in Kajli sheep (0.15) and lower than the estimates of Arthy *et al*. (2018) in Madras Red sheep (1.00). The higher estimates of heritability denotes that growth rate traits are influenced by individual genes and less affected by the environment indicating response to selection will be more when selection is based on these traits.

The maternal heritability estimates of the present study is almost in agreement with the findings of Illa *et al*. (2019) [13] in Nellore sheep and higher than the estimates obtained by Sarghale *et al*. (2014) [25] and lower than the results of Gowane *et al*. (2015) [10]. Lower estimates of maternal heritability was observed mostly in the post weaning phase and it is because of the reduction in the maternal influence on the animal's performance and after which animal has to depend on its own genes for better growth and development. This is in agreement with the findings of Illa *et al*. (2019) [13] in Nellore sheep and Mohammadi *et al*. (2010, 2013) in Sanjabi and Shal sheep respectively. Clear and high negative covariance exists between direct and maternal effects suggesting that 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 Gowane *et al*. (2015) [10] in Malpura sheep and Illa *et al*. (2019) [13] in Nellore sheep and contrary to the result of Aguirre *et al*. (2016) [1] in Santa Ines sheep whose result showed positive covariance between additive and maternal effects.

Negative correlation exists between the pre and post weaning average daily gain. The genetic correlation among the studied traits varies from -0.59 (ADG1-ADG3) to 0.52 (ADG2-ADG5) and the phenotypic correlation varies from -1 (ADG2-ADG4) to 0.50 (ADG2-ADG5). These results were in agreement with the findings of Sinha and Singh *et al*. (1997) [29] in Muzaffarnagari sheep and Gowane *et al*. (2015) [10] in Malpura sheep and comparable results obtained from the findings of Mandal *et al*. (2003) [17] in Muzaffarnagari sheep, Sanghale *et al*. (2014) in Baluchi sheep, Arthy *et al*. (2018) in Madras red sheep, Gholizadeh and Ghafouri-Kesbi (2017) [8] in Baluchi sheep and Illa *et al*. (2019) [13] in Nellore sheep. In contrary, Gowane *et al*. (2010) [9] in Garole x malpura sheep and Singh *et al*. (2016) in Marwari sheep had positive genetic and phenotypic correlations. Abegaz *et al*. (2005) suggested that the negative phenotypic correlation among pre and post weaning daily gains might be because of compensatory growth of poorly nursed lambs in the post weaning period in spite of positive genetic correlation.

The magnitude of genetic change per year of studied trait varied from -0.02 (ADG3) to 0.46 (ADG1), phenotypic change per year varied from -1.58 (ADG1) to 0.64 (ADG5) and environmental change per year has values from -2.05 (ADG1) to 2.4 (ADG3). Higher genetic change than the correct study was observed by Bosso *et al*. (2006) [4] in Djallonke's sheep, Ghafouri-Kesbi *et al*. (2009) [7] in Afshari sheep and Gholizadeh and Ghafouri-Kesbi (2017) [8] in Baluchi sheep. Shrestha *et al*. (1996) pointed out that the differences occurring in the trends estimation can be explained by selection criteria, which will vary between the different sheep breeds.

The present investigation revealed that model which included maternal genetic effects was found to be the best explaining the genetic variation in all the traits, thus highlighting the importance of maternal effect in influencing the genetic parameters of Muzaffarnagari sheep. Environmental factors also had specific role in affecting the average daily gain. Moderate genetic heritability estimates were obtained for almost all the traits, indicating that genetic improvement is possible by selection. Negative correlation among the pre and post weaning daily gains should be taken care while planning for breeding programmes. This study clearly indicates that, although genetic improvement has been obtained in this flock of Muzaffarnagari by the breeding strategy followed, there is some hampering effect of environment on average daily gain of animals. Information regarding the genetic, phenotypic and environmental trends for average daily gain of Muzaffarnagari sheep has been lacking in literature. The information generated in this study on genetic parameters, genetic, phenotypic and environmental trends can be utilized as a reference for planning breeding strategy and obtaining maximum response.

Table 1: Characteristics of the data structure of Muzaffarnagari sheep

TRAIT	ADG1	ADG2	ADG3	ADG4	ADG5
Number of records	4185	3695	3053	2699	2928
Mean	130.34	86.48	47.75	46.71	58.86
Standard deviation	43.85	36.25	28.31	28.40	18.84
CV (%)	32.36	43.09	59.29	60.80	32
Number of sires with progeny record	216	210	206	200	204
Number of dams with progeny records	1569	1470	1361	1251	1310

ADG1 average daily gain from birth to 3months of age, ADG2 average daily gain from 3 to 6 months of age, ADG3 average daily gain from 6 to 9 months of age, ADG4 average daily gain from 9 to 12 months of age, ADG5 average daily gain from 3 to 12 months of age; CV coefficient of variation.

Table 2: Least square means with Standard error for average daily gain traits of Muzaffarnagari sheep

	ADG1		ADG2		ADG3		ADG4		ADG5	
	N	MEAN±SE	N	MEAN±SE	N	MEAN±SE	N	MEAN±SE	N	MEAN±SE
Overall mean	4185	130.31±1.78	3695	86.48±1.55	3053	47.749±1.311	2699	46.71±1.33	2928	58.86±0.77
SEX	**		**		**		**		**	
Male	1999	134.26±1.91	1709	98.14±1.67	1327	53.98±1.44	1048	52.81±1.49	1143	67.19±0.85
Female	2186	125.37±1.86	1986	74.81±1.61	1726	41.51±1.35	1651	40.62±1.37	1785	50.54±0.79
Season	NS		**		**		**		**	
1	1966	131.28±1.89	1757	82.56^{a}±1.64	1406	43.85^{a}±1.41	1356	50.26^{a}±1.42	1421	57.71^{a}±0.82
2	2219	129.35±1.92	1938	90.39^{b}±1.68	1647	51.64^{b}±1.42	1343	43.16^{b}±1.46	1507	60.01^{b}±0.83
Period	**		**		**		**		**	
1(1991-94)	533	163.57^{c}±5.84	420	106.49^{b}±5.16	306	22.51^{a}±5.05	271	48.26^{b}±5.93	305	53.33^{a}±3.13
2(1995-98)	480	129.45^{a}±4.21	414	91.49^{c}±3.62	333	28.29^{a}±3.21	241	32.72^{a}±3.63	252	51.11^{a}±2.07
3(1999-02)	619	135.73^{b}±3.69	564	77.43^{ab}±3.20	420	39.86^{b}±2.87	407	50.10^{c}±3.02	419	57.44b^{c}±1.73
4(2003-06)	787	122.53^{b}±3.40	678	80.54^{ab}±3.001	613	46.41^{c}±2.62	541	46.56^{c}±2.84	564	58.53^{c}±1.61
5(2007-10)	413	117.77^{a}±3.99	384	89.13^{a}±3.36	325	54.46^{b}±2.95	307	47.11^{c}±3.15	327	63.40^{b}±1.80
6(2011-14)	842	133.52^{c}±3.81	753	87.87^{c}±3.27	664	53.16^{c}±2.87	629	43.30^{c}±3.13	680	57.82^{d}±1.76
7(2015-17)	511	109.63^{c}±5.27	482	72.11^{d}±4.49	392	89.54^{d}±3.92	303	58.95^{d}±4.28	381	70.40^{e}±2.35
Parity	*		NS		NS		NS		NS	
1	1475	130.22^{a}±2.02	1269	85.68±1.75	1066	47.92±1.49	914	44.14±1.54	998	57.59±0.88
2	1029	132.14^{b}±2.10	890	84.90±1.83	726	47.68±1.57	675	47.49±1.59	713	59.07±0.92
3	699	131.81^{b}±2.26	630	86.09±1.95	516	48.17±1.67	461	46.48±1.71	501	59.04±0.98
4	467	131.73^{b}±2.49	427	88.94±2.12	346	46.26±1.83	312	46.73±1.87	341	59.10±1.07
5	515	125.68^{b}±2.43	479	86.78±2.07	399	48.71±1.77	337	48.72±1.84	375	59.50±1.05
TOB	**		**		NS		NS		**	
1	3496	142.59^{a}±1.73	3080	83.90^{a}±1.51	2551	46.59±1.27	2251	45.85±1.29	2439	57.18^{a}±0.74
2	689	118.04^{b}±2.21	615	89.05^{b}±1.91	502	48.90±1.64	448	47.58±1.68	489	60.54^{b}±0.96

ADG1 average daily gain from birth to 3 months of age, ADG2 average daily gain from 3 to 6months of age, ADG3 average daily gain from 6 to 9 months of age, ADG4 average daily gain from 9 to 12 months of age, ADG5 average daily gain from 3 to 12 months of age; ** $p<0.01$; * $p<0.05$; 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 average daily gain traits of Muzaffarnagari sheep

Trait: ADG1	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	657.82	446.71	605.1	446.71	446.76	605.01
σ^2_m	-	25.72	133.17	-	12.87	73.48
σ_{am}	-	-	-210.34	-	-	-210.83
σ^2_c	-	-	-	25.72	12.87	59.93
σ^2_e	1167.59	1195.83	1128.23	1195.83	1195.78	1128.46
σ^2_p	1825.41	1668.26	1656.17	1668.26	1668.28	1656.04
h^2	0.36±0.04	0.27±0.04	0.37±0.06	0.27±0.04	0.27±0.04	0.37±0.06
m^2		0.02± 0.02	0.08±0.03		0.01±0.02	0.044±0.001
r_{am}	-	-	-0.74	-	-	-1
c^2	-	-	-	0.02±0.02	0.01± 0.00	0.04±0.03
BIC	35026.99	34693.29	34683.89	34693.29	34701.62	34692.22
ADG2						
σ^2_a	236.31	209.65	504.01	209.65	209.48	504.1
σ^2_m	-	20.19	173.65	-	10.08	137.5
σ_{am}	-	-	-263.44	-	-	-263.27
σ^2_c	-	-	-	20.19	10.08	36
σ^2_e	874.81	876.79	711	876.79	876.93	710.91
σ^2_p	1111.11	1106.63	1125.22	1106.63	1106.58	1125.24
h^2	0.21±0.03	0.19±0.03	0.45±0.07	0.19±0.03	0.19±0.03	0.45±0.07
m^2	-	0.02±0.01	0.15±0.03	-	0.01±0.01	0.12±0.03
r_{am}	-	-	-0.89	-	-	-1
c^2	-	-	-	0.02±0.01	0.01± 0.00	0.03±0.001
BIC	29294.71	29221.04	29174.66	29221.04	29229.24	29182.86
ADG3						
σ^2_a	54.46	53.89	169.48	53.89	53.88	169.54
σ^2_m	-	0	60.45	-	0	53.95
σ_{am}	-	-	-95.58	-	-	-95.62
σ^2_c	-	-	-	0	0	6.54
σ^2_e	608.1	609.04	538.04	609.04	609.05	538
σ^2_p	662.56	662.93	672.39	662.93	662.93	672.39
h^2	0.08±0.03	0.08± 0.03	0.25±0.06	0.08±0.03	0.08± 0.03	0.25±0.06
m^2	-	0.00±0.01	0.09±0.03	-	0.00±0.01	0.08± 0.002
r_{am}	-	-	-0.94	-	-	-1
c^2	-	-	-	0.00±0.01	0.00±0.00	0.01±0.03
BIC	22726.72	22677	22667.46	22677	22685.01	22675.47

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; BIC Bayesian information criteria
ADG1 average daily gain from birth to 3 months of age; ADG2 average daily gain from 3 to 6months of age; ADG3 average daily gain from 6 to 9 months of age.

Table 3.2: Variance components and genetic parameters for average daily gain traits of Muzaffarnagari sheep

Trait: ADG4	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	63.64	61.94	165.02	61.94	61.94	165.04
σ^2_m	-	0	42.49	-	0	42.53
σ_{am}	-	-	-83.74	-	-	-83.78
σ^2_c	-	-	-	0	0	0
σ^2_e	565.77	569.48	513.03	569.48	569.48	513.01
σ^2_p	629.41	631.42	636.8	631.42	631.42	636.8
h^2	0.10±0.03	0.10±0.03	0.26±0.06	0.10±0.03	0.10±0.03	0.26±0.06
m^2	-	0.00±0.01	0.07±0.03	-	0.00±0.01	0.07± 0.002
r_{am}	-	-	-1	-	-	-1
c^2	-	-	-	0.00±0.01	0.00±0.00	0.00±0.03
BIC	19928.76	19888.05	19872.57	19888.05	19895.94	19880.46
ADG5						
σ^2_a	48.52	45.46	97.75	45.46	45.5	97.72
σ^2_m	-	5.43	37.18	-	2.7	26.64
σ_{am}	-	-	-51.02	-	-	-51.01
σ^2_c	-	-	-	5.43	2.7	10.54
σ^2_e	185.01	183.33	152.67	183.33	183.32	152.69
σ^2_p	233.52	234.22	236.58	234.22	234.22	236.58
h^2	0.21±0.03	0.19±0.04	0.41±0.07	0.19±0.04	0.19±0.04	0.41± 0.07
m^2	-	0.02±0.02	0.16±0.04	-	0.01±0.02	0.11±0.04
r_{am}	-	-	-0.85	-	-	-1
c^2	-	-	-	0.02±0.02	0.01±0.00	0.05±0.001
BIC	18686.95	18641.91	18612.14	18641.91	18649.88	18620.11

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; BIC Bayesian information criteria
ADG4 average daily gain from 9 to 12 months of age; ADG5 average daily gain from 3 to 12 months of age.

Table 3.3: Variance components and genetic parameters for average daily gain traits of Muzaffarnagari sheep from best models

Trait	ADG1	ADG2	ADG3	ADG4	ADG5
Best Model	**3**	**3**	**3**	**3**	**3**
σ^2_a	605.1	504.01	169.48	165.02	97.75
σ^2_m	133.17	173.65	60.45	42.49	37.18
σ_{am}	-210.34	-263.44	-95.58	-83.74	-51.02
σ^2_e	1128.23	711	538.04	513.03	152.67
σ^2_p	1656.17	1125.22	672.39	636.8	236.58
h^2	0.37±0.06	0.45±0.07	0.25±0.06	0.26±0.06	0.41±0.07
m^2	0.08±0.03	0.15±0.03	0.09±0.03	0.07±0.03	0.16±0.04
r_{am}	-0.74	-0.89	-0.94	-1	-0.85
Log-L	-17325	-17325	-11318	-9920.5	-9290.1
BIC	34683.9	29174.7	22667.5	19872.6	18612.1

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; BIC Bayesian information criteria
ADG1 average daily gain from birth to 3 months of age; ADG2 average daily gain from 3 to 6months of age; ADG3 average daily gain from 6 to 9 months of age; ADG4 average daily gain from 9 to 12 months of age, ADG5 average daily gain from 3 to 12 months of age;

Table 3.3: Variance components and genetic parameters for average daily gain traits of Muzaffarnagari sheep from best models

Trait	ADG1	ADG2	ADG3	ADG4	ADG5
Best Model	**3**	**3**	**3**	**3**	**3**
σ^2_a	605.1	504.01	169.48	165.02	97.75
σ^2_m	133.17	173.65	60.45	42.49	37.18
σ_{am}	-210.34	-263.44	-95.58	-83.74	-51.02
σ^2_e	1128.23	711	538.04	513.03	152.67
σ^2_p	1656.17	1125.22	672.39	636.8	236.58
h^2	0.37±0.06	0.45±0.07	0.25±0.06	0.26±0.06	0.41±0.07
m^2	0.08±0.03	0.15±0.03	0.09±0.03	0.07±0.03	0.16±0.04
r_{am}	-0.74	-0.89	-0.94	-1	-0.85
Log-L	-17325	-17325	-11318	-9920.5	-9290.1
BIC	34683.9	29174.7	22667.5	19872.6	18612.1

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; BIC Bayesian information criteria
ADG1 average daily gain from birth to 3 months of age; ADG2 average daily gain from 3 to 6months of age; ADG3 average daily gain from 6 to 9 months of age; ADG4 average daily gain from 9 to 12 months of age, ADG5 average daily gain from 3 to 12 months of age;

Table 5: Genetic, phenotypic and environmental trends per year for average daily gain traits of Muzaffarnagari sheep

Trait	Genetic trends	Phenotypic trends	Environmental trends
ADG1	0.46	-1.58	-2.05
ADG2	0.15	0.09	-0.06
ADG3	-0.02	2.38	2.4
ADG4	0.03	0.44	0.41
ADG5	0.05	0.64	0.59

ADG1 average daily gain from birth to 3 months of age; ADG2 average daily gain from 3 to 6months of age; ADG3 average daily gain from 6 to 9 months of age; ADG4 average daily gain from 9 to 12 months of age, ADG5 average daily gain from 3 to 12 months of age;

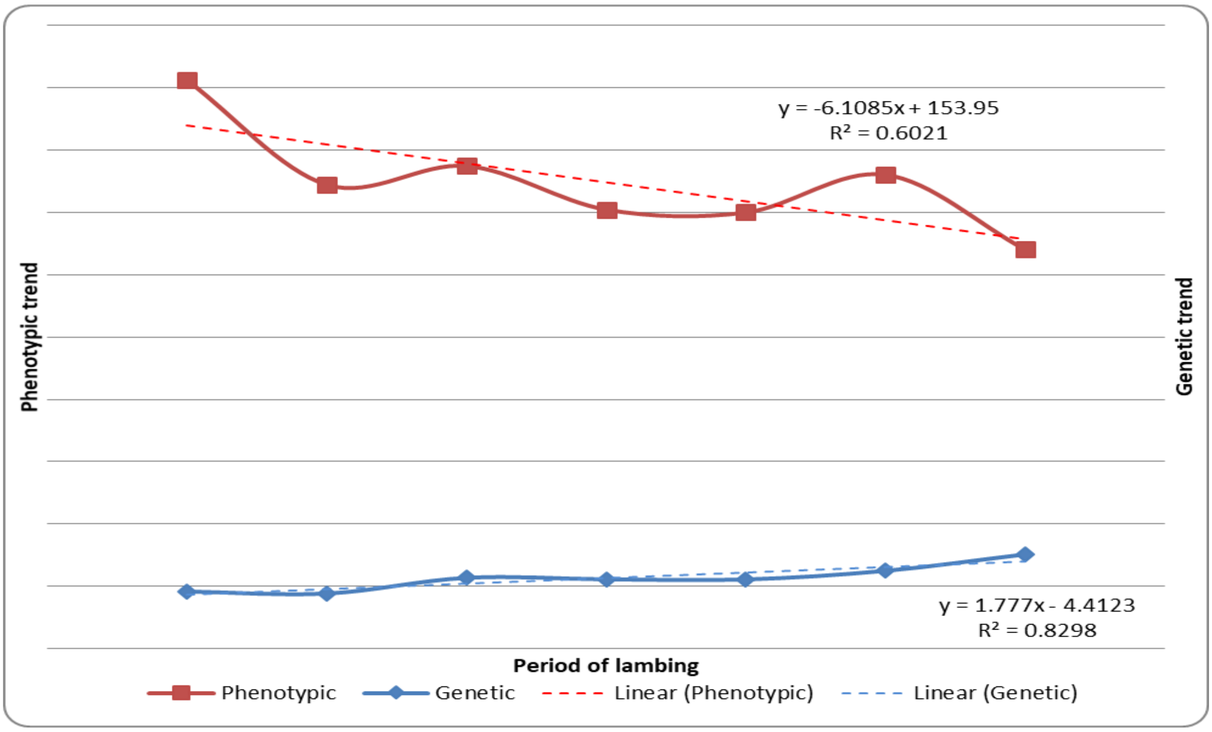

Fig 1: Period wise genetic and phenotypic trends of average daily gain from birth to weaning, R_2 coefficient of determination; y dependent variable; x independent variable

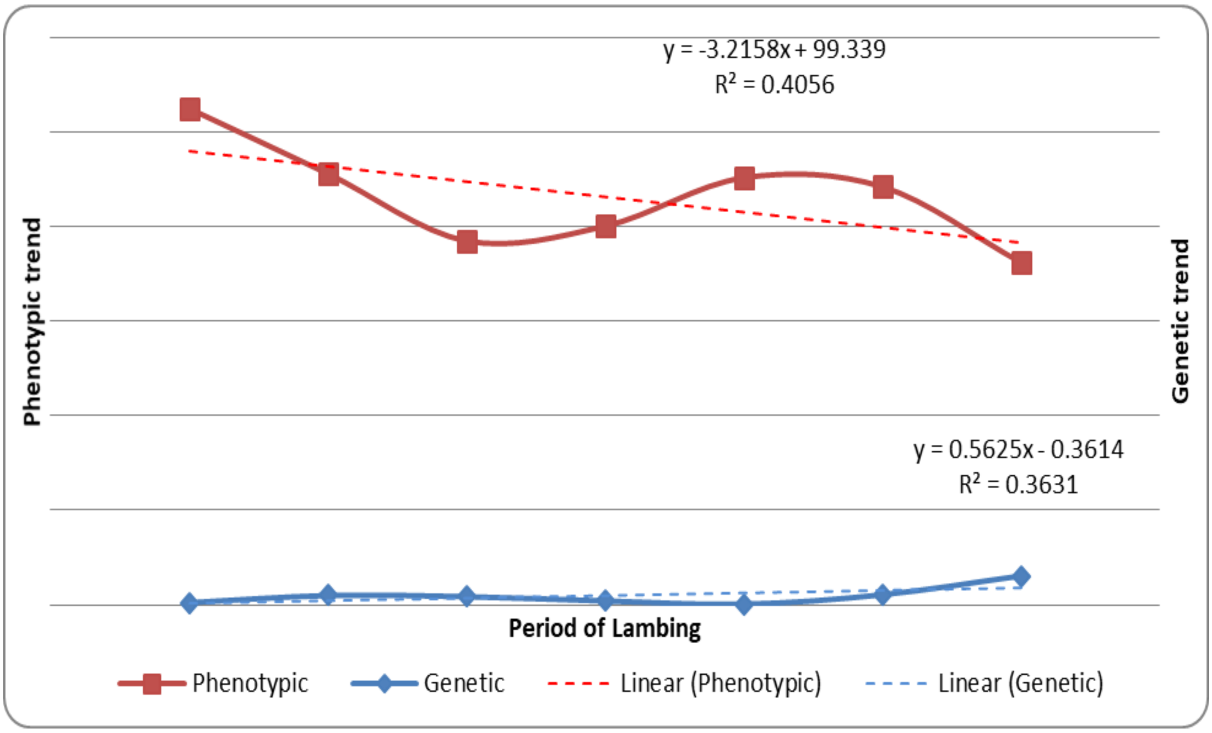

Fig 2: Period wise genetic and phenotypic trends of average daily gain from weaning to 6 months of age, R^2 coefficient of determination; y dependent variable; x independent variable

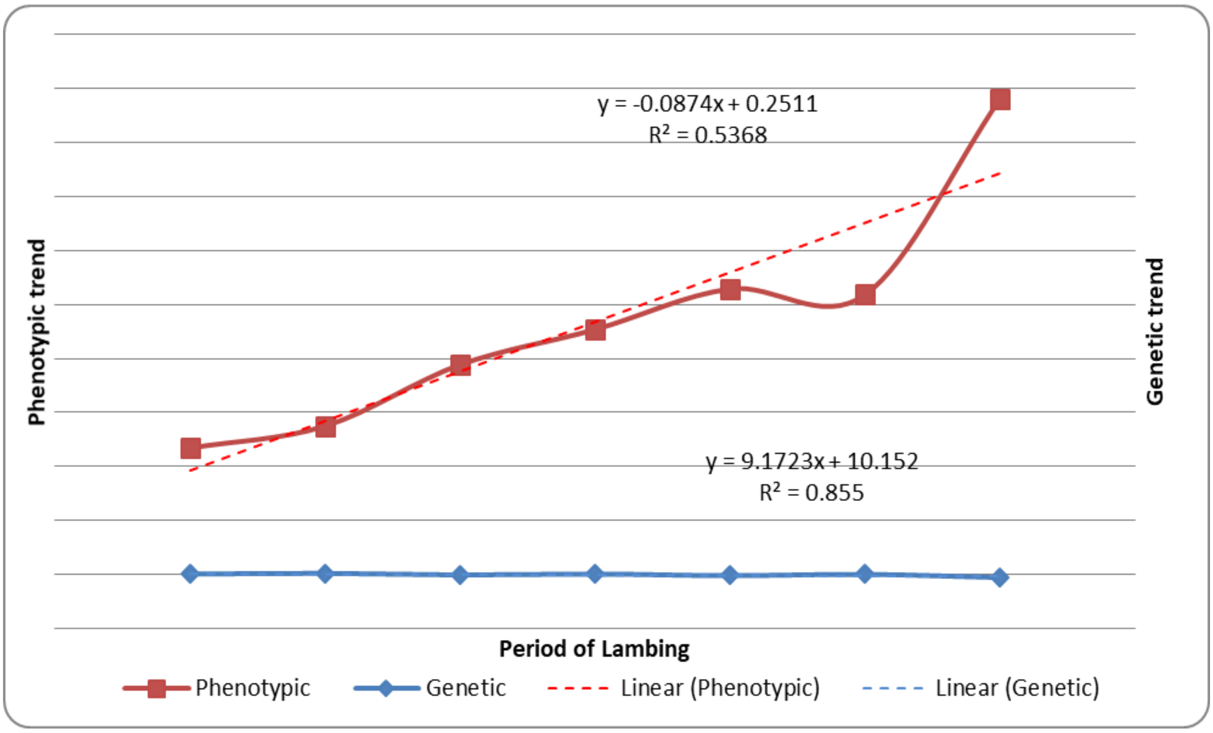

Fig 3: Period wise genetic and phenotypic trends of average daily gain from 6 to 9 months of age, R^2 coefficient of determination; y dependent variable; x independent variable

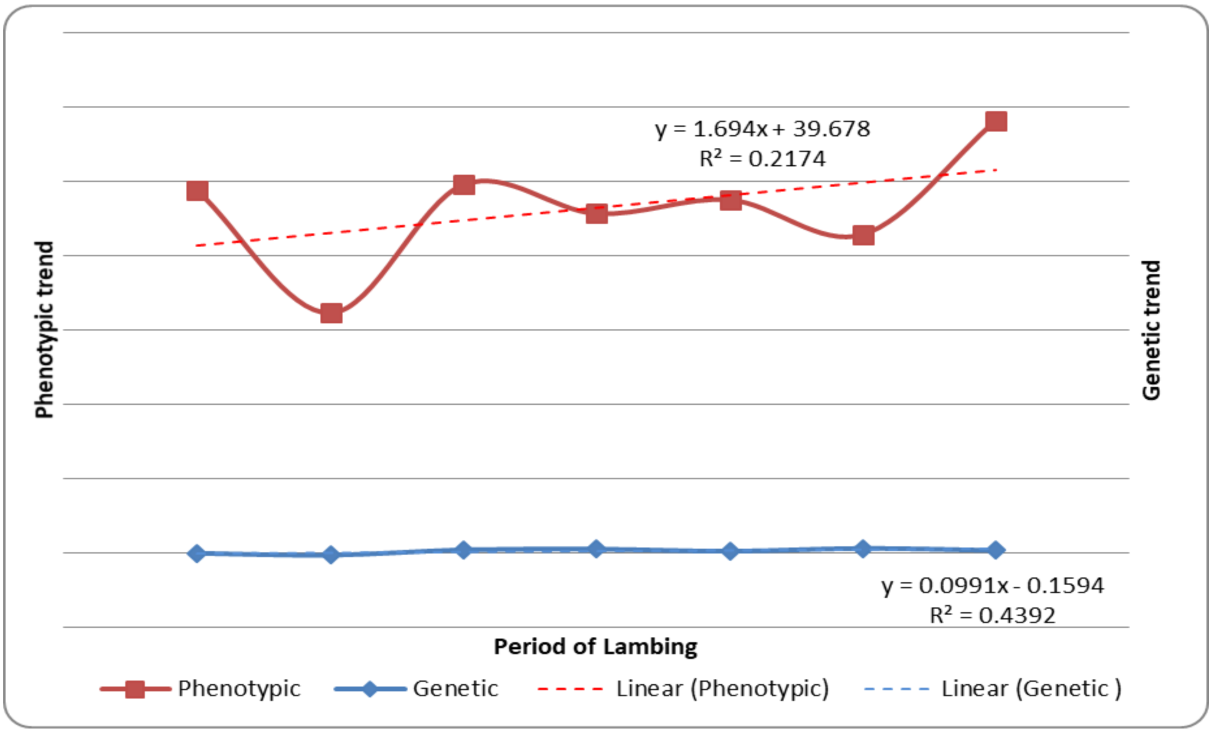

Fig 4: Period wise genetic and phenotypic trends of average daily gain from 9 to 12 months of age, R^2 coefficient of determination; y dependent variable; x independent variable

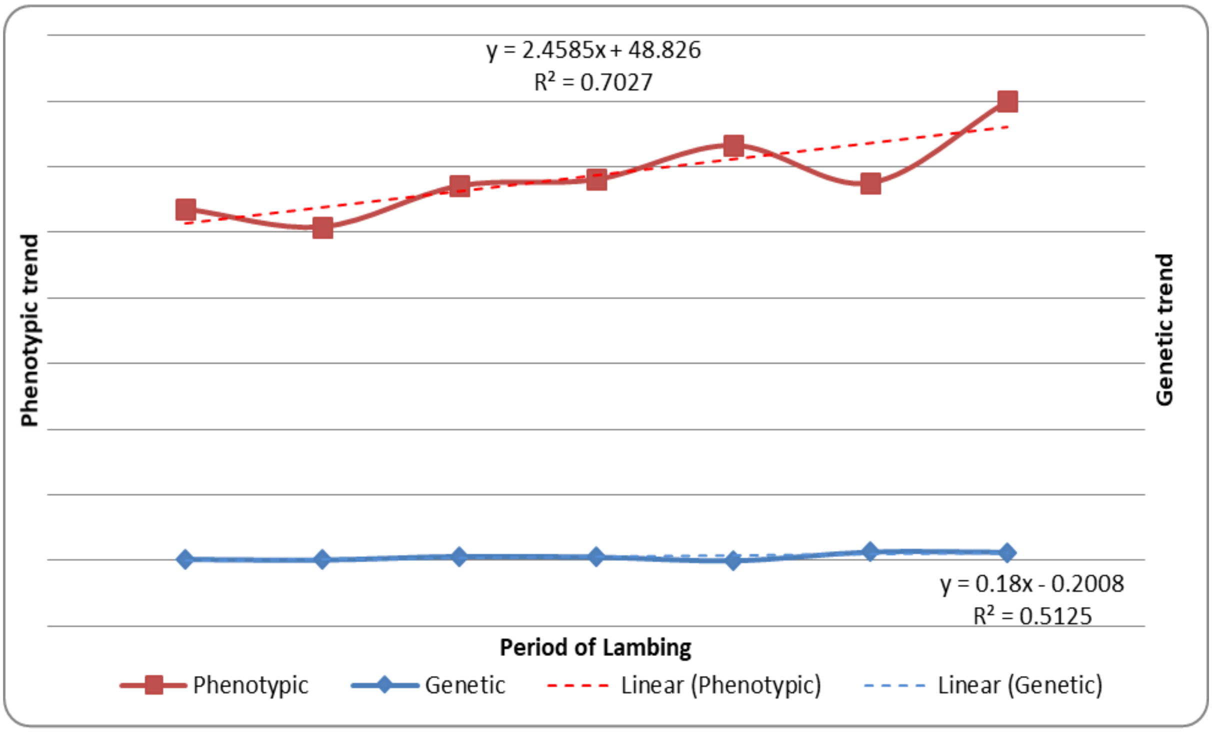

Fig 5: Period wise genetic and phenotypic trends of average daily gain from 3 to 12 months of age, R^2 coefficient of determination; y dependent variable; x independent variable

Conflict of Interest
Not available

Financial Support
Not available

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