GENETIC EVALUATION OF GROWTH AND REPRODUCTIVE PERFORMANCE AND THEIR TRENDS IN MUZAFFARNAGARI SHEEP

Thesis

Submitted to the
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Izatnagar - 243 122 (U.P.), India

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Veterinary Science
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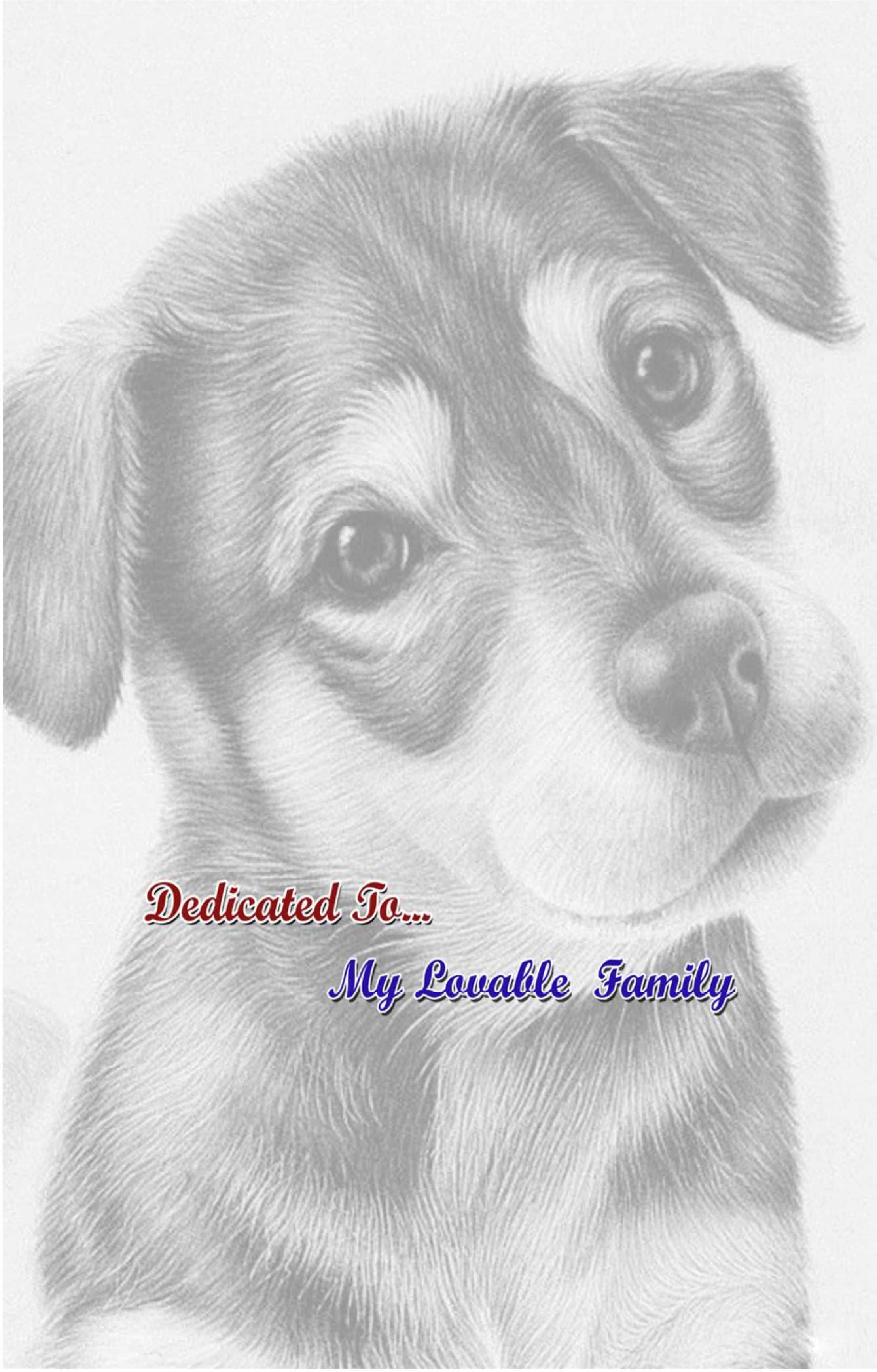

Dedicated To...

My Lovable Family

भा.कृ.अनु.प.–भारतीय पशु चिकित्सा अनुसंधान संस्थान
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Dated: 28/06/**2019**

Certificate

This is to be certified that the research work embodied in this thesis entitled **"Genetic Evaluation of Growth and Reproductive Performance and their Trends in Muzaffarnagari Sheep"** *submitted by* **Dr. Ezhil Vadhana P, Roll No. M-5899,** *for the award of* **Master of Veterinary Science** *Degree in* **Animal Genetics and Breeding** *at ICAR-Indian Veterinary Research Institute, Izatnagar, is the original work carried out by the candidate herself under my supervision and guidance.*

It is further certified that **Dr. Ezhil Vadhana P, Roll No. M-5899,** *has worked for more than 21 months in the Institute and has put in more than 150 days attendance under me from the date of registration for the* **Master of Veterinary Science** *Degree in this Deemed University, as required under the relevant ordinance.*

28/06/2019

(RAN VIR SINGH)
Chairman
Advisory Committee

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We the undersigned members of Advisory Committee of **Dr. Ezhil Vadhana P**, *Roll No. M-5899, a candidate for the degree of* **Master of Veterinary Science** *with the major discipline* **Animal Genetics and Breeding**, *agree that the thesis entitled* **"Genetic Evaluation of Growth and Reproductive Performance and their Trends in Muzaffarnagari Sheep"** *may be submitted in partial fulfillment of the requirement for the degree.*

We have gone through the contents of the thesis and are fully satisfied with the work carried out by the candidate, which is being presented for the award of **Master of Veterinary Science** *degree of this Institute.*

It is further certified that the candidate has completed all the prescribed requirements governing the award of **Master of Veterinary Science** *degree of the Deemed University, ICAR-Indian Veterinary Research Institute.*

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Date : 29-7-2019

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Date: 28.06.2019
Place: *ICAR-IVRI, Izatnagar*

(Ezhil Vadhana)

ABBREVIATIONS

% : Percentage
% : Percentage
@ : at the rate of
ΔE : Environmental trend
ΔG : Genetic trend
ΔP : Phenotypic trend
^{0}C : Degree Celsius
12WT : Weight at 12 months of age
6WT : Weight at 6 months of age
9WT : Weight at 9 months of age
A : Adenine
a : Vectors of direct additive genetic effects
AAs : Amino acid
Acc. No. : Accession number
ADG1 : Average daily gain from birth to 3 months
ADG2 : Average daily gain between 3 to 6 months
ADG3 : Average daily gain between 6 to 9 months
ADG4 : Average daily gain between 9 to 12 months
AFL : Age of ewe at first lambing
AFS : Age of ewe at first service
ALK-6 : Activin like kinase-6
BIC : Bayesian information criterion
BMPR : Bone morphogenetic protein receptor
BMPs : Bone morphogenetic proteins
bp : Base pair(s)
BWT : Weight at birth
C : Cytosine
c : Vectors of permanent environmental effects of the dam
c^2 : Maternal permanent environmental heritability
$CaCl_2$: Calcium chloride
cAMP : Cyclic adenosine mono phosphate
DMRT : Duncans multiple range test
DNA : Deoxyribo nucleic acid

dNTPs	:	2’-deoxyribonucleoside-tri-phosphate
e	:	Random error
EBV	:	Expected breeding value
EDTA	:	Ethylene-diamine tetra acetic acid
ETA	:	Expected transmitting ability
EWTL	:	Ewe’s weight at lambing
EWTS	:	Ewe’s weight at service
FAO	:	Food and Agriculture Organization
FecB	:	Booroola gene or fecundity gene
FecX	:	Fecundity X
Fig.	:	Figure
FSH	:	Follicle stimulating hormone
G	:	Guanine
g	:	Gram
GCs	:	Granulosa cells
GDFs	:	Growth differentiation factors
GDP	:	Gross domestic product
GnRH	:	Gonadotrophin releasing hormone
h^2	:	Heritability
h^2_t	:	Total heritability
hr	:	Hour(s)
KCl	:	Potassium chloride
kg	:	Kilogram
LH	:	Luteinizing hormone
Log-L	:	Log – likelihood
LS	:	Litter size
LSC	:	Least squares constant
M	:	Molar
m	:	Vectors of maternal genetic effects
m^2	:	Maternal heritability
mg	:	Milligram
Mg^{2+}	:	Magnesium chloride
$MgCl_2$	:	Magnesium chloride
min	:	Minute(s)
Ml	:	Milliliter
mM	:	Millimolar

mm	Millimeter
NaCl	Sodium chloride
NaOH	Sodium hydroxide
ng	Nanogram
NS	Non-significant
OD	Optical density
OR	Ovulation rate
PCR	Polymerase chain reaction
pH	Negative logarithm of hydrogen (H^+) ion
pMol	Picomolar
Q	Glutamine
R	Arginine
r_{am}	Genetic correlation between additive and maternal genetic effects
RBC	Red blood corpuscles
RE	Restriction enzyme
REML	Restricted maximum likelihood method
RFLP	Restriction fragment length polymorphism
RGR1	Relative growth rate from birth to 3 months
RGR2	Relative growth rate from 3 to 6 months
RGR3	Relative growth rate from 6 to 9 months
RGR4	Relative growth rate from 9 to 12 months
RGR5	Relative growth rate from 3 to 12 months
RNAse	Ribonuclease
rpm	Revolution per minute
SDS	Sodium dodecyl sulphate
SE	Standard error
sec	Second
t	Intra class correlation
T.E.	Tris-EDTA
TBE	Tris borate EDTA
Temp	Temperature
TGR-b	Transforming growth factor b
Tm	Melting temperature
TOB	Type of birth
U	Unit(s)

UV	:	Ultra violet
v	:	Volt
W/v	:	Weight/volume
WBC	:	White blood corpuscles
WWT	:	Weight at 3 months of age
β	:	Vectors of fixed effects
ε	:	Vectors of residual effects
σ^2_a	:	Additive genetic variance
σ^2_c	:	Maternal permanent environmental variance
σ^2_e	:	Residual variance
σ^2_m	:	Maternal genetic variance
σ^2_p	:	Phenotypic variance
σ_{am}	:	Covariance between direct additive and maternal genetic effects

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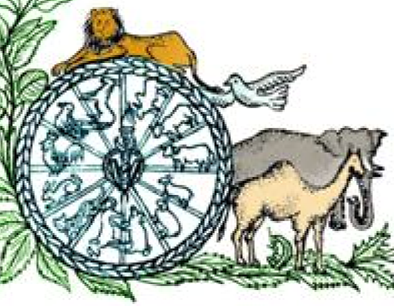


1

INTRODUCTION

Small ruminants play an important role in the livelihood of small, marginal and landless farmers. By providing additional source of income to the farmers it ensures nutritional security to the weaker section of the society. Sheep are mostly reared under arid and semi-arid agro climatic conditions and can be maintained under adverse environmental conditions including low rain fall and recurrent famine. Sheep are reared for mutton, hide, pelt, wool and manure. Sheep can thrive well on barren and waste land where other livestock can't maintain themselves.

Sheep along with goats were perhaps the first ruminants to be domesticated by man. They appear to have been firstly domesticated in the mountains of Iran, Turkestan and of civilization of Mesopotamia, Mohen-jo-Daro and Harappa in northern India. Income from sheep farming is derived from the sale of lambs, mutton, wool, skin, manure and milk. This variety of output from sheep provides a continuous distribution to farm income throughout the year and also absorbs the shocks of natural hazards such as severe drought and famine.

India's sheep population is about 65.06 million possessing 12.71% of total livestock population. India is endowed with 43 descript breeds of sheep which are reared in different agro climatic conditions. India ranks third in sheep population of the world with about 5.6% of world's sheep population. During the last few decades, shrinkage in the grazing area had resulted in tremendous rise in the cost of sheep enterprise. Hence, different strategies had emerged to improve the efficiency of meat production where the selection of animals is based on their growth rate and efficiency of feed utilization (Ghafouri-Kesbi, 2011). The role of animal breeder, therefore, is of utmost importance to improve the production efficiency for maximizing economic return to the sheep farmer. To formulate meaningful breeding plans, knowledge regarding variance and covariance components and genetic parameters for economic traits related with growth rate and reproduction is needed.

The growth rate is an economic trait of interest in domestic animals as growth of the lambs is reflection of the adaptability and economic viability of the animal and hence may be used as criteria for the selection among breeds and the individual within breeds (Singh, 2007). The reproduction and faster growth rate are important components of flock productivity and also serious limiting factors in improving the productivity in indigenous breeds of sheep.

The ewe’s sexual maturity at an early age and lambing at a regular interval helps not only in building up the flock through increased rate of replacement but also enhance the rate of genetic progress by way of reducing generation interval. Productivity can be improved by providing optimal environment viz., nutrition, management and health coverage but improvement in performance due to these factors are of temporary nature. Proper feeding and management of growing female lambs may reduce the age at first lambing. Similarly, other reproductive traits may be improved through better management. Improving the genetic make-up of sheep population through proper selection and breeding systems can make permanent changes. Besides genetic merits, growth traits are largely determined by non-genetic factors. Before planning and implementing a sheep breeding programme through selective breeding, it is necessary to evaluate the factors affecting body weights and reproduction.

A number of non-genetic factors affect these growth and reproduction traits and directly obscure recognition of the genetic potential. Adjustment of data for non-genetic factors and estimation of genetic parameters for various traits are necessary for obtaining reliable estimates for important economic traits and increasing accuracy of selection of breeding animals. An effective breeding plan can only be devised after thorough knowledge has been obtained about the inheritance of economically important traits.

The Muzaffarnagari sheep is one of the heaviest and largest mutton breeds in India and is widely distributed in the semi-arid region of western Uttar Pradesh, near Meerut, Muzaffarnagar, Saharanpur, Bijnor and in some parts of Delhi and Haryana. This breed is considered a less-known unique genotype exhibiting better growth, very good adaptability and a somewhat higher prolificacy than other Indian sheep breeds. The breed has better potential for meat and carpet wool production than other Indian sheep breeds.

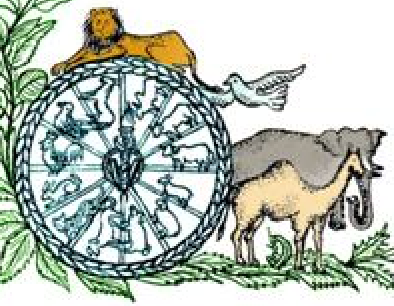
The pre requisites for bringing about changes in genotypes in the desired direction are the precise estimates of genetic parameters. Once the estimates of such parameters as heritabilities and genetic correlations of economic traits become available, choice regarding efficient breeding systems and selection programme become easy. The potential of genetic improvement in economic traits is largely decided by their heritability and genetic correlation between them (Ahmad *et al.*, 2004). It is also necessary to know about the changes occurring in a given population over the years to assess its effectiveness so as to suggest appropriate breeding strategies for maximum genetic gain.

Hence, the present study was aimed at estimating genetic, phenotypic parameters and their trends in various economic traits and factors affecting these traits in Muzaffarnagari sheep with the following objectives :

1) To estimate genetic and phenotypic parameters for growth and reproductive performance.
2) To evaluate genetic and phenotypic trends of growth and reproductive performance.
3) To genotype *FecB* gene and evaluate its association with litter size in Muzaffarnagari sheep.

* * *

Review of Literature



2

REVIEW OF LITERATURE

2.1 Growth performance at different stages and factors affecting it

Growth is an important measure of fitness of a genotype. It can be measured as body weight at a specific time and absolute growth rate (average daily gain) during a specific period. The reports given by various workers regarding the genetic analysis of growth traits in sheep are summarized below:

2.1.1 Body weight at different ages

The estimates of average body weight reported by various workers at different stages have been presented in Table 2.1. Birth weight ranged from1.89 ± 0.76 kg in Sonadi breed (Tailor and Yadav, 2010) to 3.75 ± 0.08 kg in Munjal breed (Poonia, 2004), 3 months body weight ranged from 7.89 ± 0.11 kg in Mecheri sheep (Shivkumar, 2003) to 17.70 ± 0.05 kg in Pugal sheep (Dass, 2007), 6 months body weight ranged from 12.92 ± 0.08 kg in Ganjam sheep (Patnayak *et al*., 2003) to 27.14 ± 0.57 kg in Munjal breed (Poonia, 2004), 9 months body weight ranged from 16.49 ± 0.41 kg in Malpura sheep (Singh, 1980) to 32.01± 0.23 kg in Malpura sheep (Arora *et al*., 1999) and 12 months body weight ranged from 15.91 ± 0.25 kg in Mecheri breed (Shivkumar, 2003) to 30.44 ± 0.12 kg in Marwari sheep (Narula *et al*., 2010).

2.1.2 Factors affecting body weights of sheep at different ages

Genetic and non-genetic factors have effects on body weight at different ages. Different workers studied effects of various factors like sire, sex of lamb, year of birth and parity on growth traits and their observations have been reviewed and presented below.

2.1.2.1 Effect of sire

Weaning weight was significantly affected by sire as reported by Nawaj *et al.* (1998) in Kajli and Lohi sheep. The 3 months and 12 months body weights of Madras Red sheep was significantly affected by sire groups as reported by Devendarn *et al.* (2007). Body weights at all ages up to yearling significantly affected by sire as reported by Gohil (2010) and Singh (2012) in Marwari sheep and Parihar (2012) in Magra sheep and Kumar (2017) in Nellore and Arthy (2018) in Madras Red sheep.

Table 2.1: Least-squares means (kg) at different ages from various references

Least-squares means (kg) at different ages

Breed / Genetic Group	Birth	3 months	6 months	9 months	12 months	References
Muzaffarnagari	2.745				32.85 ±0.99	Bhadula *et al.* (1980)
	3.25 ± 0.04	14.45±0.29	19.92 ±0.37	24.25 ±0.45	28.90 ±0.53	Kaila *et al.* (1989)
	2.80 ± 0.02	10.58±0.14	18.84 ±0.40	27.26 ±0.86		Bhadula and Bhat (1980)
Malpura	2.88 ± 0.14	13.73 ± 0.66	13.95 ± 0.40	16.49 ± 0.41	19.01 ± 0.50	Singh (1980)
Muzaffarnagari	3.48 ± 0.07	16.82 ± 0.03	25.16 ± 0.41			Sinha and Singh (1997)
Malpura	2.91 ± 0.02	12.86 ± 0.09	19.24 ± 0.15	22.26 ± 0.16	25.62 ± 0.18	Charyulu *et al.* (1998)
Nali and its crosses	3.21	10.78	14.53		19.39	Malik *et al.* (1998)
Marwari	2.80 ± 0.01	11.72 ± 0.07	15.22 ± 0.05	18.52 ± 0.06	20.97 ± 0.09	Singh *et al.* (1998)
Malpura	2.90 ± 0.02	13.37 ± 0.21	20.87 ± 0.31	32.01 ± 0.23	27.63 ± 0.26	Arora *et al.* (1999)
Avikalin	2.98 ± 0.03	15.13 ± 0.19	21.92 ± 0.35		28.70 ± 0.28	Arora *et al.* (1999)
Chokla	2.81 ± 0.01	12.12 ± 0.11	16.91 ± 0.13			Kumar (2000)
Bharat Merino	3.21 ± 0.08	16.20 ± 0.16	22.03 ± 0.27		29.74 ± 0.34	Tomar *et al.* (2000a)
Bharat Merino	3.42 ± 0.03	15.74 ± 0.45	22.31 ± 0.91		30.26 ± 1.01	Tomar *et al.* (2000b)
Marwari	2.97 ± 0.01	12.95 ± 0.06	17.35 ± 0.05	20.75 ± 0.05	23.53 ± 0.06	Joshi (2001)
Marwari	3.15± 0.01	14.01 ± 0.06	19.37 ± 0.07	23.08 ± 0.07	25.75 ± 0.08	Dass and Singh (2002)
Ganjam	2.07 ± 0.02	8.60 ± 0.05	12.92 ± 0.08	16.51 ± 0.17	18.61 ± 0.22	Patnayak *et al.* (2003)
Marwari	2.67 ± 0.01	11.47 ± 0.06	15.51 ± 0.05	18.94 ± 0.07	20.64 ± 0.08	Sharma *et al.* (2003)
Mecheri		9.64±0.15	13.25±0.19	16.54±0.26	18.72±0.25	Jagatheesan *et al.* (2003)
Mecheri	2.20 ± 0.02	7.89 ± 0.11			15.91 ± 0.25	Shivkumar (2003)
Muzaffarnagari	3.12 ± 0.23				28.04 ± 0.64	Mandal *et al.* (2003)
Malpura	3.02	16.2	24.58	26.99	29.13	Kumar *et al.* (2004)
Munjal	3.75 ± 0.08	16.87 ± 1.03	27.14 ± 0.57			Poonia (2004)

Breed / Genetic Group	**Birth**	**3 months**	**6 months**	**9 months**	**12 months**	**References**
Nali	3.02 ± 0.02	10.66 ± 0.10	14.14 ± 0.14			Dey and Poonia (2005)
Marwari	2.77 ± 0.04	11.78 ± 0.20	16.45 ± 0.27	18.74 ± 0.33	20.70 ± 0.31	Nehra and Singh (2006)
Pugal	2.62 ± 0.01	17.70 ± 0.05	23.67 ± 0.09		29.62 ± 0.26	Dass (2007)
Madras Red	2.79 ± 0.01	9.43 ± 0.01	14.84 ± 0.01	18.67 ± 0.01	20.81 ± 0.01	Devendran *et al.* (2007)
Vembur	2.87 ± 0.04					Ravimurgan *et al.* (2007)
Mecheri	2.27 ± 0.06					Sarvana *et al.* (2007)
Chokla	2.74 ± 0.02	10.94 ± 0.10	17.80 ± 0.12	20.52 ± 0.13	24.23 ± 0.16	Prince *et al.* (2008)
Madgyal	3.08 ± 0.02	18.16 ± 0.13	23.94 ± 0.19	27.55 ± 0.21	31.00 ± 0.22	Waghmode *et al.* (2008)
Malpura	3.09 ± 0.16	14.16 ± 0.08	21.44 ± 0.11		28.00 ± 0.13	Mishra *et al.* (2009b)
Magra	3.02 ± 0.01	15.41 ± 0.07	23.07 ± 0.10	27.28 ± 0.01	29.49 ± 0.11	Narula *et al.* (2009)
Madras Red	2.68 ± 0.01	9.64 ± 0.03	15.02 ± 0.10	17.80 ± 0.12	19.88 ± 1.14	Shivkumar *et al.* (2009)
Nellore	2.88 ± 0.04	13.39 ± 0.07	17.52 ± 0.05	20.53 ± 0.07	24.67 ± 0.08	Reddy *et al.* (2009)
Marwari	3.08 ± 0.02	15.22 ± 0.20	21.13 ± 0.30	25.49 ± 0.33	28.02 ± 0.38	Gohil (2010)
Marwari	2.93 ± 0.01	15.88 ± 0.09	22.59 ± 0.12	28.22 ± 0.11	30.44 ± 0.12	Narula *et al.* (2010)
Sonadi	1.89 ± 0.76	10.48 ± 0.84	16.42 ± 0.55	20.06 ± 0.43	22.17 ± 0.48	Tailor and Yadav (2010)
Mecheri		8.02±0.07	11.37±0.11	13.99±0.13	16.81±0.15	Thiruvenkadan *et al.* (2010)
Malpura	3.55 ± 0.03	14.01 ± 0.15	21.05 ± 0.35	23.65 ± 0.33	28.04 ± 0.35	Gowane and Arora (2010)
Kheri	3.40 ± 0.02	13.10 ± 0.11	20.04 ± 0.31	22.78 ± 0.28	26.91 ± 0.33	Gowane and Arora (2010)
Malpura	3.00 ± 0.01	13.53 ± 0.07	20.54 ± 0.09	23.68 ± 0.11	27.19 ± 0.12	Arora *et al.* (2010)
Polled Dorset	3.35 ± 0.09					Khan *et al.* (2011)
Crossbred	3.47 ± 0.06					Khan *et al.* (2011)
Marwari	3.14 ± 0.01	15.13 ± 0.13	21.14 ± 0.18	25.85 ± 0.16	28.87 ± 0.21	Singh (2012)
Magra	3.04 ± 0.01	14.20 ± 0.10	21.86 ± 0.22	25.67 ± 0.26	27.89 ± 0.33	Parihar (2012)
Deccani	2.87 ± 0.01	13.86 ± 0.10	18.02 ± 0.12	21.17 ± 0.15	23.94 ± 0.18	Chikurdekar *et al.* (2012)
Madras Red	2.76	9.90	14.53	18.16	21.05	Balasubramanyam *et al.* (2012)
Madras Red	2.687± .019	10.548± .093	14.943± .125	17.902± .165	20.369± .202	Ganesan *et al.* (2013)
Muzaffarnagari	3.14±0.01	13.86 ± 0.09				Mandal *et al.* (2015)
Harnali	3.35±0.05	12.41±0.08				Lalit *et al.* (2016)
Madras red	2.67	10.05	14.56	18.36	21.36	Arthy *et al.* (2018)
Overall average of adult body weight	25.5572					

2.1.2.2 Effect of year/period of birth

The year differences could be due to varying availability of feed and fodders, physical environment and other managemental factors prevailing in different years. The reports showing significant effect of year on body weight at different ages in different years are tabulated in Table 2.2. However, few workers also reported non-significant effect of the year/period of birth on body weight. Non-significant effect of year reported by Dass and Acharya (1970) in Magra, Bohra *et al*. (1979) in Malpura and Sonadi breeds, Khan and Bhatt (1981) at birth, 3 and 6 months' body weight in Muzaffarnagari and Corriedale half breds, Singh *et al*. (1998) in Marwari sheep, Nawaj *et al*. (1998) in Kajli and Lohi sheep and Ravimurgan *et al*. (2007) in Vembur lambs.

Table 2.2: Reports showing significant effect of the year of birth on body weights of lambs at different ages

Breed / genetic group	**Body weight**	**References**
Deccani	Birth	Kulkarni and Deshpande (1990)
Marwari	All ages up to yearling	Nehra (1991)
Marwari	All ages up to yearling	Ganai (1992)
Avikalin	All ages up to yearling	Singh and Dhillon (1992)
Nali	Birth	Sharma (1995)
Marwari	Birth	Singhal (1996)
Marwari	Birth	Pannu *et al*. (1994)
Marwari	3, 6, 9 and 12 months of age	Singh *et al*. (1998)
Nali	All ages up to yearling	Sharma *et al.* (1999a)
Muzaffarnagari	All ages up to yearling	Lal *et al.* (2000)
Marwari	All ages up to yearling	Joshi (2001)
Marwari	All ages up to yearling	Dass and Singh (2002)
Marwari	All ages up to yearling	Joshi *et al.* (2003)
Muzaffarnagari	Birth and 12 months of age	Mandal *et al.* (2003)
Nali and Marwari	Birth, 3 and 6 months of age	Sharma *et al.* (2003)
Munjal	All ages up to yearling	Poonia (2004)
Nellore	Birth and 3 months of age	Rao *et al.* (2004)
Bharat Merino	Birth, 3, 6 and 12 months of age	Swain *et al.* (2004)
Nali	Birth, 3 and 6 months of age	Dey and Poonia (2005)
Marwari	All ages up to yearling	Nehra and Singh (2006)
Marwari	All ages up to yearling	Narula *et al.* (2007)
Mecheri	Birth	Sarvana *et al.* (2007)

Marwari	All ages up to yearling	Dass *et al*. (2008)
Chokla	Birth	Prince *et al*. (2008)
Madgyal	3, 6, 9 and 12 months of age	Waghmode *et al*. (2008)
Malpura	Birth, 3, 6 and 12 months of age	Mishra *et al*. (2009b)
Magra	All ages up to yearling	Narula *et al*. (2009)
Nellore	All ages up to yearling	Reddy *et al*. (2009)
Marwari	All ages up to yearling	Gohil (2010)
Marwari	Birth	Narula *et al*. (2010)
Mecheri	12 months of age	Thiruvenkadan *et al*. (2010)
Polled Dorset and Crossbred	Birth	Khan *et al*. (2011)
Marwari	All ages up to yearling	Singh (2012)
Magra	3, 6, 9 and 12 months of age	Parihar (2012)
Deccani	All ages up to yearling	Chikurdekar *et al*. (2012)
Madras Red	All ages up to yearling	Balasubramanyam *et al*. (2012)
Harnali	Birth and 3 months	Lalit *et al*. (2016)
Madras Red	All ages upto yearling	Ganesan *et al*. (2013)
Nellore	All Ages upto yearling	Kumar *et al*. (2017)
Madras Red	All ages upto yearling	Arthy *et al*. (2018)
Marwari	All ages up to yearling	Narula *et al*. (2007)
Mecheri	Birth	Sarvana *et al*. (2007)
Marwari	All ages up to yearling	Dass *et al*. (2008)
Chokla	Birth	Prince *et al*. (2008)
Madgyal	3, 6, 9 and 12 months of age	Waghmode *et al*. (2008)
Malpura	Birth, 3, 6 and 12 months of age	Mishra *et al*. (2009b)
Magra	All ages up to yearling	Narula *et al*. (2009)
Nellore	All ages up to yearling	Reddy *et al*. (2009)
Marwari	All ages up to yearling	Gohil (2010)
Marwari	Birth	Narula *et al*. (2010)
Mecheri	12 months of age	Thiruvenkadan *et al*. (2010)
Polled Dorset and Crossbred	Birth	Khan *et al*. (2011)
Marwari	All ages up to yearling	Singh (2012)
Magra	3, 6, 9 and 12 months of age	Parihar (2012)
Deccani	All ages up to yearling	Chikurdekar *et al*. (2012)
Madras Red	All ages up to yearling	Balasubramanyam *et al*. (2012)
Harnali	Birth and 3 months	Lalit *et al*. (2016)
Madras Red	All ages upto yearling	Ganesan *et al*. (2013)
Nellore	All Ages upto yearling	Kumar *et al*. (2017)
Madras Red	All ages upto yearling	Arthy *et al*. (2018)

2.1.2.3 Effect of sex of lamb

Various workers have reported the significant effect of sex of lambs and their observations and results are summarized in Table 2.3. However, non-significant effect of the sex of lamb on birth weight was observed by Pannu *et al.* (1994) in Marwari lambs, Nawaj *et al*. (1998) in Kajli and Lohi sheep and Khan *et al*. (2011) in Crossbred. Non-significant effect of the sex of lamb on birth and 3 months body weight was reported by Singh and Prakash (1986) in Gaddi and its crosses with Rambouillet, Negi *et al*. (1987) in Russian Merino, Sahani *et al.* (2002) in Marwari sheep and Tailor and Yadav (2011) in Sonadi sheep at all ages up to yearling.

Table 2.3: Reports showing significant effect of the sex of lamb on body weight of lambs at different ages

Breed / genetic group	Body weight	References
Marwari	All ages up to yearling	Nehra (1991)
Marwari	All ages up to yearling	Ganai (1992)
Marwari	All ages up to yearling	Pannu (1994)
Sonadi	Birth	Mehta *et al.* (1995)
Nali	All ages up to yearling	Sharma (1995)
Malpura	All ages up to yearling	Arora and Narula (1996)
Marwari	3, 6, 9 and 12 months of age	Pannu *et al.* (1994)
Marwari	All ages up to yearling	Singh *et al.* (1998)
Avikalin and Malpura	Birth, 3 and 6 months of age	Arora *et al.* (1999)
Nali	Birth, 3,9 and 12 months	Sharma *et al.* (1999)
Marwari	All ages up to yearling	Joshi (2001)
Marwari	All ages up to yearling	Dass and Singh (2002)
Marwari	All ages up to yearling	Joshi *et al.* (2003)
Marwari	6, 9 and 12 months of age	Sahani *et al.* (2002)
Malpura	All ages up to yearling	Sharma *et al.* (2003)
Munjal	Birth	Poonia (2004)
Nellore	Birth and 3 months	Rao *et al.* (2004)
Bharat Merino	Birth, 3, 6 and 12 months of age	Swain *et al.* (2004)
Nali	Birth, 3 and 6 months of age	Dey and Poonia (2005)
Marwari	All ages up to yearling	Nehra and Singh (2006)
Madras Red	All ages up to yearling	Shivkumar *et al.* (2006)
Mecheri	Birth	Sarvana *et al.* (2007)
Pugal	Birth, 3,6 and 12 months	Dass (2007)

Madras Red	All ages up to yearling	Devendran *et al.* (2007)
Mecheri	Birth	Kumar *et al.* (2007)
Marwari	All ages up to yearling	Narula *et al.* (2007)
Vembur	Birth	Ravimurgan *et al.* (2007)
Marwari	All ages up to yearling	Dass *et al.* (2008)
Chokla	All ages up to yearling	Prince *et al.* (2008)
Nellore	All ages up to yearling	Reddy *et al.* (2009)
Madgyal	All ages up to yearling	Waghmode *et al.* (2008)
Magra	All ages up to yearling	Narula *et al.* (2009)
Madras Red	Birth	Shivkumar *et al.* (2009)
Marwari	All ages up to yearling	Gohil (2010)
Marwari	All ages up to yearling	Narula *et al.* (2010)
Mecheri	12 months	Thiruvenkadan *et al.* (2010)
Malpura and Kheri	All ages up to yearling	Gowane and Arora (2010)
Polled Dorset	Birth	Khan *et al.* (2011)
Marwari	All ages up to yearling	Singh (2012)
Magra	All ages up to yearling	Parihar (2012)
Deccani	All ages up to yearling	Chikurdekar *et al.* (2012)
Madras Red	All ages up to yearling	Balasubramanyam *et al.* (2012)
Madras Red	All ages	Ganesan *et al.* (2013)
Harnali	Birth and 3 months	Lalit (2016)
Nellore	All Ages upto yearling	Kumar *et al.* (2017)
Madras Red	All ages	Arthy *et al.* (2018)

2.1.2.4. Effect of parity

Various workers have reported the significant effect of parity on body weight at different ages and their observations and results are summarized below. Swain *et al.* (2004) observed significant effect of parity of ewes on all body weights up to yearling in Bharat Merino sheep.

Singh (2012) observed highly significant effect of parity of dam on body weights at birth and nine-month age while non-significant effect on body weights at 3, 6 and 12 months of age in Marwari sheep.

Kumar *et al.* (2017) observed significant effect of parity on body weights except for 12 months of age in Nellore sheep.

2.1.2.5. Effect of dam's weight at lambing

Birth weight and subsequent body weights of lambs were significantly affected by the weight of dam at lambing as reported by various workers and is summarized below in Table 2.4.

Table 2.4: Reports showing significant effect of dam's weight at lambing on body weight of lambs at different ages

Breed / genetic group	Body weight	References
Marwari	All ages up to yearling	Nehra (1991)
Marwari	All ages up to yearling	Ganai (1992)
Avikalin	All ages up to yearling	Singh and Dhillon (1992)
Marwari	All ages up to yearling	Pannu *et al.* (1994)
Nali	All ages up to yearling	Malik *et al.* (1998)
Marwari	All ages up to yearling	Singh *et al.* (1998)
Nali	Birth and 3 months of age	Sharma *et al.* (1999a)
Malpura andAvikalin	All ages up to yearling	Sharma *et al.* (1999b)
Marwari	All ages up to yearling	Joshi (2001)
Nali and Marwari	Birth and 3 months of age	Sharma *et al.* (2003)
Avikalin	Birth	Ahmad *et al.* (2004)
Munjal	Birth	Poonia (2004)
Malpura	All ages up to yearling	Swain *et al.* (2004)
Marwari	Birth and 3 months of age	Narula *et al.* (2007)
Muzaffarnagari	Birth and 3 months of age	Dass *et al.* (2008a)
Marwari	Birth	Dass *et al.* (2008b)
Chokla	All ages up to yearling	Prince *et al.* (2008)
Malpura	All ages up to yearling	Mishra *et al.* (2009b)
Magra	Birth and 3 months of age	Narula *et al.* (2009)
Malpura	All ages up to yearling	Sharma *et al.* (2009)
Marwari	All ages up to yearling	Gohil (2010)
Marwari	Birth and 3 months of age	Narula *et al.* (2010)
Marwari	All ages up to yearling	Singh (2012)
Magra	All ages up to yearling	Parihar (2012)
Madras Red	All ages	Ganesan *et al.* (2013)
Harnali	Birth and 3 months of age	Lalit *et al.* (2016)
Nellore	All Ages upto yearling	Kumar *et al.* (2017)

2.1.3. Average daily gain in body weight from birth to yearling age

Average daily gain in body weight between different ages from different references are given in Table 2.5

Table 2.5 Estimates of average daily gain of various breeds

Breed / Genetic Group	**ADG1 (g)**	**ADG2 (g)**	**ADG3 (g)**	**ADG4 (g)**	**ADG5 (g)**	**References**
Muzaffarnagari	127.8 ±3.3	49.4 ±1.6				Mandal *et al*. (2003)
Ganjam	72.6			37.0		Patnayak *et al*. (2003)
Mecheri	0.063 ±0.001kg					Shivkumar (2003)
Nali	84.72±1.06	37.36±1.09				Dey and Poonia (2005)
Chokla	91 ±1.0g	75 ±1.9g	32 ±0.6g			Prince *et al*. (2008)
Garole × Malpura	104.91 ±1.27g	63.12 ±1.07g				Mishra *et al*. (2009a)
Magra	137.41 ±0.83g	84.09 ±0.75g	34.89 ±0.41g			Narula *et al*. (2009)
Marwari	143g	75.14g	40.77g			Narula *et al*. (2010)
Sonadi	92g	60g	33g	41g		Tailor and Yadav (2010)
Marwari	134.80 ± 2.14g	66.47 ±1.73g	48.96 ±2.02g	31.23 ±2.25g	68.28 ±1.00g	Gohil (2010)
Marwari	133.59 ±1.430g	66.75 ±1.031g	38.67 ±1.170g	31.23g		Singh (2012)
Magra	124.20 ±1.135g	78.88 ±1.792g	32.99 ±0.895g		68.52 ±0.745g	Parihar (2012)
Madras Red	87.357g	47.894g	31.717g	25.615 g		Ganesan (2013)
Harnali	100.66 ±0.86g	35.07 ±0.39 g				Lalit (2016)
Madras Red	80.13g	49.05g	43.00g	34.21g	41.18g	Arthy *et al*. (2018)

2.1.4 Factors affecting average daily gain in body weight of lambs during different periods

The reports regarding effect of genetic and non-genetic factors on average daily gain in body weight during different periods have been reviewed and presented below:

2.1.4.1 Effect of year/period of birth

Qualitative and quantitative changes in pasture occur due to year-to-year fluctuations in ambient temperature, rainfall, humidity, management and health condition of the flock over the years are also important for proper growth of lambs. The significant effect of year of birth on growth rate reported by various workers has been reviewed and summarized in Table 2.6.

The non-significant effect of year of birth was reported on live weight gain from 3-6 months of age in Gaddi and its crosses with Russian Merino and Rambouillet by Negi *et al.* (1987).

Table 2.6: Reports showing significant effect of the year of birth on average daily gain in body weight of lambs during different period

Breed / genetic group	Gain in weight during	References
Nali	0-3, 3-6, 6-9 and 9-12 months	Sharma (1995)
Karakul	0-3, 3-6, 6-9 and 9-12 months	Arya (1997)
Marwari	0-3, 3-6, 6-9 and 9-12 months	Pannu *et al.* (1994)
Marwari	0-3, 3-6, 6-9 and 9-12 months	Dass *et al.* (1998)
Marwari and Nali	0-3, 3-6, 6-9 and 9-12 months	Sharma (1998)
Nali	0-3, 3-6, 6-9 and 9-12 months	Sharma *et al.* (1999a)
Marwari	All ages up to yearling	Joshi (2001)
Marwari	All age group up to yearling	Joshi *et al.* (2003)
Muzaffarnagari	Pre and post weaning	Mandal *et al.* (2003)
Nali	Pre and post weaning	Dey and Poonia (2005)
Marwari	0-3, 3-6, 6-9 and 9-12 months	Dass *et al.* (2008)
Chokla	0-3, 3-6, 6-9 and 9-12 months	Prince *et al.* (2008)
Magra	0-3, 3-6 and 6-12 months	Narula *et al.* (2009)
Marwari	All age group up to yearling	Gohil (2010)
Marwari	0-3, 3-6 and 6-12 months	Narula *et al.* (2010)
Marwari	All ages up to yearling	Singh (2012)
Magra	All ages up to yearling	Parihar (2012)
Madras Red	All ages up to yearling	Ganesan (2013)
Harnali	0-3 and 3-6 months	Lalit (2013)
Madras Red	All ages up to yearling	Arthy (2018)

2.1.4.2. Effect of sex

Average daily gain in weight is both significantly and non-significantly affected by sex of the animal which is mentioned in Table 2.7 and 2.8, respectively.

Table 2.7: Reports showing significant effect of the sex of lamb on average daily gain in body weight of lambs during different periods

Breed / genetic group	Gain in weight during	References
Gaddi and its crosses	0-6, 0-9, 0-12, 3-6 and 3-12 months	Negi *et al.* (1987)
Muzaffarnagari and its crosses	Pre weaning and post weaning	Kaila *et al.* (1989)
Nali	0-3, 6-9 months	Sharma (1995)
Malpura, Awassi x Malpura	9-12 months	Arora and Narula (1996)
Polwarth	Birth and weaning weight	Lanzoni *et al.* (1996)
Karakul	0-3, 3-6 and 6-9 months	Arya (1997)
Marwari	0-3, 6-9 and 0-12 months	Pannu *et al.* (1994)
Marwari	0-3, 3-6, 6-9 and 9-12 months	Dass *et al*. (1998)
Marwari	0-3, 3-6, 6-9 months	Joshi *et al*. (2003)
Nali	Pre and post weaning	Dey and Poonia (2005)
Marwari	0-3, 3-6, 6-9 and 9-12 months	Dass *et al*. (2008)
Chokla	0-3, 3-6 and 6-12 months	Prince *et al.* (2008)
Garole x Malpura half bred	0-3, 3-6 and 6-12 months	Mishra *et al.* (2009a)
Magra	0-3, 3-6 and 6-12 months	Narula *et al.* (2009)
Marwari	0-3, 3-6, 6-9 and 9-12 months	Gohil (2010)
Marwari	0-3, 3-6 and 6-12 months	Narula *et al.* (2010)
Marwari	0-3, 3-6, 6-9 and 9-12 months	Singh (2012)
Magra	0-3, 3-6, 6-12 and 0-12 months	Parihar (2012)
Madras Red	All ages up to yearling	Ganesan (2013)
Harnali	0-3,3-6 months	Lalit (2016)
Madras Red	All ages up to yearling	Arthy (2018)

Table 2.8: Reports showing non-significant effect of the sex of lamb on average daily gain in body weight of lambs during different periods

Breed / genetic group	Gain in weight during	References
Gaddi and its crosses	0-3, 6-9, 6-12 and 9-12 months	Negi *et al.* (1987)
Magra, Soviet Merinox Magra,Corriedale x Magra	0-3, 3-6 and 6-9 months	Sharma (1989)
Karakul and its crosses	0-3 and 9-12 months	Singh (1990)
Marwari	3-6 and 9-12 months	Pannu (1994)
Nali	3-6 and 9-12 months	Sharma (1995)
Karakul	9-12 months	Arya (1997)
Nali	3-6 and 9-12 months	Sharma *et al.* (1999a)
Marwari	9-12 months	Joshi *et al.* (2003)
Madras Red	0-3, 6-9 and 9-12 months	Shivkumar *et al.* (2009)
Mecheri	Post weaning	Thiruvenkadan *et al.* (2010)

2.1.4.3 Effect of parity

Since Indian shepherds keep complete records of the animal rarely, information on breeding data of animals in field is less comparing to the farm bred animals. The information on effect of parity on body weight gain is very scanty in literature.

The weight gain after weaning was significantly affected by parity of ewe as reported by Thiruvenkadan *et al*. (2010) in Mecheri lambs.

Gohil (2010) observed non-significant effect of parity on body weight gain during 0-3, 3-6 and 0-12 months of age while significant effect observed during 6-9 and 9-12 months of age in Marwari sheep.

Singh (2012) observed non-significant effect of parity on body weight gain during 0-3, 3-6 and 6-12 months of age in Marwari sheep.

Parihar (2012) observed significant effect of parity on body weight gain during 0-3 and 3-6 months while non-significant effect during 6-12 and 0-12 months of age in Magra sheep.

2.1.4.4 Effect of sire

Since Indian shepherds keep complete records of the animal rarely, information on breeding data of animals in field is less comparing to the farm bred animals.

The information on effect of sire on body weight gain is very scanty in literature. Significant effect of sire on body weight gain during different age group observed by Gohil (2010) and Singh (2012) in Marwari sheep.

Parihar (2012) also observed significant effect of sire on body weight gain during different age group up to yearling in Magra sheep.

2.1.4.5 Effect of ewe's weight at lambing

Dam's weight at lambing was found to have significant effect on body weight gain. This favourable effect may be due to better prenatal environment provided to foetus for growth and development, more secretion of milk by dam and mothering ability of dam.

Significant effect of dam's weight at lambing on average daily gain reported by Joshi *et al*. (2003) during birth to 3 months, 3 to 6 months, 6 to 12 months and birth to 12 months of age.

Gohil (2010) reported significant effect of dam's weight during birth to 3 months and 3 to 6 months of age in Marwari sheep.

Singh (2012) reported significant effect of dam's weight at lambing during birth to 3 months of age while non-significant effect during 3-6 months and 6-12 months of age in Marwari sheep.

Parihar (2012) also reported significant effect of dam's weight at lambing on body weight gain during 0-3, 6-12, 0-12 months of age while non-significant effect during 3-6 months of age in Magra sheep.

Lalit *et al*. (2016) reported significant effect of dam's weight at lambing on 0-3 and 3-6 months.

Ganesan *et al*. (2013) reported significant effect of dam's weight at lambing for 3-6 months.

2.2 Reproduction traits

Reproductive efficiency is an important component of flock productivity of indigenous breeds of sheep. To augment the efficiency of production, it is necessary to study all the factors affecting the reproduction traits. Reproduction traits viz. age at first service, weight at first service, service period, age at first lambing, lambing interval etc. in sheep are important factors that determine economic returns from sheep farming.

The annual reproduction rate was significantly affected by year of mating and weight at mating as reported by Dixit *et al*. (2002) in Bharat Merino sheep.

2.2.1 Age of ewes at first service

The age of ewe at first service was estimated as 579.27±2.24 days in Marwari sheep by Dass *et al*. (2004), 448 to 779 days in Nali sheep by Dey (2004) and 18-24 months in Marwari sheep by Verma *et al*. (2005)

The age at first service was estimated as 593.3±265.87 days in Hissardale sheep by Akhtar *et al*. (2007), 709.67±8.38 days in Sonadi sheep by Tailor *et al*. (2007), 615.6±8.2 days in Lohi sheep by Babar and Javed (2009) and 24.4±0.06 months in Chokla sheep by Jain *et al*. (2009) and 563.08 ± 14.43 days in munjal sheep by Umeel (2018).

2.2.1.1 Effect of non-genetic factors on age at first service

The age of ewe at first service was non-significantly influenced by the year of birth as reported by Dey and Poonia (2005) in Nali sheep and the age of ewe at first service was not significantly affected by the year and season of birth of the ewe as reported by Babar and Javed (2009) in Lohi sheep. It was non significantly affected by age of dam at lambing in Munjal Breed as reported by Umeel (2018).

Table 2.9: Reports showing significant effect of non-genetic factors on age at first service

Breed / genetic group	Factor	References
Malpura	Year of birth	Arora and Swarnakar (1995)
Malpura	Season of birth	Arora and Swarnakar (1995)
Bharat Merino	Year of birth	Singh and Koli (1997)
Bharat Merino	Season of birth	Singh and Koli (1997)
Corriedale	Dam's age at lambing	Bhat *et al.* (1999)
Rambouillet	Year of birth	Jain *et al.* (2001)
Chokla and its crossbred	Year of birth	Kumar *et al.* (2001)
Chokla and its crossbred	Season of birth	Kumar *et al.* (2001)
Bharat Merino	Dam's weight at lambing	Dixit *et al.* (2002)
Marwari	Year of birth	Dass *et al.* (2004)
Marwari	Dam's weight at lambing	Dass *et al.* (2004)
Lohi	Dam's weight at lambing	Babar and Javed (2009)
Munjal	Period of Birth	Umeel (2018)

2.2.2 Weight of ewe at first service

The weight at first service was estimated as 26.11-27.31 kg in Chokla sheep by Kumar *et al*. (2001), 26.61±0.24 kg in Marwari sheep by Dass *et al*. (2004), 22 to 24 kg in Nali sheep by Dey (2004) and 42.10±0.24 kg in Lohi sheep by Babar and Javed (2009) and 29.06 ± 0.16 days in munjal sheep by Yadav (2018)

2.2.2.1 Effect of non-genetic factors on weight of ewe at first service

The dam's weight at first service was non-significantly influenced by type of birth as reported by Babar and Javed (2009) in Lohi sheep. It is not significantly influenced by age of dam at lambing in Munjal sheep as reported by Yadav (2018).

Table 2.10: Reports showing significant effect of non-genetic factors on weight at first service

Breed / genetic group	Factor	References
Patanwadi and its crossbred	Year of birth	Shah and Patel (1990)
Patanwadi and its crossbred	Season of birth	Shah and Patel (1990)
Malpura	Year of birth	Arora and Swarnakar (1995)
Malpura	Season of birth	Arora and Swarnakar (1995)
Chokla and its crossbred	Season of service	Kumar *et al.* (2001)
Chokla and its crossbred	Breed	Kumar *et al.* (2001)
Chokla and its crossbred	Year of birth	Kumar *et al.* (2001)
Munjal	Year of birth	Yadav *et al.* (2018)

The annual reproduction rate was significantly affected by year of mating and weight at mating as reported by Dixit *et al*. (2002) in Bharat Merino sheep.

2.2.3 Age of ewe at first lambing

The age of ewe at first lambing was estimated 16-18 months in Muzaffarnagari sheep by Kumar *et al*. (2006), 746.9 ±266.0 days in Hissardale sheep by Akhtar *et al*. (2007), 15.47 ±0.07 months in Pugal sheep by Dass (2007), 18-24 months in Nali sheep by Singh *et al*. (2007), 530.53±12.39 days in Munjal sheep by Poonia (2008) and 31.9±0.6 months in Chokla sheep by Jain *et al*. (2009).

Yadav *et al*. (2009) observed age at first lambing as 20-24 months in Marwari sheep. Umeel *et al*. (2018) reported age of ewe at first lambing as 713.48 ± 14.02 days in Munjal sheep. Kumar *et al*. (2018) reported age of ewe at first lambing as 789.98±10.40 days in Harnali sheep.

2.2.3.1 Effect of non-genetic factors on age at first lambing

Age of first lambing is non significantly affected by age of dam at lambing in Munjal sheep as reported by Umeel *et al*. (2018).

Table 2.11: Reports showing significant effect of non-genetic factors on age at first lambing

Breed / genetic group	Factor	References
Malpura	Year of birth	Arora and Swarnakar (1995)
Malpura	Season of birth	Arora and Swarnakar (1995)
Bharat Merino	Year of birth	Singh and Koli (1997)
Bharat Merino	Season of birth	Singh and Koli (1997)
Corriedale	Year of birth	Bhat *et al*. (1999)
Muzaffarnagari	Year of birth	Dass (2000)
Bharat Merino	Year of birth	Dixit *et al*. (2002)
Bharat Merino	Season of birth	Dixit *et al*. (2002)
Bharat Merino	Dam's weight at lambing	Dixit *et al*. (2002)
Marwari	Year of birth	Dass *et al*. (2004)
Marwari	Dam's weight at lambing	Dass *et al*. (2004)
Munjal	Year of Birth	Umeel (2018)

2.3 Genetic and phenotypic parameters

To bring the desired change in genotypes, the precise estimates of phenotypic and genetic parameters, viz. heritability, phenotypic and genetic correlations among economic traits and breeding values of the traits are essential for making a decision regarding efficient breeding system and selection programme.

2.3.1 Heritability estimates

The potential for genetic improvement of trait is largely dependent upon its heritability and its genetic correlations with other traits. The heritability of the traits varies from one population to another population and changes from time to time. In India, paternal half sib method (sire model like LSMLMW package of Harvey, 1990) is generally used for the estimation of heritability.

The reports given by various workers regarding the heritability estimates of growth and wool traits in sheep summarized below:

2.3.1.1 Heritability estimates of body weight at different ages

The reviews given by various authors revealed that the heritability estimates of birth weight ranged from 0.01 in Deccani and its crosses (Kulkarni and Deshpande, 1990) to 0.68±0.19 in Harnali (Lalit, 2016). The heritability estimates of 3 months body weight ranged from 0.01±0.07 in Magra and its crosses (Sharma, 1989) to 0.93±0.21 in Russian Merino (Singh *et al*., 1984).

The heritability estimates of 6 months body weight ranged from 0.01±0.09 in Magra and its crosses (Sharma, 1989) to 0.86 in Marwari sheep (Gohil, 2010). The heritability estimates of 9 months body weight ranged from 0.08±0.40 in Muzaffarnagari sheep (Bhadula and Bhat, 1980) to 0.90 in Magra sheep (Parihar, 2012) and that of yearling age range from 0.062 in Kajli and Lohi (Nawaj *et al*., 1998) to 0.98 in Magra sheep (Parihar, 2012).

2.3.1.2 Heritability estimates for average daily gains during different periods as reported by various workers

Akhtar *et al*. (2007) estimated heritability of pre weaning average daily gain as 0.11 ± 0.03 in Hissardale sheep.

Singh (2012) reported estimates of heritability for average daily gain during 0-3, 3-6, 6-12 months of age as 0.39 ± 0.060, 0.23 ± 0.055 and 0.51 ± 0.074, respectively, in Marwari sheep.

Parihar (2012) reported estimates of heritability for average daily gain during 0-3, 3-6, 6-12, 0-12 months of age as 0.25 ± 0.067, 0.95 ± 0.134, 0.74 ± 0.122 and 0.89 ± 0.139 respectively, in Magra sheep.

Ganesan *et al*. (2013) reported estimates of heritability for average daily weight gains during 0-3, 3-6,6-9 and 9-12 months as 0.47404 ± 0.15818, 0.41969 ± 0.16009, 0.20515 ± 0.15057 and 0.46108 ± 0.18137 respectively.

Mandal *et al*. (2015) reported estimates of heritability for average daily weight gain as 0.15 to 0.21.

Tables 2.12: Estimates of heritability of body weight at birth and weaning of lambs reported by different workers

Breed / genetic group	**Birth weight**	**3 months**	**References**
Muzaffarnagari	0.17±0.16	0.53±0.32	Bhadula and Bhat (1980)
Russian Merino	-	0.93 ± 0.021	Singh *et al.* (1984)
Deccani		0.49 ± 0.05	Kulkarni and Deshpande (1986)
Dorset and Dorset x Nellore	0.17 ± 0.16		Gupta and Reddy (1988)
Nali	0.26 ± 0.14	0.22 ± 0.16	Poonia *et al.* (1988)
Magra and its crosses	0.08 ± 0.05	0.01 ± 0.07	Sharma (1989)
Deccani and its crosses	0.01		Kulkarni and Deshpande (1990)
Avivastra	0.24 ± 0.08	0.34 ± 0.09	Kushwaha *et al.* (1995)
Marwari	0.07 ± 0.083	0.34 ± 0.119	Pannu *et al.* (1994)
Muzaffarnagari	0.32	0.43±0.12	Sinha and Singh (1997)
Marwari	0.043 ± 0.032	0.125 ± 0.042	Dass *et al.* (1998)
Chokla	-	0.35 ± 0.18	Kushwaha *et al.* (1998)
Kajli and Lohi	0.036 ± 0.090	-	Nawaj *et al.* (1998)
Chokla	0.138 ± 0.070	0.238 ± 0.079	Kumar (2000)
Marwari	0.31 ± 0.107	0.26 ± 0.101	Joshi (2001)
Avikalin crossbred	0.203 ±0.070	0.229 ± 0.072	Ahmad (2002)
Marwari and Nali	0.101 ± 0.055	0.03 ± 0.051	Sharma *et al.* (2003)
Muzaffarnagari	0.07±0.01	0.18±0.02	Mandal (2003)
Bharat Merino	0.248 ± 0.087	0.366 ± 0.100	Swain *et al.* (2004)
Marwari	0.117 ± 0.099	0.169 ± 0.105	Nehra and Singh (2006)
Muzaffarnagari	0.09±0.02	-	Mandal (2006)
Hissardale	0.08 ± 0.02	0.166 ± 0.03	Akhtar *et al.* (2007)
Malpura	0.29 ± 0.06	0.18 ± 0.06	Mishra *et al.* (2009b)
Corriedale	-	0.16 ± 0.079	Ganai *et al.* (2010)
Marwari	0.33 ± 0.062	0.74 ± 0.086	Gohil (2010)
Malpura	0.19 ± 0.04	0.18 ± 0.04	Gowane *et al.* (2010)
Marwari	0.27 ± 0.04	0.40 ± 0.01	Singh (2012)
Magra	0.29 ± 0.067	0.23 ± 0.065	Parihar (2012)
Madras Red	0.26± 0.14	0.51±0.16	Ganesan (2013)
Muzaffarnagari	0.15	0.16	Mandal (2015)
Harnali	0.40±0.05	0.38±0.05	Lalit (2016)
Harnali	0.68 ± 0.19	0.49±0.17	Kumar (2006)
Nellore	0.08±0.03	0.03±0.02	Kumar (2017)
Madras Red	0.48	0.47	Arthy (2018)

Tables 2.13: Estimates of heritability body weight at six, nine and twelve months of age

Breed / genetic group	6 months	9 months	12 months	References
Bikaneri	0.80	-	-	Bhasin (1969)
Patanwadi	-	-	0.64	Shukla (1973)
Muzaffarnagari	0.18±0.31	0.08 ± 0.40	-	Bhadula and Bhat (1980)
Deccani	-	0.26 ± 0.05	0.43 ± 0.05	Kulkarni and Deshpande (1986)
Magra and its crosses	0.01 ± 0.09	0.18 ± 0.10	0.075 ± 0.14	Sharma (1989)
Marwari	0.08 ± 0.10	0.13 ± 0.10	0.08 ± 0.10	Nehra (1991)
Marwari	0.21 ± 0.13	0.36 ± 0.15	0.23 ± 0.14	Ganai (1992)
Avivastra	0.32 ± 0.09	-	-	Kushwaha *et al.* (1995)
Avikalin	-	0.21 ± 0.03	-	Arora and Kushwaha (1996)
Marwari	0.34 ± 0.118	0.12 ± 0.094	0.23 ± 0.174	Pannu *et al*. (1994)
Muzaffarnagari	0.27±0.09			Sinha and Singh (1997)
Marwari	0.258±0.054	0.201 ± 0.049	0.169 ± 0.047	Dass *et al*. (1998)
Chokla	0.27 ± 0.17	-	-	Kushwaha *et al.* (1998)
Kajli and Lohi	-	-	0.062 ± 0.156	Nawaj *et al.* (1998)
Nali	0.172 ± .188	0.281 ± 0.217	0.062 ± 0.156	Sharma *et al.* (1999)
Chokla	0.245 ± 0.08	-	-	Kumar (2000)
Marwari	0.38 ± 0.116	0.46 ± 0.125	0.58 ± 0.139	Joshi (2001)
Bharat Merino	0.41 ± 0.08	-	0.49 ± 0.09	Tomar *et al*. (2000a)
Avikalin crossbred	0.312 ± .081	-	0.391 ± 0.089	Ahmad (2002)
Marwari and Nali	0.838 ± .120	0.271 ± 0.080	0.267 ± 0.086	Sharma *et al.* (2003)
Muzaffarnagari	0.19±0.03	0.16±0.03	0.26±0.04	Mandal (2003)
Bharat Merino	0.199 ± .081	-	0.235 ± 0.086	Swain *et al.* (2004)
Marwari	0.084 ± .095	0.129 ± 0.100	0.083 ± 0.095	Nehra and Singh (2006)
Muzaffarnagari	0.08±0.10			Mandal (2006)
Malpura	0.28 ± 0.07	-	0.28 ± 0.08	Mishra *et al.* (2009b)
Corriedale	0.12 ± 0.062	-	-	Ganai *et al.* (2010)
Marwari	0.86 ± 0.092	0.82 ± 0.090	0.79 ± 0.089	Gohil (2010)
Marwari	0.27 ± 0.02	0.15 ± 0.04	0.79 ± 0.089	Gowane *et al.* (2010)
Malpura	0.42 ± 0.01	0.34 ± 0.12	0.11 ± 0.04	Singh (2012)
Magra	0.68 ± 0.106	0.90 ± 0.133	0.98 ± 0.142	Parihar (2012)
Madras Red	0.52±0.17	0.20±0.15	0.65±0.19	Ganesan (2013)
Harnali	0.45±0.06	-	0.29±0.05	Lalit (2016)
Harnali	0.65 ± 0.15	-	0.44 ±0.17	Kumar (2006)
Nellore	0.12±0.04	0.16±0.05	0.10±0.05	Kumar (2017)

Lalit *et al*. (2016) reported estimates of heritability for average daily weight gains during 0-3, 3-12 months as 0.40±0.06 and 0.33±0.02 respectively

Arthy *et al*. (2018) reported estimates of average daily gains during 0-3 and 3-12 months as 0.51 and 1.54 respectively.

2.3.1.3 Heritability estimates of reproduction traits

Akhtar *et al*. (2007) estimated high heritability of age at first service and age at first lambing as 0.44 ±0.11 and 0.44±0.11 in Hissardale sheep.

Umeel *et al*. (2018) reported heritability estimates for Age at first service, Weight at first service, Age at first lambing, Weight at first lambing and First lambing interval as 0.19±0.12, 0.24±0.15, 0.17±0.10, 0.27±0.15 and 0.05±0.01, respectively.

Kumar *et al*. (2018) reported heritability estimate of age at first lambing as 0.38±0.16 in Harnali sheep.

2.3.2 Genetic correlation

Genetic correlations among different traits are mainly attributed to pleiotropic action of genes and their estimates are useful to know the correlated response in one character while selection is based on other character.

Ahmad *et al*. (2004) estimated genetic correlation of birth weight with 3 months, 6 months and 12 months weight as 0.49, 0.45 and 0.37, respectively; 3 months with 6 and 12 months weight as 0.67 and 0.51, respectively; and 6 months with 12 months body weight as 0.73 in Avikalin sheep.

Swain *et al*. (2004) estimated genetic correlation of birth weight with 3 months, 6 months and 12 months weight as 0.77 ± 0.14, 0.65 ± 0.21 and 0.47 ± 0.23, respectively; 3 months with 6 months and 12 months weight as 0.93 ± 0.07 and 0.53 ± 0.17, respectively; and 6 months with 12 months body weight as 0.84 ± 0.10 in Bharat Merino sheep.

Nehra and Singh (2006) found all the genetic correlations between various body weights up to yearling age were positive except genetic correlations of birth weight with 9 and 12 months body weight in Marwari sheep.

Mishra *et al*. (2009) estimated genetic correlation of birth weight with 3 months, 6 months and 12 months weight as 0.28 ± 0.19, 0.32 ± 0.16 and 0.39 ± 0.17, respectively; 3 months with 6 months and 12 months weight as 0.97 ± 0.04 and 0.94 ± 0.08, respectively; and 6 months with 12 months body weight as 0.99 ± 0.04 in Malpura sheep.

Gohil (2010) estimated genetic correlation of birth weight with 3 months, 6 months, 9 months and 12 months weight as 0.48 ± 0.09, 0.45 ± 0.09, 0.42 ± 1.00 and 0.41 ± 0.10, respectively; 3 months with 6, 9 and 12 months weight as 0.89 ± 0.02, 0.82 ± 0.04 and 0.62 ± 0.06, respectively; 6 months with 9 and 12 months body weight as 0.89 ± 0.02 and 0.65 ± 0.05, respectively; and 9 month with 12 month body weight as 0.83 ± 0.03 in Marwari sheep.

Singh (2012) estimated genetic correlation of birth weight with 3 months, 6 months, 9 months and 12 months weight as 0.48 ± 0.093, 0.23 ± 0.110, 0.37 ± 0.123 and 0.44 ± 0.139, respectively; 3 months with 6, 9 and 12 months weight as 0.83 ± 0.049, 0.88 ± 0.079 and 0.56 ± 0.124, respectively; 6 months with 9 and 12 months body weight as 0.84 ± 0.067 and 0.39 ± 0.143, respectively; and 9 month with 12 month body weight as 0.76 ± 0.090 in Marwari sheep.

Parihar (2012) estimated genetic correlation of birth weight with 3 months, 6 months, 9 months and 12 months weight as 0.28 ± 0.203, -0.33 ± 0.165, -0.36 ± 0.155 and -0.18 ± 0.166, respectively; 3 months with 6, 9 and 12 months weight as 0.40 ± 0.142, 0.26 ± 0.153 and 0.25 ± 0.153, respectively; 6 months with 9 and 12 months body weight as 0.90 ± 0.030 and 0.83 ± 0.046, respectively; and 9 month with 12 month body weight as 0.96 ± 0.012 in Magra sheep.

Ganesan (2013) estimated genetic correlation between birth weight and 6months, 9months, 12months weight are low at -0.03787 ± 0.36598, -0.31497 ± 0.69571 and 0.17610 ± 0.50488 respectively whereas all other genetic correlation are quite high. The estimate of genetic correlation between 3 months and 12 months weight were high as 0.96711 ± 0.06946 in Madras Red sheep.

Kumar (2017) observed that genetic correlations of birth with weaning weight (0.435), 6 months (0.622), 9 months (0.526) and 12 months (0.679) were high to moderate and suggested a strong genetic association without any antagonism among these traits in Nellore sheep. The estimates of genetic correlation of weaning weight with post-weaning weights such as 6 months (0.935), 9 months (0.845) and 12 months (0.79) were high and ranging from 0.84 to 0.90.

Kumar *et al*. (2018) reported that the genetic correlation of birth weight was found positive with weaning and 6 months weight but negative with other traits. The genetic correlations of 3 and 6 months weight were found positive and moderate to high in magnitude with 12 months and adult body weight ranging from 0.25±0.16 to 0.61±0.12. The genetic correlations of yearly and adult body weight were estimated positive with all performance traits with moderate to high in magnitude ranging from -0.25±0.16 to 0.61±0.12 except with birth weight in Harnali sheep. This is not registered in NBAGR.

Arthy *et al*. (2018) observed that genetic and phenotypic correlation values were positive and high except for phenotypic correlation of BW with body weights at later ages. The genetic correla-tion was found to be positive and high among the weights at later ages. The phenotypic correlations were found to be lower than the values for genetic correlation.

2.3.3 Phenotypic correlation

The correlation of phenotypic values, which can be directly measured, is the association between two traits. This is estimated by measurement of the two traits on an individual in the population. The phenotypic correlations between various body weights reported by various workers are presented in Table 2.14. The findings of various workers indicated that the phenotypic correlations of birth weight with weight at higher age decreased successively. Almost all the workers found positive correlations among different body weights.

Table 2.14: Estimation of phenotypic correlations among body weights

Criteria	Body weight at various ages				
Breed / genetic group	**3 months**	**6 months**	**9 months**	**12 months**	**References**
Correlation of Birth weight	-	-	0.22	-	Sharma (1989)
	0.24	0.16	0.06	0.12	Nehra (1991)
	0.73	0.45	0.19	0.06	Ganai (1992)
	0.38	0.34	0.38	0.35	Singh *et al.* (1998)
	0.49	0.42	-	0.29	Mishra *et al.* (2009)
	0.42	0.36	0.33	0.31	Gohil (2010)
	0.38	0.28	0.32	0.30	Singh (2012)
	0.36	0.24	0.24	0.21	Parihar (2012)
	-	-	-	0.24	Kumar (2017)
	0.25	0.32	0.26	0.23	Arthy (2018)
	0.22	0.71	-	0.03	Kumar (2018)
Correlation of 3 months	-	0.81	-	-	Jagtap *et al.* (1988)
	-	-	0.68	-	Sharma (1989)
	-	0.75	0.43	0.48	Nehra (1991)
	-	0.66	0.71	0.78	Ganai (1992)
	-	0.87	0.81	0.77	Singh *et al.* (1998)
	-	0.87	0.81	0.77	Mishra *et al.* (2009)
	-	0.72	0.61	0.54	Gohil (2010)
	-	0.72	0.64	0.55	Singh (2012)
	-	0.66	0.51	0.48	Parihar (2012)
	-	-	-	0.59	Kumar (2017)
	-	0.74	0.64	0.60	Arthy (2018)
	-	0.42	-	0.26	Kumar (2018)
Correlation of 6 months weight	-	0.78	-	0.62	Jagtap *et al.* (1988)
	-	-	0.57	0.58	Nehra (1991)
	-	-	0.97	0.99	Ganai (1992)
	-	-	0.58	0.81	Singh *et al.* (1998)
	-	-	-	0.75	Mishra *et al.* (2009)
	-	-	0.78	0.64	Gohil (2010)
	-	-	0.78	0.60	Singh (2012)
			0.79	0.74	Parihar (2012)
	0.76	-	-	0.64	Kumar (2017)
	-	-	0.81	0.75	Arthy (2018)

	-	-	-	0.51	Kumar (2018)
Correlation of 9 months weight	-	-	-	0.82	Jagtap *et al*. (1988)
	-	-	-	0.86	Nehra (1991)
	-	-	-	1.07	Ganai (1992)
	-	-	-	0.83	Singh *et al*. (1998)
	-	-	-	0.77	Gohil (2010)
	-	-	-	0.74	Singh (2012)
				0.90	Parihar (2012)
	0.64	0.83		0.86	Kumar (2017)
	-	-	-	0.87	Arthy (2018)

2.4 Genetic, phenotypic and environmental trends

The selection is termed as non-random differential reproduction of genotype leading to the increase in frequency of desirable genes or gene combination. Though basic genetic effect of selection is to change the genotypic frequencies yet there is a simultaneous change in the gene frequencies and genetic architecture of the gene pool. The phenotypic effects of selection are observed by studying the two parameters that is change in the mean value of the population as a result of change in gene frequency and shift in the original range of expression of the traits due to new genetic combinations. The genetic trend observed over time depends upon the intensity of selection and genetic and phenotypic variability in the traits investigated. The variability and intensity determine the selection differential and the genetic gain per generation is measured by the difference between the mean values of population before selection and the offspring produced after the selection and rate of the genetic progress per unit of time depends on the generation interval which later could be predicted in terms of genetic gains per year.

Joshi (2001) observed positive phenotypic and environmental trends for all traits viz., body weight of 6 months, 12 months, genetic trend were found negative for all growth during over all study period (1994-1998) in Marwari sheep.

Dey and Poonia (2006) observed genetic and phenotypic trends negative for all traits viz., body weight of 6 months, 12 months, environmental trends were found positive for all traits except 6 months body weight in Nali flock during study period (1978-1998).

Arora *et al*. (2010) estimate genetic, phenotypic and environmental trends in Malpura sheep for birth, 3 months, 6 months, 9 months, 12 months body weight were presented in Table 2.15.

Table 2.15: Genetic, phenotypic and environmental trends in Malpura sheep

Year Trait	1998-2007 Genetic	 Phenotypic	 Environmental
Birth weight	0.06 ± 0.007	0.00 ± 0.004	-0.07 ± 0.0008
3 month weight	0.58 ± 0.046	0.31 ± 0.026	-0.27 ± 0.053
6 month weight	0.61 ± 0.07	0.37 ± 0.037	-0.24 ± 0.08
9 month weight	0.95 ± 0.11	0.07 ± 0.04	-0.88 ± 0.12
12 month weight	0.46 ± 0.11	0.03 ± 0.04	-0.42 ± 0.12

Mohammadi *et al*. (2011) observed genetic trends in Zandi sheep for 6 months, 9 months and yearling body weight during the period under study (1993-2008) as 21 ± 1.44, 72 ± 6.09 and 65 ± 5.06 gm/year, respectively.

Reddy *et al*. (2011) estimated genetic trends on the growth performance of Nellore sheep for 6 months and 12 months of age as 17.52 ± 0.15 and 24.67 ± 0.21, respectively.

Parihar (2012) estimated genetic, phenotypic and environment trends in Magra flock for 6 month and 12 month body weight were presented in Table 2.16.

Table 2.16 Estimation of genetic, phenotypic and environmental trends in Magra flock as reported by (Parihar, 2012)

Year Trait	N	1999-2008 Genetic trend	 Phenotypic trend	 Environmental trend
6 month weight	1533	-1.02 ± 0.019	0.78 ± 0.036	1.80 ± 0.115
12 month weight	1144	-1.15 ± 0.135	1.17 ± 0.048	2.32 ± 0.168

Arthy *et al*. (2018) observed that there was an increasing genetic and phenotyp-ic trends observed for almost all the traits. The genetic trend values for birth, 3, 6, 9 and 12 months weights were 0.0015±0.000 kg, 0.0261 ±0.002 kg, 0.0368 ±0.005 kg, 0.0429 ±0.006 kg, 0.017 ±0.007 kg respectively. The phenotypic trend for birth, 3, 6, 9 and 12 months weights were 0.0165 ±0.000 kg, 0.0985 ±0.001 kg, 0.041 ±0.002 kg, 0.039 ±0.002 kg, 0.0081 ±0.003 kg respectively in Madras Red sheep.

2.5 Genotyping the presence of *FecB* gene in Muzaffarnagari sheep

Three fecundity genes have been identified in sheep, namely bone morphogenetic protein receptor type 1B (BMPR-IB or activin-like kinase - 6, ALK6), Known as *FecB* on chromosome 6 (Souza *et al*., 2001); growth differentiation factor 9 GDF9), known as *FecG* on chromosome 5 (Hanrahan *et al*., 2004) and bone morphogenetic protein 15 (BMP15) Known as *FecX* on chromosome X (Hanrahan *et al*., 2004; Galloway *et al*., 2000).

Members of transforming growth factor-β (TGF-β) superfamily have wide ranging influences on many tissue and organ systems including the ovary in sheep. Two members of TGF-β superfamily, growth/differentiate factor-9 (GDF-9) and bone morphogenetic protein-15(BMP-15; also designated as GDF-9B) are expressed in an oocyte-specific manner from a very early stage and play a key role in affecting high prolificacy in sheep. Mode of inheritance pattern of *FecB* gene include autosomal dominance with additive effects on ovulation rate (BMPR-1B)

2.5.1 Origin of *FecB* mutation

The *FecB* mutation was first identified in Booroola Merino sheep originating from Australia but recent DNA marker technology has revealed that its origin trace back to sheep in Asia. At 1980 in Armidale workshop Drs Laurie Piper and Bernie Bindon proposed that the high prolificacy of the Booroola Merino might in part due to a single major gene or closely linked group of minor genes (Piper and Bindon, 1984), which would explain why some Booroola rams did not pass high prolificacy to their progeny

Review of literature on *FecB* gene revealed that only four sheep breeds viz, Garole, Hu, Han and Javanese thin tailed breeds are having *FecB* mutation naturally (Davis *et al*., 2002 and 2006).

2.5.2 Structure of BMPR-IB Gene

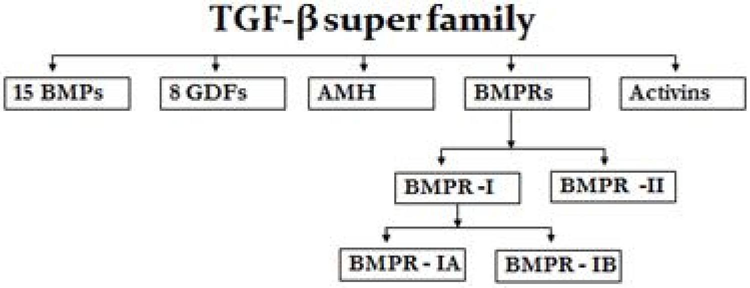


Fig.2.1 Position of BMPR-IB gene in TGF-ß super family in diagram

The coding regions of BMPR-IB gene is 3255bp long (GenBank Acc. NO. AF357007) and are arranged in 12 exons in Fig.2.2

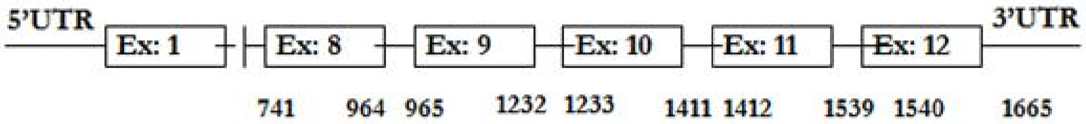


Fig 2.2 Schematic diagram of Exon & intron boundaries of *Fec*B gene

(GenBank Accession No. AF357007 of *Ovis aris*)

The BMPR-IB receptor mature peptide consists of 502 amino acids, consisting of an extracellular ligand binding domain (1- 136 AA), a trans membrane domain (137-205 AA), an amino acid stretch involved in phosphorylation called the GS domain (206-502 AA), a serine threonine kinase domain and a C-terminal motif of 11 amino acids as non-activating non-down regulating (NANDOR) box, thought to be involved in phosphorylation as well as receptor down regulation (Lehmann *et al.*, 2003).

2.5.3 Role of BMPR-IB in folliculogenesis

BMPR-IB reported as a potent receptor for various BMP factors such has BMP-15, -2, -4, -6 and BMP-7. This BMP-2, -4 and -6 inhibits both basal and FSH stimulated progesterone production. GDF-9 was a potent stimulator of granulosa cells proliferation in the rat (McNatty *et al.*, 2005; Vitt *et al.*, 2000). It inhibits both FSH induced progesterone and estradiol production (Vitt *et al.*, 2000) and decreases LH receptor mRNA synthesis. It induces cumulus expansion, enhances hyaluroman synthase 2(HAS2) and cyclo oxygenase 2 (Cox- 2) expression (Elvin *et al.*, 1999).

2.5.4 Mutation in BMPR-IB gene

A point mutation (A to G) was reported in BMPR-IB at position 746 of cDNA sequence (GenBank Acc. No. AF357007) and at 830 (Wilson *et al*., 2001; GenBank Acc. No. AF312016) in causes the genesis gene point mutation at nucleotide leads from glutamine (neutral or acid) present in non-carrier animals with arginine in carrier Booroola at position 249 (Q249R) which fall in the intracellular kinase-signaling domain of the receptor protein (Souza *et al*., 2001; Fabre *et al*., 2003; Ranga, 2008; Sivakumar, 2008).

Three additional polymorphisms were also observed in wild lyre sequences. The exon 10 of BMPR-1B harbours point mutation (Ranga, 2008) at position 1113 of coding sequence (C1113A) (GenBank Acc. No. AF357007). This C1113A point mutation acts as a marker for the presence of the Booroola genotype. The pyrimidine base cytosine (C), present in wild type genotype, is mutated to purine base adenine (A) in Booroola carrier animal (Souza *et al*., 2001; Mulsant *et al*., 2001). This mutation occurs in the region coding for kinase domain of bone morphogenetic protein receptor- 1B (BMPR-IB). Two other substitutions in 3' untranslated region (UTR) were also reported (Lehmann *et al*., 2003).

2.5.5 Effect of mutations in fecundity genes on ovulation rate

The *FecB*, Q249R mutation in the BMPR-IB, has been hypothesized as a partial "loss function" mutation (Mulsant *et al*., 2001). The presence of Q249R mutation in BMPR-1B is associated with loss of responsiveness to BMP-4 (Fabre *et al*., 2003). This loss in receptor activity is also illustrated by the fact that granulosa cells from homozygous *FecB* carrier ewes were less sensitive to the action of BMP-4 on proliferation and inhibition of progesterone production than those from the non-carrier ewes (Mulsant *et al*., 2001; Fabre *et al*., 2003). This Q249R substitution cause loss of responsiveness of BMPR-IB receptor to its BMPs ligand and impair the antiluetinizing function of BMPR-IB leading to an advanced differentiation of granulosa cells (GCs) and prematuration of the graffian follicle and more number of ovulations per cycle.

Mutations in fecundity genes would likely to impair the proliferative action of BMPs from the first steps of folliculogenesis. The final consequence is the presence of follicles with lower number of granulosa cells in ovaries from the mutated *FecB* carrier ewes (Montgomery *et al*., 1992; 2001) In the presence of loss functions mutations, the BMP inhibiting action on FSH pathway in granulosa cells is decreased, enabling higher FSH sensitivity (Shackell *et al*., 1993; McNattty *et al*., 2005).

2.5.6 Booroola ewes:

A highly prolific strain of merino ewes has also given significant insight in to the role of BMP system in ovarian function. These sheep carry an autosomal gene designated as Booroola (the gene locus, *FecB*), that causes increase ovulation rates and litter sizes (Bindon *et al*., 1986). Unlike Inverdale and Hanna in which homozygous mutant ewes infertile, Homozygous Booroola ewes exhibit ovulation rates that are even higher than the heterozygote’s. Three independent groups reported the same point mutation in the ALK 6 gene that is associated with Booroola phenotype (Wilson *et al*., 2001; Mulsant *et al*., 2001; Souza *et al*., 2001). The mutation is an A to G transition at nucleotide 830 that results in Q249R substitution in the regulatory serine/threonine - kinase domain of the ALK-6 protein. The mutation result in Q249R reduces the BMP dependent function of ALK6 receptor.

Despite the relatively wide spread expression of the ALK-6 receptor in sheep (Wilson *et al*., 2001). The aberrant phenotype caused by the Booroola mutation is the most part restricted to female reproduction (Montgomery *et al*., 2001). The most striking feature of the Booroola ewes can be observed in the ovary. Booroola follicle mature and ovulate at smaller size than those in wild type ewes. The follicles in Booroola exhibit increased responsiveness to FSH as evidence by increased cAMP content and progesterone production by cultured granulose cells (McNatty *et al*., 1986). Based on the similarity of the Booroola ewes and Inverdale and Hanna heterozygous ewes it has been proposed that BMP-15 also be a ligand that involved in the phenotype of Booroola ewes (Wilson *et al*., 2001). This notion is supported by finding of (Moore *et al*., 1995) showing of the candidate BMP type -I receptors. BMP-15 has the highest affinity for ALK-6 they support the role for BMP-15 in the phenotype. The Booroola is provided by the finding that ewes carrying both the Booroola and Inverdale genes have multiplicatively higher ovulation rate than those with each of these alone. This would be expected if ALK-6 is receptor for BMP-15 (Davis *et al*., 1999; McNatty *et al*., 2001). The granulosa cells of Booroola ewes are less sensitive to BMP-4 and GDF-5 with respect to inhibition of progesterone biosynthesis (Mulsant *et al*., 2001).

2.5.7 Sources of *FecB* gene

2.5.7.1 WorId sheep breeds having *FecB* gene

A number of prolific breeds all over the world were screened besides Garole and Booroola, the mutated gene was present in Javanese, Indonesia (Davis *et al*., 2002), Small Tailed Han, China (Liu *et al*., 2003; Wang *et al*., 2003; Davis *et al*., 2006), and Hu, China sheep (Wang *et al*., 2003; Davis *et al*., 2006; Guan *et al*., 2006). However, the expression of this gene varied in different breeds. The *FecJ* gene was the major gene segregating in Javanese thin tailed sheep (JIT) and had a smaller additive effect on litter size and ovulation rate than that of the *FecB* gene (Roberts *et al*., 2000). The effect of one copy of *FecJ* on ovulation rate in the Javanese sheep was about 0.8 (Bradford *et al*., 1991), which was only half of that reported for the *FecB* in other breeds by (Piper *et al*., 1984). The mean litter sizes of the homozygous carriers of the *FecB* and *FecJ* were comparable with Booroola having the mean litter size of 2.59 (Piper and Bindon, 1984) and JIT of 2.83 (Bradford *et al*., 1991), although the difference between the corresponding ovulation rates of Booroola (5.65) and JIT (2.92) was large. (Davis *et al*., 2002) subsequently found that the FecJ gene has the same mutation as *FecB* and its effects were lower in JIT breed. The Chinese Hu sheep was reported to have a mean litter size of about 2. I (individual litters range from 1 to 8) (Feng *et al*., 2006; Yue, 1996) and 2.61 (Tu *et al*., 1989; Wang *et al*., 2003) and had the ability to lamb twice per year. The presence of a single *FecB*^{BB} genotype, suggested fixing of the mutation in the Hu population. The Small Tailed Han sheep from China are also highly prolific, averaging 2.47 lambs born per ewe lambing (Feng *et al*., 2006).

2.5.7.2 Indian sheep breeds having *FecB* gene

Garole sheep in India were crossed with the Deccani breed in 1996 and the Fl backcrossed to the Deccani in 2000 (Nimbkar *et al*., 2007). Since 2001 the DNA marker test has been used to maintain *FecB* in the backcrossed Deccani sheep. A breeding programme crossing Garole and Malpura sheep commenced in India in 1997 (Sharma *et al*., 2003) and recent tests have confirmed the presence of *FecB* in 74% of the crossbred sheep (Kumar *et al*., 2006). Whereas the Deccani introgression programme aimed to backcross to the Deccani to maintain attributes of the Deccani that is well suited to the semi-arid Deccan plateaue in Maharashtra. The Malpura programme in the hot semi-arid environment of Rajasthan has involved interbreeding the cross to establish a prolific strain comprised of 50% Garole and 50% Malpura genes. Garole sheep have also been crossbred with Avikalin sheep in India using artificial insemination (Naqvi *et al*., 2002). A composite breed comprised of the Garole, Deccani, Bannur and breeds carrying *FecB* is under development in India (Nimbkar *et al*., 2007). A composite breed comprised of Garole and Muzaffarnagari carrying *FecB* is also under development in joint collaboration of 1VRI, Izatnagar, U.P and CIRG, Makdoom, U.P. *FecB* mutation in Garole (Pardeshi *et al*., 2005; Kumar *et al*., 2006; Sivakumar *et al*., 2008; Ranga, 2008; Sukhaputra, 2010), Kendrapada (Kumar *et al*., 2008) and Kuzi (Sukhaputra, 2010) were reported in India.

* * *

Materials and Methods

3

MATERIALS AND METHODS

3.1 Source of Data

Phenotypic data were collected from the history sheet and register of Muzaffarnagari flock maintained at Animal Genetics and Breeding Division of the Central Institute for Research on Goats (CIRG), Makhdoom, Mathura, Uttar Pradesh, India. The records (N=24476) on body weight from birth to 12 months at various ages and reproductive traits of Muzaffarganari sheep spread over a period of 27 years (1991-2017) were collected for the present study. In Indian conditions, regarding quantum of data, as a MVSc scholar to complete degree huge data is not available.

3.2 Climate and general managemental practices of sheep farm

All India Coordinated Research Project (AICRP) on sheep for mutton was established in year 1976 at CIRG, Makhdoom. The main objectives of this unit was to improve body weight through crossbreeding of local Muzaffarnagari sheep with exotic rams of Dorset and Suffolk breed to evolve a new mutton breed. Subsequently, changes were made and the objectives were modified to improve the Muzaffarnagari sheep for mutton and carpet wool production using pure breeding. In 1990, the major title of the programme was modified to Network Project on Sheep Improvement on Muzaffarnagari sheep and survey of Muzaffarnagari breed in its home tract in Muzaffarnagar. At present the breed is being improved for higher body weights through selective breeding.

The Institute occupies an area of about 300 ha and maintains purebred Muzaffarnagari flock. It is situated between Agra and Mathura at $27^{o}10'$N and $78^{0}02'$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. Soil pH is around 8.5 and ground water is alkaline with 7.8 pH. The climate is almost semi arid. The temperature ranges from 0^0C to over 45^0C, with annual precipitation of about 750mm, mainly during the monsoon from July to September.

Table 3.1 Temperature, relative humidity and rainfall conditions of CIRG during the year 2017-18

Month	Mean daily temperature (°c)	Relative humidity (%)	Rainfall (mm)/wet days
January	13.1	71.7	0.0
February	18.9	62.3	0.0
March	25.60	48.18	0.0
April	32.6	25.3	1.5 (2)
May	34.9	31.6	9.7 (3)
June	34.5	54.5	19.74 (7)
July	32.2	75.6	84.9 (12)
August	31.5	79.7	47.8 (9)
September	30.9	71.9	28.2 (6)
October	28.4	54.5	0.0
November	21.1	61.8	0.0
December	16.3	67.7	0.0

3.2.1 Feeding

There are three systems of feeding management of animals. At CIRG the animals were maintained under two systems of feeding management i.e. intensive and semi-intensive at farm condition.

- Dry fodder feeding: Gram, Arhar and Gwar bhusa.
- Cultivated fodder for Rabi season: Berseem, Oat, Barley
- Cultivated fodder for Kharif season: Cowpea, Bajara, Jowar
- Tree loppings: Subabool, Ber, Neem, Sahtoot
- Common grasses in the field: Anjana and Doob grass

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.

Fig. 3.1: Ewes feeding their lambs

Fig. 3.2: Clean drinking water trough

Fig. 3.3: Supplementary feeding of lambs and ewes

Fig. 3.4: Breeding rams

Fig. 3.5: Drenching of sheep for controlling endoparasites

All the lambs were weaned at 3 months age due to poor milk production and short lactation period of their dams. 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 age.

The adult ration consists of 72% TDN and 16% DCP. Essential ingredients of this ration were maize/rice polish (15%), barley (20%), ground nut cake (35%), wheat bran (20%), molasses (7%), mineral mixture (1.5%) and salt (1.5%). In this duration lambs were provided *ad libitum* growth ration, consisting of 72% TDN and 16% DCP. Essential ingredients of this ration were maize/rice polish (15%), barley (20%), ground nut 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.

Table 3.2 Composition of grower ration for Muzaffarnagari sheep

S.No	**Feed ingredient**	**Quantity (kg/100)kg**
1	Maize grain	20
2	Barley grain	20
3	Groundnut cake (expeller)	6
4	Soybean meal	5
5	Mustard cake (expeller)	5
6	Guar korma	5
7	Wheat bran	15
8	Deoiled rice bran	14
9	Molasses	7
10	Mineral mixture(BIS certified)	2
11	Common salt (Good quality)	1

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 6 hrs grazing. Ewes at 100 days onwards of their pregnancy and during lactation were provided supplementary feeding, where as dry ewes were fed only on maintenance ration. Green fodder like Guar, Berseem, Lucerne, Moringa were supplied regularly by the

Farm Section of the institute throughout the year as per availability in different seasons. The dry fodder like Gram or Arhar bhusa was also fed to the animals. The animals were sent for grazing for 5-6 hours daily. The grazing area of the institute is undulating ravine of sandy land with low organic C and available N and dominated with Kans and other saccharum infested.

3.2.2 Breeding

Sheep is a regular breeder. But due to problems in the management of lambs, the controlled breeding is practiced at the farm in order to achieve good survival rate and growth of the lambs. Heat detection of ewes was done in the morning and evening during the breeding season. The ewes in heat were mated with the selected rams in the morning. Mating plan was designed in such a way so that inbreeding could be avoided. Sheep were bred twice in one estrous. Each year in first breeding season (April-May) 10 breeding rams are selected on the basis of their 6 month body weight and semen quality. Before using for breeding each ram is also checked for Brucella and Brucella free rams are used for breeding. The breeding rams are used for breeding at 18 months as whereas females at 12 month age.

For better management of lambs the lambing are taken two times in a year. Moreover, these two lambing season (Feb-March and September-October) are major lambing season for this breed. These two seasons also protect lambs from extreme summer and winter because by the time extreme summer and winter starts the attain more than two month age. Hence, Breeding seasons were restricted in such a way that the lambing takes place in 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 above mentioned seasons. However, in farmer’s flocks, the breeding takes place throughout the year as breeding rams always stay with the flock. The majority of breeding falls in the month of April-June and September-November with lambing in September-November and February-April.

3.2.3 Shearing

To provide comfort and protect from extreme summer, the shearing of sheep is essential. Muzaffarnagari sheep is primarily maintained for mutton purpose, although it also produces greasy fleece of 1.2 kg/annum. Animals are shorn twice a year at six month interval in the months of April and October in farm conditions. Before shearing, the animals are washed properly to remove dust, thorns and other vegetative parts from the coat to ease the shearing operation. The shearing is carried out through hand scissors. The sale of the wool of this breed is a little problem, as it does not fit to the parameters of ideal carpet quality wool and less wool production in this region to develop woolen mandies. The wool quality breed is course hence not suitable for manufacture of any kind of carpets. However this wool is utilized after blending with fine carpet wool for manufacture of blankets, kashmir carpet etc. Nowadays there is no demand for sheep wool in our country. The sheep farmers are facing lots of problems to sell their wool. Now focus is given to improve the growth traits for mutton production. Breeders are growing interest in improving animals for mutton production instead of wool production.

3.2.4 Health cover

Flock health management of sheep is very important to overcome mortality and to achieve proper growth rate. The approach for treatment and control of diseases in herd is different from that of an individual animal. So to prevent the spread of disease within the herd, certain group control measures and treatment are done.

3.2.5 Vaccination

Sheep is vulnerable to infectious diseases and it requires timely vaccination. A vaccination schedule or calendar has to be prepared to plan and execute the vaccination in time for the herd. In Sheep, vaccination starts at an age of 3 months, because early vaccination can neutralize the maternal antibodies and the animal is also not competent enough to produce antibodies because of a nascent immune system. Vaccination is done annually along with boosters to improve the antibody titer. Only P.P.R vaccine is given once in three years. Other diseases against which vaccination done are sheep pox, foot and mouth disease, hemorrhagic septicemia and enterotoxemia. For enterotoxemia, vaccination has to be done before monsoon, to avoid any mortality due to overeating of palatable carbohydrate diet.

3.2.6 Prevalence of infectious diseases

Most important clinical syndromes encountered in sheep are pneumonia, diarrhea, endoparasitism, colibacillosis in neonatal lambs, mange, conjunctivitis, foot rot and ectoparasites.

Diarrhoea in adults can be due to non-specific causes or indigestion, and Johne's disease. If the animal is going progressively weak along with chronic intermittent diarrhea, it has to be diagnosed for Johne's disease caused by *Mycobacterium avium paratuberculosis* and the positive animal has to be culled, to avoid spread to other animals in the herd. Colibacillosis caused by *Escherichia coli*, mainly in young lambs of less than a month age, leads to scours, and it can cause huge mortality in lambs if not properly controlled.

Pneumonia is one of the most important causes of mortality in sheep. Pneumonia caused by infectious agents can be reduced by giving proper spacing, hygienic flooring, and scientific designing of shelter to comfort all the seasons. Fumigation of shelter can be done by using formaldehyde and potassium permanganate to disinfect and purify the air, which can reduce the incidence of pneumonia, if done regularly.

Foot-rot in sheep is contagious and is caused by bacteria, *Fusobacterium necrophorum*. This infection is precipitated due to dampness in the flooring which leads to accumulation of dirt in the hooves creating an anerobic atmosphere ambient for the growth of *Fusobacterium* sp, causing foot–rot. This can be controlled by maintaining dry and hygienic flooring through proper ventilation and timely removal of fecal materials. The infected animals are treated using a foot dip containing zinc sulphate and copper sulphate, along with antibiotic therapy. Incidence of foot rot in Sheep at CIRG is almost nil.

3.2.7 Control of parasitic diseases

Gastro-Intestinal nematodes are a potential threat to the sheep husbandry as they affect the growth rate and the lambs will not attain their desired body weight at market age and excessive load can even lead to mortality in lambs. Periodic deworming is very paramount in containing the endoparasitism. Incidence of *Haemonchus contortus* is between 30-35% at this farm. It is observed higher in rainy season than other seasons of the year. Deworming schedule has to be planned based on the seasons which are critical for the development of parasites leading to endoparasitism. Before monsoon, deworming is usually done, as moisture helps to retain the eggs in the fecal matter, which subsequently can cause infestation by feco-oral route. Tapeworm infestation can be reduced by use of specific anthelmintics like

Praziquantel. Liver fluke causes damage of liver due to the migration of larva and leads to hypoproteinemia and subsequently affects growth rate and wool yield. Use of copper sulphate is recommended to control the intermediate vectors like snails which harbor the parasite. It can be controlled by the use of flukicides like Oxyclosanide, Triclabendazole etc.

Ectoparasites like ticks, lice, fleas and other flies also cause problems in the herd, and can reduce the quality of hide and wool, besides, causing anemia and other communicable diseases. It can be checked by the use of ectoparasiticides like organo-phosphorus compounds, organochlorine compounds, pyrethroids etc. The best way is by dipping, which is the most efficient method used to control ticks and lice, besides used as a spray or pour-on forms. Dipping can be done by using 0.05 to 0.1 % pyrethroids like Cypermethrin (Ectomin®) or Deltamethrin (Butox®).

All animals were inspected thoroughly in the morning before sending out for grazing for any kind of abnormalities/sickness. Animals showing any abnormality or ailment were sorted out and kept in isolation ward for the observation of Veterinary Officer. Regular treatment and strict prophylactic measures were practiced for vaccination against Enterotoxaemia, Foot and Mouth Disease, Sheep Pox, H.S., PPR etc. Deworming with different anthelmintics was practiced at pre-monsoon and post monsoon seasons and as and when required. Dipping was done after 15-20 days of each shearing. All sheds and corrals were disinfected frequently with lime. All sheds were disinfected with lime at regular interval.

3.3 Collection of Data

The following information were collected from the Muzaffarnagari flock maintained at Animal Genetics and Breeding Division of the Central Institute for research on Goats (CIRG), Makhdoom, Mathura, Uttar Pradesh from 1991 to 2017:

1. Animal number
2. Sex
3. Date of birth
4. Sire number
5. Dam number

6. Season
7. Year
8. Parity
9. Type of birth
10. Birth weight (kg)
11. Weight at 3 months of age (kg)
12. Weight at 6 months of age (kg)
13. Weight at 9 months of age (kg)
14. Weight at 12 months of age (kg)
15. Ewe's weight at service (kg)
16. Ewe's weight at lambing (kg)
17. Date of first service (days)
18. Date of first lambing (days)
19. Litter size

3.4 Generation of Traits

From the above obtained data, following traits were generated:

1. Weight at birth (kg)
2. Weight at 3 months of age (kg)
3. Weight at 6 months of age (kg)
4. Weight at 9 months of age (kg)
5. Weight at 12 months of age (kg)
6. Average daily gain from birth to 3 months (g)
7. Average daily gain between 3 to 6 months (g)
8. Average daily gain between 6 to 9 months (g)
9. Average daily gain between 9 to 12 months (g)
10. Relative growth rate (g)
11. Age of ewe at first service (days)
12. Age of ewe at first lambing (days)
13. Litter size

Formulas :

Average daily gain (g/day) = W_2-W_1 / t_2-t_1

Relative growth rate = (W_2-W_1 / W_1) X 100

3.5 Standardisation of data

Pedigree cleaning was done in which manual error containing same tag number in both sexes of parents were removed. Extreme values were removed such that the data was normalized. Sires which had <5 progenies were removed from the data. Dams record on more than 5 parity are excluded.

3.6 Classification of Data

The data were classified according to different seasons, periods, parity, type of birth and sex to observe the effect of different non-genetic factors on the traits under study.

3.6.1 Classification of seasons

Season is considered to be one of the main factors of the environment that affects the growth of animals. There is wide variation of climatic conditions throughout the year, difference being more between the seasons and less within the seasons.

Seasons	Code	Number of animals
March-April	1	2034
October-November	2	2462

3.6.2 Classification of Periods

The data for present investigation were spread over a period of 27 years (1991-2017). The expression of different traits varied in different periods because of differences in the managemental practices as well as variation in agro climatic conditions over the years. So, the periods were classified into 7 groups.

Periods	Code	Number of animals
1991-1994	1	580
1995-1998	2	544
1999-2002	3	589
2003-2006	4	879
2007-2010	5	472
2011-2014	6	878
2015-2017	7	666

3.6.3 Classification of Parity

Parity ranged from 1 to 5. To observe the effect of parity on traits under study, parity was classified into 5 different groups.

Parity	Number of animals
1	1673
2	1155
3	782
4	522
5	576

3.6.4 Classification of Type of Birth (TOB)

To observe the effect of type of birth on different traits under study type of birth was classified into two different groups

TOB	Code	Number of animals
Single	1	3933
Twin	2	780

Fig. 3.6: Collection of blood sample from Muzaffarnagari, CIRG

Fig. 3.7: Collection of blood sample from Muzaffarnagari , CIRG

Fig. 3.8: Clean drinking watering of Muzaffarnagari, CIRG

Fig. 3.9: Clean drinking watering of Muzaffarnagari, CIRG

Fig. 3.10: Grazing field at CIRG

Fig. 3.11: Stall feeding of Muzaffarnagari, CIRG

3.6.5 Classification of Sex

To observe the effect of sex on different traits under study, sex was classified into two different groups.

Sex	Code	Number of animals
Male	1	2279
Female	2	2434

3.7 Trait wise Frequency distribution

The number of records available for the analysis of different traits is summarized below:

Trait	Code	Number of animals
Birth weight (kg)	BWT	4514
Weight at 3months(weaning) (kg)	WWT	4152
Weight at 6months (kg)	6WT	3713
Weight at 9months (kg)	9WT	3295
Weight at 12months (kg)	12WT	2903
Ewe’s weight at service (kg)	EWTS	2668
Ewe’s weight at lambing (kg)	EWTL	2652
Average Daily Gain from 0 to 3 months (g)	ADG1	4152
Average Daily Gain from 3 to 6 months (g)	ADG2	3665
Average Daily Gain from 6 to 9 months (g)	ADG3	3027
Average Daily Gain from 9 to 12 months (g)	ADG4	2673
Average Daily Gain from 3 to 12 months (g)	ADG5	2902
Relative Growth Rate from 0 to 3 months	RGR1	4151
Relative Growth Rate from 3 to 6 months	RGR2	3665
Relative Growth Rate from 6 to 9 months	RGR3	3027
Relative Growth Rate from 9 to 12 months	RGR4	2673
Relative Growth Rate from 3 to 12 months	RGR5	2902
Age at first lambing (days)	AFL	1039
Age at first service (days)	AFS	1081
Litter size	LS	1090

3.8 Statistical analysis for genetic parameters estimation

In order to overcome non-orthogonality of the data due to unequal sub-class frequencies, least-squares technique using LSMLMW computer programme designed by (Harvey, 1990) was utilized to estimate the effect of non-genetic factors.

3.8.1 Growth traits

3.8.1.1 Mixed model analysis for growth traits

Following model was used for analysis of body weights from birth to 12 months of age

$$\text{Yijklmno} = \mu + S_i + G_j + S_k + M_l + P_m + T_n + D + e_{ijklmno}$$

Where, Yijklmno= Oth observation under ith sire of jth sex, kth season, lth period, mth parity and nth type of birth

μ = Population mean common to all observations

S_i = Effect of ith sire

G_j = Effect of jth sex

S_k = Effect of kth season

M_l = Effect of lth period

P_m = Effect of mth parity

T_n = Effect of nth type of birth

D = Dam's weight at lambing

$e_{ijklmno}$ = Random error particular to ijklmnoth individual

3.8.1.2 Duncan's Multiple Range Test (DMRT)

Duncan's multiple range test as modified by Kramer (1957) was used for testing differences among least squares means (using the inverse coefficient matrix). The differences will be considered significant, if

$$(\boldsymbol{Xi} - \boldsymbol{Xj})\sqrt{\frac{\mathbf{2}}{(\boldsymbol{C_{ii}} + \boldsymbol{C_{jj}} - \mathbf{2}\boldsymbol{C_{ij}})}} > \boldsymbol{\sigma eZpn2}$$

Where

X_i and X_j were the least square means for ith and jth treatment and C_{ii}, C_{jj} and C_{ij} are diagonal and off diagonal elements in the inverse coefficient matrix in the least square normal equations, $Z_p n_2$ was studentized ranged value in Duncan's table (0.05) at n_2 degrees of freedom, p was number of means in the range chosen, σ is standard deviation of error, n_2 is degree of freedom for error.

3.8.1.3 Estimation of genetic parameters for growth traits using Restricted Maximum Likelihood Method (REML)

A mixed model was carried out to obtain restricted maximum likelihood estimate of covariance components with software WOMBAT (Meyer, 2013). (Co)variance components and genetic parameters were estimated by restricted maximum likelihood (REML) procedures using a derivative-free algorithm fitting six different animal models of DFREML, Version 3.0. Only significant effects ($p \leq 0.05$) were included in the models which were subsequently used for genetic analysis. All fixed effects were significant for the considered traits with few exceptions. 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 their details are as follows:

1. $Y = X\beta + Z_a a + \varepsilon$
2. $Y = X\beta + Z_a a + Z_m m + \varepsilon$, with $Cov (a_m, m_o) = 0$
3. $Y = X\beta + Z_a a + Z_m m + \varepsilon$, with $Cov (a_m, m_o) = A\sigma_{am}$
4. $Y = X\beta + Z_a a + Z_c c + \varepsilon$
5. $Y = X\beta + Z_a a + Z_m m + Z_c c + \varepsilon$, with $Cov (a_m, m_o) = 0$
6. $Y = X\beta + Z_a a + Z_m m + Z_c c + \varepsilon$, with $Cov (a_m, m_o) = A\sigma_{am}$

Where,

Y = the vector of record

β, a, m, c, and ε = 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 = incidence matrices that relate these effects to records

A = the numerator relationship matrix between animals

σ_{am} = the covariance between additive direct and maternal genetic effects.

3.8.1.4 Estimation of genetic and phenotypic correlations for growth traits

A series of bivariate animal model analysis was carried out to estimate genetic and phenotypic correlations between the traits with starting values obtained from single trait analysis.

3.8.2 Reproductive traits

3.8.2.1 Mixed model analysis for reproduction traits

Fixed effect of various genetic and non-genetic factors on reproduction traits was estimated by the following statistical model.

$$Y_{ijklm} = \mu + S_i + S_j + M_k + P_l + e_{ijklm}$$

Where, Y_{ijklm} = mth observation under ith sire, jth season, kth period and lth parity

μ= Population mean common to all the observations

S_i = Effect of ith sire

S_j = Effect of jth season

M_k = Effect of kth period

P_l = Effect of lth parity

e_{ijklm} = Random error

3.8.2.2 Duncan's Multiple Range Test (DMRT)

Duncan's multiple range test as modified by Kramer (1957) was used for testing differences among least squares means (using the inverse coefficient matrix). The differences will be considered significant, if

$$(Xi - Xj)\sqrt{\frac{2}{(C_{ii} + C_{jj} - 2C_{ij})}} > \sigma eZpn2$$

Where

X_i and X_j were the least square means for ith and jth treatment and C_{ii}, C_{jj} and C_{ij} are diagonal and off diagonal elements in the inverse coefficient matrix in the least square normal equations, $Z_p n_2$ was studentized ranged value in Duncan's table (0.05) at n_2 degrees of freedom, p was number of means in the range chosen, σ is standard deviation of error, n_2 is degree of freedom for error.

3.8.2.3 Estimation of genetic parameters for reproduction traits using Restricted Maximum Likelihood Method (REML)

A mixed model was carried out to obtain restricted maximum likelihood estimate of covariance components with software WOMBAT (Meyer, 2013). (Co)variance components and genetic parameters were estimated by restricted maximum likelihood (REML) procedures using a derivative-free algorithm fitting six different animal models of DFREML, Version 3.0. Only significant effects ($p \leq 0.05$) were included in the models which were subsequently used for genetic analysis. All fixed effects were significant for the considered traits with few exceptions. 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:

1. $Y = X\beta + Z_a a + \varepsilon$
2. $Y = X\beta + Z_a a + Z_m m + \varepsilon$, with $\mathrm{Cov}(a_m, m_o) = 0$
3. $Y = X\beta + Z_a a + Z_m m + \varepsilon$, with $\mathrm{Cov}(a_m, m_o) = A\sigma_{am}$
4. $Y = X\beta + Z_a a + Z_c c + \varepsilon$
5. $Y = X\beta + Z_a a + Z_m m + Z_c c + \varepsilon$, with $\mathrm{Cov}(a_m, m_o) = 0$
6. $Y = X\beta + Z_a a + Z_m m + Z_c c + \varepsilon$, with $\mathrm{Cov}(a_m, m_o) = A\sigma_{am}$

Where,

Y = the vector of record

β, a, m, c, and ε = 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 = incidence matrices that relate these effects to records

A = the numerator relationship matrix between animals

σ_{am} = the covariance between additive direct and maternal genetic effects.

Bayesian information criterion (BIC) was computed to rank the models. The model yielding the smallest BIC explains better variation in the trait**.**

3.8.2.4 Estimation of genetic and phenotypic correlations for reproduction traits

A series of bivariate animal model analysis was carried out to estimate genetic and phenotypic correlations between the traits with starting values obtained from single trait analysis

3.9 Estimation of genetic, phenotypic and environmental trends:

The phenotypic trend (ΔP) was estimated as the regression (bPT) of population performance (P) on time (T). The population performance is the period wise average (least squares means) of age at first calving. The genetic trend was estimated by Henderson's principle (Henderson, 1973) 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).

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

where,

EBV = expected breeding value;

h^2 = heritability;

t = intra class correlation (0.25 h^2 for the half sib progeny);

n = number of half sib progeny;

LSC = least squares constant.

Least square constants were obtained from model 1 of WOMBAT analysis. The expected transmitting abilities (ETA) were obtained by dividing the respective EBVs by 2. The weighted averages of sires transmitting abilities for periods were then regressed on periods. The environmental trends were obtained by subtracting the genetic trend from the phenotypic trend.

3.10 Genotyping the flock of Muzaffarnagari sheep for the presence of *FecB* gene

3.10.1 Collection of blood samples

About 5ml of blood was collected from jugular vein of each animal in 5ml sterile tube containing 2.7% EDTA (pH 8.0) as an anticoagulant. The blood samples were mixed gently with anticoagulant and maintained in cold chain till transportation to the laboratory. After reaching laboratory samples were kept in deep freeze at -20°C till the isolation of genomic DNA.

3.10.2 DNA Isolation

Genomic DNA for Muzzafarnagari sheep was isolated from the blood samples collected in 2.7% EDTA by Phenol: Chloroform extraction method as described by Sambrook *et al.* (2001) with slight modification. The steps followed for genomic DNA isolation samples were as follows

1. The blood samples were taken out of deep freeze and were thawed at room temperature.
2. Thawed blood samples were transferred to 15ml Polypropylene centrifuge tube and were centrifuged @ 300 rpm for 20 mins at room temperature.
3. The reddish tinged supernatant, containing plasma and lysed RBC was discarded by careful pipetting.
4. The pellet containing WBC and RBC was mixed with more than two volume of chilled RBC lysis buffer and kept in ice for 10mins after gently mixing it end to end, once or twice.
5. It was then again centrifuged @ 3000 rpm for 15mins at room temperature and the black tarry coloured supernatant containing lysis RBC was discarded by pipetting.
6. Step 4 and 5 were repeated 3-4 times till the WBC pellet became free of the reddish tinge.
7. Once a clear ‘Off white’ coloured pellet of WBC is obtained, DNA extraction buffer was added @ 3ml per 10ml blood and vortexed to gently disperse the WBC pellet in the extraction buffer.

8. WBC pellet mixed with DNA extraction buffer was incubated at 37°C for 30mins.
9. Subsequently, 10% SDS @ 200ml per 10ml blood was added and mixed gently by inverting the tube once or twice. Care should be taken while mixing, because after adding SDS, lysis of cell wall occurs and DNA is lies fully exposed. As a result the content of the tube becomes viscous.
10. Finally Proteinase-K (20mg/ml solution) was added @ 20ml/10ml blood in two pulses. Half of the requirement was added in the first pulse, after which content of the tube were mixed gently, end-to-end and incubated at 50°C for 3-4 hrs. This was followed by the second pulse of remaining about overnight incubation at 50°C.
11. On the 2nd day, equal volume of Tris saturated phenol (pH 7.8) was added to the tube.
12. The tubes were kept on shaker and gently rotary movements were given for 15min to mix the contents thoroughly.
13. Subsequently, the tubes were centrifuged @ 4000 rpm for 20 mins at room temperature.
14. After centrifugation, the contents of the tubes gets separated in to two layers, the upper aqueous layer (containing DNA) and a lower heavier layer of phenol (containing proteins). A white, thin layer of protein was also visible at the interphase of the two layers: the upper aqueous phase was transferred to another 15ml polypropylene tube with the help of 1ml wide bore (3mm diameter) microtip. Care was taken not to disturb the protein interface layer.
15. Similar extraction (as in steps 11-14) was done once with phenol: chloroform: Isoamyl alcohol (25:24:1) and once with chloroform: Isoamyl alcohol (24:1)
16. Finally, aqueous phase was taken in a 50ml polypropylene centrifuge tube and 3 M sodium acetate @ 100ml per ml of aqueous phase was added to it followed by gently mixing.
17. More than two volumes of chilled isopropanol was added to the tube and mixed gently by swirling the tube once or twice. The tube was left at room temperature to allow the precipitation of DNA.

18. The precipitated DNA was transferred into a sterile 1.5ml eppendorf tube (using the wide born microtip of 1ml capacity) along with 500ml isopraponol and centrifuge 10,000 rpm for 10mins at room temperature.
19. Supernatant was discarded without disturbing the DNA pellet.
20. The DNA pellet was then washed twice with 70% ethanol, similar to step 18 and 19.
21. Finally, DNA pellet was air dried for 1hr to remove traces of ethanol and was subsequently dissolved in 200 1 TE buffer.
22. The eppendorf tubes were kept in water bath at 60^{o}C for 2hr to inhibit DNAase activity and to dissolve pellet properly in the TE buffer.
23. After 2hr of incubation, the DNA was cooled and stored at -20^{o}C for further use.

3.10.3 Evaluation of quality, purity and concentration of the genomic DNA

3.10.3.1 Quality of DNA

The genomic DNA isolated from whole blood collected in 2.7% EDTA was checked by horizontal submarine agarose gel electrophoresis to ensure the intact DNA without any shearing. At first, gel casting plate was sealed with adhesive tape and placed on a leveling table. 1% agarose was dissolved in 1X TBE buffer by heating. The agarose solution was cooled to 45^{o}C and poured into the gel casting tray after adding ethidium bromide (10mg/ml) @ 0.5µg/ml. gel was allowed to solidify and the comb and adhesive tape were removed gently. The gel casting tray was submerged in gel tank having 1X TBE buffer. 2µl of loading dye was mixed and then loaded in the well. Electrophoresis was carried out at 60V for 1 hour and gel was visualized under UV transilluminator and documented by using gel documentation system. The samples having good quality DNA (intact band without smearing in gel) were used for further analysis (Sambrook *et al.*, 2001)

3.10.3.2 Purity of DNA

The purity of the genomic DNA from whole blood was assessed by A 260/A 280 using Spectrophotometer.

3.10.3.3 Concentration of DNA

The concentration of genomic DNA from whole blood was estimated by A 260/A280 using Spectrophotometer.

3.10.4 Standardization of Working DNA

After checking the quality, purity and concentration of the stock DNA it has been further diluted with autoclaved nuclease free water based on the concentration value. The working DNA was vortexes and stored in 4^{o}C for overnight and the concentration was checked in 1% agarose gel electrophoresis. Further dilution was done based on the result of agarose gel electrophoresis.

Table 3.3: Primers sequence of *FecB* (140bp)

Locus	Primer	Location	Primer sequence	Size of amplicon (bp)
BMPR-1B	F-12	Exon 8	5'- GTCGCTATGGGGAAGTTTGGATG-3'	140
	R-15	Exon 8	5'- CAAGATGTTTTCATGCCTCATCAACACGGTC-3'	

Table 3.4: PCR – reaction components for *FecB* gene

S.No.	PCR – reaction components	Amount (µl)
1	Nuclease Free Water	20.1 µl
2	dNTPS mixture (25mM)	0.2 µl
3	Forward primer (10pm/µl)	0.5 µl
4	Reverse primer (10pm/µl)	0.5 µl
5	Taq DNA polymerase (5u/µl)	0.2 µl
6	Genomic DNA (100mg/µl)	1.0 µl
	Total	25 µl

3.10.5 Amplification of *FecB* gene

Forced PCR-RFLP method used to amplify *FecB* gene, it is a method that deliberately introduce a point mutation in to one of the primers so that the PCR product will contain our restriction site. The primer set has been engineered to introduce a point mutation contain an *AvaII* restriction site (G↓GACC) and (C↓TCAG) whereas products from non-carrier of mutation lack this site. Both the forward and reverse primers used in present study were in Table 3.3. The PCR reaction components and PCR programme were given in Table 3.4 – Table 3.6.

Table 3.5: PCR – reaction components for *FecB* gene (PCR MM)

S.No.	PCR – reaction components	Amount (µl)
1	Nuclease free water	10.5 µl
2	Forward primer (10pm/µl)	0.5 µl
3	Reverse primer (10pm/µl)	0.5 µl
4	2X Green taq PCR MM	12.5 µl
5	Genomic DNA (100mg/µl)	1.0 µl
	Total	25 µl

3.10.5.1 Checking of Amplified Products

The amplified PCR products were checked by running 8 µl PCR product in 2% ultrapure (metaphore) agarose in submarine horizontal gel electrophoresis in 1X TBE buffer at 65V for 1 hour, 100 bp DNA ladder was also run along with the sample to ascertain the size of amplicon. In addition, negative control was also run along with the product to ensure that there was no contamination PCR carry over. At last the amplified products were visualized under UV light and documented using gel documentation system.

3.10.6 Restriction enzyme digestion

In 0.2ml PCR tubes all the components for RE digestion were taken in the order as milli Q water at first, followed by RE buffer and then finally *AvaII* restriction enzyme (G↓GACC) for *FecB*. This master mix dispensed into the labeled (0.2ml) and finally PCR products of required quantity were added to it. The tubes for RE digestion were spun for two minutes subsequently incubated as per the conditions recommended by the manufacture for proper and complete digestion. The details of RE digestion reactions components for *FecB* were given in the Table 3.7. For complete digestion products were stored at 4°C for further use.

3.10.6.1 Gel electrophoresis for RE digested PCR products

RE digested products were resolved by submarine agarose gel electrophoresis. A 3.5% ultrapure (metaphore) agarose suspension in 1X TBE (Tris, Boric acid, EDTA) buffer was prepared and heated until it was completely melted and dissolved to give a clear transparent solution. Ethidium bromide (10mg/ml) @ 5µl per 100ml of ultrapure agarose solution was added when it was cooled to about 45°C and mixed gently to avoid bubble formation, meanwhile prepared the gel casting tray. The agarose solution was poured into gel casting tray and allowed to solidify for 30 min then comb was removed and samples were loaded. Electrophoresis was performed at 45V for 5 min followed by 65V for 2 hours. Then the gel was visualized and documented with gel documentation system.

3.10.6.2 Estimation of the size of the restricted fragments

$$\boldsymbol{Genotype\ frequency} = \frac{\boldsymbol{No\ of\ individuals\ of\ a\ particular\ genotype}}{\boldsymbol{Total\ no\ of\ all\ individuals}}$$

$$\boldsymbol{Gene\ frequency} = \frac{\boldsymbol{2D + H}}{\boldsymbol{2N}}$$

50bp DNA ladder was used for estimation of the fragment size. The molecular marker was run along with the digested products in gel electrophoresis size of the fragments was estimated using software installed in the computer (Gene tools from syngene).

3.10.7 Estimation of Genotype and Gene Frequencies

The genotypes were determined by reading the restriction fragment patterns of each digested sample in the gels. The gene and genotype frequency were estimated by the standard protocol given by Falconer and Mackay (1996).

Where,

D = No of homozygotes of a particular genotype

H = No. of heterozygotes having that gene

N = Total No. of individuals

Table 3.6: PCR Programme for *FecB* gene

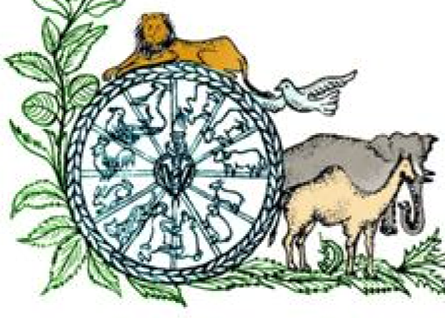
S.NO	Step	Temperature	Time
1	Initial denaturation	94°C	5 min
2	Denaturation	94°C	1 min
3	Annealing	66°C	1 min
4	Extension	72°C	1 min
5	30cycles of step 2 to 4		
6	Final extension	72°C	10 min

Table 3.7: RE digestion reaction components for *FecB* gene

S.NO	Reaction components	Amount
1	Restriction enzyme (10µg/µl)	0.2 µl
2	10 X assay buffer	1.0 µl
3	Autoclaved distilled water	3.8 µl
4	PCR product	15.0 µl
	Total volume	20 µl

* * *

Results



4

RESULTS

The results of present investigation on Muzaffarnagari sheep have been presented and discussed as given below.

The main objective of present investigation was to examine the effect of genetic and non-genetic factors, estimation of genetic and non-genetic parameters using REML for growth and reproduction parameters and analysis of genetic, phenotypic and environmental trends for growth and reproduction parameters. Keeping in this view, the results of the present investigation have been presented under the following headings/sub headings:

4.1 Influence of various factors on growth and reproduction traits

4.1.1 Influence of various factors on different body weight traits

The least squares means of body weight traits were given in the Table 4.1.

Least squares estimates of overall population mean ± SE (kg) for different body weight traits BWT, WWT, 6WT, 9WT, 12WT, EWTS and EWTL were observed as 3.41±0.02, 15.14±0.17, 22.19±0.22, 27.25±0.23, 31.33±0.24, 38.42±0.32 and 39.64±0.38, respectively.

4.1.1.1 Effect of Sex

The effect of sex (male and female) was highly significant ($P<0.01$) on all body weight traits. The least squares estimates of mean ± SE (kg) for BWT, WWT, 6WT, 9WT, 12WT, EWTS and EWTL were 3.48 ± 0.23, 15.66 ± 0.18, 24.52 ± 0.24, 29.57 ± 0.25, 34.32 ± 0.27, 38.54 ± 0.34 and 39.54 ± 0.39 respectively in male animals and 3.34 ± 0.23, 14.62 ± 0.17, 21.29 ± 0.23, 24.93 ± 0.24, 28.33 ± 0.25, 38.29 ± 0.34 and 39.8 ± 0.40 respectively in female animals.

4.1.1.2 Effect of Season

The effect of season of birth (1 and 2) was highly significant ($P<0.01$) on BWT and 9WT, significant ($P<0.05$) on WWT and 6WT, and non-significant ($P>0.05$) on 12WT, EWTS and EWTL. The least squares estimates of mean ± SE (kg) for BWT, WWT, 6WT, 9WT, 12WT, EWTS and EWTL were 3.46 ± 0.24, 15.28 ± 0.18, 22.70 ± 0.24, 26.62 ± 0.25, 31.15 ± 0.26, 38.40 ± 0.35 and 39.46 ± 0.41 respectively in lambs born in S-1 and 3.36 ± 0.23, 14.99 ± 0.18, 23.11 ± 0.24, 27.87 ± 0.25, 31.50 ± 0.26, 38.44 ± 0.32 and 39.82 ± 0.40 respectively for lambs born in S-2.

Table 4.1 Least squares means (kg) with Standard error for body weight traits of Muzaffarnagari sheep (Contd…)

	EWTS		**EWTL**	
	N	**Mean ± SE (kg)**	**N**	**Mean ±SE (kg)**
Overall mean	2592	38.42±0.32	2592	39.64±0.38
Sex	NS		NS	
Male	1302	38.54±0.34	1302	39.54±0.39
Female	1290	38.29±0.34	1290	39.82±0.40
Season	NS		NS	
1	1221	38.40±0.35	1221	39.46±0.41
2	1371	38.44±0.32	1371	39.82±0.40
Period	**		**	
1(1991-94)	101	$31.73^{a}\pm0.42$	101	$35.94^{a}\pm0.85$
2(1995-98)	303	$34.82^{b}\pm0.82$	303	$41.55^{c}\pm0.82$
3(1999-02)	332	$36.74^{b}\pm0.77$	332	$44.10^{c}\pm0.75$
4(2003-06)	480	$39.20^{d}\pm0.64$	480	$33.90^{c}\pm0.81$
5(2007-10)	301	$39.52^{c}\pm0.69$	301	$40.41^{b}\pm0.80$
6(2011-14)	720	$41.67^{e}\pm0.68$	720	$40.95^{d}\pm0.06$
7(2015-17)	355	$41.65^{f}\pm0.90$	355	$40.95^{d}\pm0.06$
Parity	**		**	
1	1001	$35.02^{a}\pm0.34$	1001	$36.54^{a}\pm0.40$
2	673	$37.39^{b}\pm0.37$	673	$39.26^{b}\pm0.43$
3	434	$39.19^{c}\pm0.40$	434	$40.55^{c}\pm0.47$
4	292	$40.02^{d}\pm0.44$	292	$41.13^{d}\pm0.52$
5	192	$40.47^{d}\pm0.50$	192	$40.72^{cd}\pm0.58$
Type of birth	**		**	
1	2119	$37.14^{a}\pm0.31$	2119	$38.81^{a}\pm0.37$
2	473	$39.69^{b}\pm0.39$	473	$40.46^{b}\pm0.46$

** $P<0.01$,*$P<0.05$; Different superscripts indicates significant differences

Table 4.1 Least square means (kg) with Standard error for body weight traits of Muzaffarnagari sheep

	BWT		WWT		6WT		9WT		12WT	
	N	Mean ± SE (kg)	N	Mean±SE (kg)	N	Mean ±SE (kg)	N	Mean ±SE (kg)	N	Mean ±SE (kg)
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	$3.48^{a}\pm0.23$	1999	$15.66^{a}\pm0.18$	1730	$24.52^{a}\pm0.24$	1420	$29.57^{a}\pm0.25$	1143	$34.32^{a}\pm0.27$
Female	2342	$3.34^{b}\pm0.23$	2186	$14.62^{b}\pm0.17$	2013	$21.29^{b}\pm0.23$	1902	$24.93^{b}\pm0.24$	1786	$28.33^{b}\pm0.25$
Season		**		*		*		**		NS
1	2116	$3.46^{a}\pm0.24$	1966	$15.28^{a}\pm0.18$	1778	$22.70^{a}\pm0.24$	1555	$26.62^{a}\pm0.25$	1422	31.15±0.26
2	2409	$3.36^{b}\pm0.23$	2219	$14.99^{b}\pm0.18$	1965	$23.11^{b}\pm0.24$	1767	$27.87^{b}\pm0.25$	1507	31.50±0.26
Period		**		**		**		**		**
1(1991-94)	579	$3.45^{b}\pm0.08$	533	$18.09^{c}\pm0.55$	424	$27.71^{c}\pm0.74$	352	$29.47^{b}\pm0.83$	305	$32.89^{b}\pm0.98$
2(1995-98)	544	$3.86^{d}\pm0.06$	480	$15.48^{ab}\pm0.40$	415	$23.75^{b}\pm0.52$	350	$26.81^{a}\pm0.55$	253	$29.83^{a}\pm0.65$
3(1999-02)	685	$3.11^{a}\pm0.05$	619	$15.29^{b}\pm0.35$	570	$22.28^{b}\pm0.46$	470	$25.88^{b}\pm0.49$	419	$31.51^{d}\pm0.54$
4(2003-06)	875	$2.99^{a}\pm0.05$	787	$14.05^{ab}\pm0.32$	696	$21.27^{b}\pm0.43$	643	$25.58^{b}\pm0.45$	564	$30.47^{d}\pm0.51$
5(2007-10)	423	$3.34^{b}\pm0.06$	413	$13.99^{a}\pm0.38$	393	$21.86^{a}\pm0.48$	349	$26.57^{a}\pm0.51$	327	$31.13^{c}\pm0.56$
6(2011-14)	874	$3.51^{c}\pm0.05$	842	$15.58^{c}\pm0.36$	762	$23.60^{d}\pm0.47$	723	$28.21^{c}\pm0.50$	680	$31.18^{e}\pm0.55$
7(2015-17)	545	$3.58^{c}\pm0.07$	511	$13.49^{c}\pm0.49$	483	$19.86^{e}\pm0.65$	435	$28.21^{d}\pm0.68$	381	$32.27^{f}\pm0.74$
Parity		**		*		NS		NS		NS
1	1604	$3.28^{a}\pm0.03$	1475	$14.97^{a}\pm0.19$	1287	22.70±0.25	1154	26.97±0.26	998	30.75±0.28
2	1123	$3.41^{b}\pm0.03$	1029	$15.29^{b}\pm0.20$	904	22.96±0.26	794	27.24±0.27	714	31.44±0.23
3	744	$3.45^{b}\pm0.03$	699	$15.31^{b}\pm0.21$	636	23.01±0.28	559	27.40±0.29	501	31.54±0.31
4	502	$3.43^{b}\pm0.03$	467	$15.33^{b}\pm0.23$	431	23.35±0.30	380	27.70±0.32	341	31.67±0.34
5	552	$3.47^{b}\pm0.03$	515	$14.79^{b}\pm0.23$	485	22.50±0.30	435	26.93±0.37	375	31.23±0.33
Type of birth		**		**		**		**		**
1	3784	$3.78^{a}\pm0.02$	3496	$16.61^{a}\pm0.16$	3124	$24.13^{a}\pm0.22$	2776	$28.41^{a}\pm0.22$	2440	$32.44^{a}\pm0.23$
2	741	$3.04^{b}\pm0.03$	689	$13.67^{b}\pm0.21$	619	$21.68^{b}\pm0.27$	546	$26.09^{b}\pm0.29$	489	$30.21^{b}\pm0.30$

**P<0.01, *P<0.05, NS-Non significant; Different superscripts indicates significant differences

Table 4.2 Least square means (g) with Standard error for average daily gain traits of Muzaffarnagari sheep

	ADG1		ADG2		ADG3		ADG4		ADG5	
	N	Mean ± SE (kg)	N	Mean±SE (kg)	N	Mean ±SE (kg)	N	Mean ±SE (kg)	N	Mean ±SE (kg)
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^{a}±1.91	1709	98.14^{a}±1.67	1327	53.98^{a}±1.44	1048	52.81^{a}±1.49	1143	67.19^{a}±0.85
Female	2186	125.37^{b}±1.86	1986	74.81^{b}±1.61	1726	41.51^{b}±1.35	1651	40.62^{b}±1.37	1785	50.54^{b}±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
Type of birth		**		**		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

**P<0.01, *P<0.05, NS-Non significant; Different superscripts indicates significant differences

Table 4.3 Least square means with Standard error for relative growth rate traits of Muzaffarnagari sheep

	RGR1		RGR2		RGR3		RGR4		RGR5	
	N	Mean ± SE (kg)	N	Mean±SE (kg)	N	Mean ±SE (kg)	N	Mean ±SE (kg)	N	Mean ±SE (kg)
Overall mean	4184	353.32±5.27	3695	53.16±1.01	3053	20.20±0.63	2699	16.42±0.52	2928	111.03±1.91
Sex		*		**		**		**		**
Male	1998	$357.68^{a}\pm5.66$	1709	$58.14^{a}\pm1.09$	1327	$21.40^{a}\pm0.69$	1048	$16.99^{a}\pm0.58$	1143	$121.73^{a}\pm2.13$
Female	2186	$348.96^{b}\pm5.51$	1986	$48.18^{b}\pm1.52$	1726	$19.00^{b}\pm0.64$	1651	$15.86^{b}\pm0.53$	1785	$100.33^{b}\pm1.96$
Season		NS		**		**		**		**
1	1966	350.18±5.62	1757	$50.56^{a}\pm1.07$	1406	$18.41^{a}\pm0.67$	1356	$17.89^{a}\pm0.55$	1421	$107.28^{a}\pm2.05$
2	2218	356.45±5.70	1938	$55.75^{b}\pm1.09$	1647	$21.99^{b}\pm0.68$	1343	$14.96^{b}\pm0.57$	1507	$114.78^{b}\pm2.08$
Period		**		**		**		**		**
1(1991-94)	533	$446.11^{d}\pm17.33$	420	$56.46^{a}\pm3.38$	306	$6.33^{a}\pm2.41$	271	$15.21^{b}\pm2.30$	305	$85.50^{a}\pm7.81$
2(1995-98)	480	$323.68^{a}\pm12.48$	414	$55.57^{c}\pm2.37$	333	$11.16^{a}\pm1.53$	241	$11.71^{a}\pm1.41$	252	$94.73^{b}\pm5.16$
3(1999-02)	619	$397.11^{cd}\pm10.93$	564	$46.81^{ab}\pm2.09$	420	$16.98^{b}\pm1.37$	407	$18.14^{cd}\pm1.17$	419	$102.00^{c}\pm4.31$
4(2003-06)	787	$363.98^{c}\pm10.09$	678	$53.39^{b}\pm1.97$	613	$20.26^{c}\pm1.25$	541	$17.84^{cd}\pm1.10$	564	$114.69^{d}\pm4.02$
5(2007-10)	413	$318.27^{b}\pm11.85$	384	$59.12^{ab}\pm2.20$	325	$24.93^{bc}\pm1.41$	307	$17.74^{de}\pm1.22$	327	$129.92^{cd}\pm4.47$
6(2011-14)	841	$343.61^{cd}\pm11.31$	753	$51.50^{ab}\pm2.14$	664	$22.80^{bc}\pm1.37$	629	$14.77^{c}\pm1.21$	680	$109.13^{cd}\pm4.39$
7(2015-17)	511	$280.46^{cd}\pm15.62$	482	$49.24^{c}\pm2.94$	392	$38.93^{bc}\pm1.87$	303	$19.56^{e}\pm1.66$	381	$141.24^{e}\pm5.85$
Parity		**		*		NS		NS		NS
1	1475	$368.91^{b}\pm5.99$	1269	$53.06^{a}\pm1.15$	1066	20.31±0.71	914	15.78±0.60	998	109.80±2.19
2	1029	$358.36^{ab}\pm6.23$	890	$51.71^{a}\pm1.20$	726	20.25±0.75	675	16.75±0.62	713	111.52±2.29
3	699	$352.50^{ab}\pm6.70$	630	$52.32^{ab}\pm1.28$	516	20.34±0.79	461	16.20±0.66	501	110.07±2.45
4	467	$351.75^{ab}\pm7.37$	427	$53.85^{b}\pm1.39$	346	18.98±0.87	312	16.24±0.72	341	109.88±2.66
5	514	$335.06^{a}\pm7.20$	479	$54.84^{b}\pm1.36$	399	21.11±0.84	337	17.15±0.71	375	113.87±2.61
Type of birth		*		**		**		**		**
1	3496	$347.69^{a}\pm5.12$	3080	$46.52^{a}\pm0.99$	2551	$18.78^{a}\pm0.61$	2251	$15.37^{a}\pm0.50$	2439	$97.02^{a}\pm1.85$
2	688	$358.94^{b}\pm6.57$	615	$59.80^{b}\pm1.25$	502	$21.62^{b}\pm0.78$	448	$17.48^{b}\pm0.65$	489	$125.04^{b}\pm2.39$

**$P<0.01$, *$P<0.05$, NS-Non significant; Different superscripts indicates significant differences

4.1.1.3 Effect of Period

The effect of period (1, 2, 3, 4, 5, 6 and 7) was highly significant ($P<0.01$) on all body weight traits. The least squares estimates of mean ± SE (kg) for all body weight traits were given in the Table.

4.1.1.4 Effect of Parity

The effect of parity (1, 2, 3, 4 and 5) was highly significant ($P<0.01$) on BWT, EWTS and EWTL, significant ($P<0.05$) on WWT and non-significant ($P>0.05$) on all other traits. The least squares estimates of mean ± SE (kg) were highest on 4th parity for WWT, 6WT, 9WT and 12WT and 5th parity for BWT, EWTS and EWTL.

4.1.1.5 Effect of Type of Birth

The effect of type of birth (single and twin) was highly significant ($P<0.01$) on all the body weight traits. The least squares estimates of mean ± SE (kg) for BWT, WWT, 6WT, 9WT and 12WT were higher in lambs born as single (3.78 ± 0.02, 16.61 ± 0.16, 24.13 ± 0.22, 28.41 ± 0.22 and 32.44 ± 0.23 repectively. than lambs born as twins (3.04 ± 0.03, 13.67 ± 0.21, 21.68 ± 0.27, 26.09 ± 0.29 and 30.21 ± 0.30 repectively. But lambs born as twins were having higher EWTS (39.69 ± 0.39) and EWTL (40.46 ± 0.46).

4.1.2 Influence of various factors on different growth rate traits

4.1.2.1 Influence of various factors on average daily gain (ADG)

The least squares means of average daily gain traits were given in the Table 4.2.

Least squares estimates of overall population mean ± SE (g) for different body weight gain traits ADG1, ADG2, ADG3, ADG4 and ADG5 were 130.31 ± 1.78, 86.48 ± 1.55, 47.75 ± 1.31, 46.71 ± 1.33 and 58.86 ± 0.77 respectively.

4.1.2.1.1 Effect of Sex

The effect of sex was highly significant ($P<0.01$) on all ADG. The least squares estimates of mean ± SE (g) for ADG1, ADG2, ADG3, ADG4 and ADG5 were 135.26 ± 1.91, 98.14 ± 1.67, 53.98 ± 1.44, 52.81 ± 1.49 and 67.19 ± 0.85 respectively in male animals and

125.37 ± 1.86, 74.81 ± 1.61, 41.51 ± 1.35, 40.62 ± 1.37 and 50.54 ± 0.79 respectively in female animals.

4.1.2.1.2 Effect of Season

The effect of season was highly significant ($P<0.01$) on all ADG except ADG1 in which it is non-significant ($P>0.05$). The least squares estimates of mean ± SE (g) for ADG1, ADG2, ADG3, ADG4 and ADG5 were 131.28 ± 1.89, 82.56 ± 1.64, 43.85 ± 1.41, 50.26 ± 1.42 and 57.71 ± 0.82 respectively in lambs born in S-1 and 129.35 ± 1.92, 90.39 ± 1.67, 51.64 ± 1.42, 43.16 ± 1.46 and 60.01 ± 0.83 respectively in lambs born in S-2.

4.1.2.1.3 Effect of Period

The effect of period was highly significant ($P<0.01$) on all ADG. The least squares estimates of mean ± SE (g) for ADG1, ADG2, ADG3, ADG4 and ADG5 were mentioned in the table.

4.1.2.1.4 Effect of Parity

The effect of parity was significant ($P<0.05$) on ADG1 and non-significant ($P>0.05$) on all other ADGs. The least squares estimates of mean ± SE (g) for ADG1, ADG2, ADG3, ADG4 and ADG5 were approximately highest in 3rd parity (131.81 ± 2.26, 86.09 ± 1.95, 48.17 ±1.67, 46.48 ± 1.71 and 59.04 ± 0.98 respectively.

4.1.2.1.5 Effect of Type of Birth

The effect of type of birth (single and twin) was highly significant ($P<0.01$) ADG1, ADG2 and ADG5 and non-significant ($P>0.05$) on ADG3 and ADG4. The least squares estimates of mean ± SE (g) for ADG1, ADG2, ADG3, ADG4 and ADG5 were 142.59 ± 1.73, 83.90 ± 1.51, 46.59 ± 1.27, 45.85 ± 1.29 and 57.18 ± 0.74 respectively in animals born as single and 118.04 ± 2.21, 89.05 ± 1.91, 48.90 ± 1.64, 47.58 ± 1.68 and 60.54 ± 0.96 respectively.

4.1.2.2 Influence of various factors on relative growth rate

The least squares means of relative growth rate traits are depicted in Table 4.3

Least squares estimates of overall population mean ± SE for different body weight gain traits RGR1, RGR2, RGR3, RGR4 and RGR5 were 353.32 ± 5.27, 53.16 ± 1.01, 20.20 ± 0.63, 16.42 ± 0.52 and 111.03 ± 1.91 respectively.

4.1.2.2.1 Effect of Sex

The effect of sex was highly significant ($P<0.01$) on all RGR except for RGR1 in which it is significant ($P<0.05$). The least squares estimates of mean ± SE for RGR1, RGR2, RGR3, RGR4 and RGR5 were 357.68 ± 5.66, 58.14 ± 1.09, 21.39 ± 0.69, 16.99 ± 0.58 and 121.73 ± 2.13 respectively in male animals and 348.96 ± 5.51, 48.18 ± 1.52, 19.00 ± 0.64, 15.86 ± 0.53 and 100.33 ± 1.96 respectively in case of female animals.

4.1.2.2.2 Effect of Season

The effect of season was non-significant ($P>0.05$) on RGR1 but highly significant ($P<0.01$) on RGR2, RGR3, RGR4 and RGR5. The least squares estimates of mean ± SE for RGR1, RGR2, RGR3, RGR4 and RGR5 were 350.18 ± 5.62, 50.63 ± 1.07, 18.41 ± 0.67, 17.89 ± 0.55 and 107.28 ± 2.05 respectively for lambs born in S-1 and 356.45 ± 5.70, 55.75 ± 1.09, 21.99 ± 0.68, 14.96 ± 0.57 and 114.78 ± 2.08 respectively for lambs born in S-2.

4.1.2.2.3 Effect of Period

The effect of season was highly significant ($P<0.01$) on all RGR except on RGR1 in which it was non-significant ($P>0.05$). The least squares estimates of mean ± SE for RGR1, RGR2, RGR3, RGR4 and RGR5 were given in the table.

4.1.2.2.4 Effect of Parity

The effect of parity was highly significant ($P<0.01$) on RGR1, significant ($P<0.05$) on RGR2 and non-significant ($P>0.05$) on RGR3, RGR4 and RGR5. The least squares estimates of mean ± SE for RGR1, RGR2, RGR3, RGR4 and RGR5 were approximately highest in 5th parity (335.06 ± 7.19, 54.84 ±1.36, 21.11 ± 0.84, 17.15 ± 0.71 and 113.87 ± 2.61 respectively.

4.1.2.2.5 Effect of Type of Birth

The effect of type of birth (single and twin) was highly significant (P<0.01) for all RGR except for RGR1 in which it is significant (P<0.05). The least squares estimates of mean ± SE for RGR1, RGR2, RGR3, RGR4 and RGR5 were highest for animals born as twins (358.94 ± 6.57, 59.79 ± 1.25, 21.62 ± 0.78, 17.48 ± 0.65 and 125.04 ± 2.39 respectively than for animals which are born as single (347.69 ± 5.12, 46.52 ± 0.99, 18.78 ± 0.61, 15.37 ± 0.50 and 97.02 ± 1.85 repectively.

4.1.3 Influence of various factors on reproduction traits

The least squares means of reproduction traits are depicted in Table 4.4

Least squares estimates of overall population mean ± SE (kg) for different reproduction traits Age at First Lambing (AFL), Age at First Service (AFS) and Litter Size (LS) were 698.87 ± 73.94, 599.54 ± 8.54 and 1.07 ± 0.02 respectively.

4.1.3.1 Effect of Season

The effect of season was significant (P<0.05) on LS and non-significant (P>0.05) on AFL and AFS. The least squares estimates of mean ± SE (kg) for AFL, AFS and LS were higher for lambs born in S-1 (724.56 ± 74.21, 620.13 ± 10.83 and 1.08 ± 0.02 repectively. than for lambs born in S-2 (673.19 ± 74.23, 578.96 ± 9.89 and 1.06 ± 0.02 repectively..

4.1.3.2 Effect of Period

The effect of period was highly significant (P<0.01) on AFL and AFS and non-significant (P>0.05) on LS. The least squares estimates of mean ± SE (kg) for AFL, AFS and LS were given in the Table.

Table 4.4 Least squares means with Standard error for reproduction traits of Muzaffarnagari sheep

	AFS		AFL		LS	
	N	**Mean ±SE (days)**	**N**	**Mean ±SE (days)**	**N**	**Mean ±SE (days)**
Overall mean	1079	599.54±8.54	1039	698.87±73.94	1094	1.07±0.02
Season		NS		NS		*
1	507	620.13±10.83	493	724.56±74.21	511	$1.08^{a}\pm0.02$
2	572	578.96± 9.89	546	673.19±74.23	583	$1.06^{b}\pm0.02$
Period		**		**		NS
1(1991-94)	191	$656.64^{c}\pm15.73$	175	$785.04^{d}\pm75.47$	209	1.04±0.03
2(1995-98)	69	$781.45^{d}\pm23.33$	96	$912.69^{e}\pm76.61$	136	1.03±0.03
3(1999-02)	202	$521.35^{a}\pm14.68$	187	$603.88^{a}\pm75.75$	203	1.03±0.02
4(2003-06)	141	$587.03^{b}\pm17.08$	145	$653.62^{bc}\pm75.70$	153	1.06±0.03
5(2007-10)	110	$600.86^{b}\pm18.31$	117	$689.70^{c}\pm74.49$	115	1.1±0.03
6(2011-14)	255	$541.77^{a}\pm12.76$	239	$632.99^{ab}\pm74.86$	227	1.08±0.02
7(2015-17)	111	$507.70^{a}\pm17.84$	80	$614.19^{ab}\pm76.89$	41	1.05±0.04
Parity		NS		NS		NS
1	358	604.49±12.19	358	703.86±93.87	380	1.07±0.01
2	265	596.76±13.03	249	694.02±94.02	268	1.07±0.01
3	198	617.82±14.52	185	714.64±94.33	193	1.10±0.02
4	117	579.96±17.93	112	679.59±94.98	116	1.08±0.02
5	141	598.67±17.02	133	698.86±94.72	135	1.09±0.02
Type of birth		NS		NS		
1	920	588.87±7.23	899	750.89±33.60		
2	159	610.22±15.08	139	774.65±37.03		

** $P<0.01$,*$P<0.05$, NS-non significant; Different superscripts indicates significant differences

4.1.3.3 Effect of Parity

The effect of parity was non-significant ($P>0.05$) on all reproduction traits. The least squares estimates of mean ± SE (kg) for AFL, AFS and LS were highest in the 3rd parity 714.64 ± 94.33, 617.82 ± 14.52 and 1.10 ± 0.02 repectively..

4.2 Genetic Parameters for different Growth Traits using REML

Variance and covariance estimates of growth and reproduction traits are given in Table 4.5 to 4.24

4.2.1 Birth Weight (BWT)

Variance components and genetic parameters estimated by different models for BWT are presented in Table 4.5

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 0.09 kg, 0.24 kg, 0.34 kg and 0.28 ± 0.03 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 0.05 kg, 0.05 kg, 0.24 kg, 0.34 kg, 0.15 ± 0.03 and 0.16 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 0.10 kg, 0.11 kg, -0.07, 0.21 kg, 0.34 kg, 0.29 ± 0.05, 0.31 ± 0.03, 0.14 and -0.31 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 0.05 kg, 0.05 kg, 0.24 kg, 0.34 kg, 015 ± 0.03, 0.16 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 0.05 kg, 0.03 kg, 0.03 kg, 0.24 kg, 0.34 kg, 0.15 ± 0.03, 0.08 ± 0.02 and 0.08 ± 0.002 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent

environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2), maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 0.10 kg, 0.08 kg, -0.07, 0.03 kg, 0.21 kg, 0.34 kg, 0.29 ± 0.05, 0.23 ± 0.006, 0.1, 0.08 ± 0.04 and -0.31

4.2.2 Body weight at 3months (WWT)

Variance components and genetic parameters estimated by different models for WWT are presented in Table 4.6

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 6.48 kg, 10.06 kg, 16.54 kg and 0.39 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 3.92 kg, 0.50 kg, 10.25 kg, 14.66 kg, 0.27 ± 0.04 and 0.03 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 5.33 kg, 1.69 kg, -2.08, 9.59 kg, 14.53 kg, 0.37 ± 0.06, 0.12 ± 0.03, -0.69 and 0.22 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 3.92 kg, 0.50 kg, 10.25 kg, 14.66 kg, 0.27 ± 0.04 and 0.03 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 3.92 kg, 0.25 kg, 0.25 kg, 10.25 kg, 17.02 kg, 0.27 ± 0.04, 0.02 ± 0.02 and 0.02 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2), maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 5.33 kg, 1.25 kg, -2.08, 0.44 kg, 9.59 kg, 14.53 kg, 0.37 ± 0.06, 0.09 ± 0.03, -0.81, 0.03 ± 0.001 and 0.21 respectively.

4.2.3 Body weight at 6 months (6WT)

Variance components and genetic parameters estimated by different models for 6WT are presented in Table 4.7

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 7.76 kg, 17.68 kg, 25.44 kg and 0.31 ± 0.03 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 5.29 kg, 0.69 kg, 17.35 kg, 23.32 kg, 0.23 ± 0.03 and 0.03 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 11.09 kg, 4.41 kg, -6.06, 14.04 kg, 23.47 kg, 0.47 ± 0.06, 0.19 ± 0.03, -0.87 and 0.18 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 5.28 kg, 0.69 kg, 17.35 kg, 23.32 kg, 0.23 ± 0.03 and 0.03 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 5.29 kg, 0.34 kg, 0.34 kg, 17.35 kg, 23.32 kg, 0.23 ± 0.03, 0.02 ± 0.02 and 0.02 ± 0.00 respectively.

Table 4.5 Variance components and genetic parameters for BWT of Muzaffarnagari sheep

Trait: BWT	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
σ^2_a	0.09	0.05	**0.10**	0.05	0.05	0.10
σ^2_m	-	0.05	**0.11**	-	0.03	0.08
σ_{am}	-	-	**5 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**	-	-	0.10
c^2	-	-	-	0.16±0.02	0.08±0.002	0.08 ± 0.04
h^2_t	-	-	**-0.31**	-	-	-0.31
Log-L	279.28	291.79	**311.67**	291.79	291.79	311.67
BIC	-541.73	-558.35	**-589.69**	-558.35	-549.94	-581.27

Table 4.6 Variance components and genetic parameters for WWT of Muzaffarnagari sheep

Trait: WWT	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
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	17.02	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
Log-L	-7719.86	-7528.35	**-7519**	-7528.35	-7528.35	-7519
BIC	15456.39	15081.69	**15071.3**	15081.69	15090.02	15079.63

Table 4.7 Variance components and genetic parameters for 6WT of 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
Log-L	-7762.63	-7617.77	**-7583.14**	-7617.77	-7617.77	-7583.14
BIC	15541.7	15260.2	**15199.15**	15260.2	15268.41	15207.36

Table 4.8 Variance components and genetic parameters for 9WT of Muzaffarnagari sheep

Trait: 9WT	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
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
Log-L	-6811.12	-6690.45	**-6673.98**	-6690.45	-6690.45	-6673.98
BIC	13638.44	13405.19	**13380.34**	13405.19	13413.29	13388.44

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 11.09 kg, 3.86 kg, -6.06, 0.55 kg, 14.04 kg, 23.47 kg, 0.47 ± 0.06, 0.16 ± 0.03, -0.93, 0.02 ± 0.001 and 0.17 respectively.

4.2.4 Body weight at 9 months (9WT)

Variance components and genetic parameters estimated by different models for 9WT are presented in Table 4.8

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 6.68 kg, 17.31 kg, 23.99 kg and 0.28 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 4.02 kg, 0.41 kg, 17.52 kg, 21.95 kg, 0.18 ± 0.03 and 0.02 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 7.45 kg, 2.81 kg, -3.72, 15.48 kg, 22.02 kg, 0.34 ± 0.06, 0.13 ± 0.03, -0.81 and 0.15 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 4.02 kg, 0.41 kg, 17.52 kg, 21.95 kg, 0.18 ± 0.03 and 0.02 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 4.02 kg, 0.21 kg, 0.21 kg, 17.52 kg, 21.95 kg, 0.18 ± 0.03, 0.01 ± 0.00 and 0.01 ± 0.02 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 7.45 kg, 2.33 kg, -3.72, 0.48 kg, 15.49 kg, 22.02 kg, 0.34 ± 0.06, 0.11 ± 0.03, -0.89, 0.02 ± 0.001 and 0.14 respectively.

4.2.5 Body weight at 12 months (12WT)

Variance components and genetic parameters estimated by different models for 12WT are presented in Table 4.9

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 8.46 kg, 16.59 kg, 25.05 kg and 0.34 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 5.11 kg, 0.46 kg, 17.13 kg, 22.70 kg, 0.23 ± 0.04 and 0.02 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 9.44 kg, 3.00002 kg, -4.21, 14.60 kg, 22.83 kg, 0.41 ± 0.06, 0.13 ± 0.04, -0.79 and 0.2 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 5.10 kg, 0.46 kg, 17.13 kg, 22.70 kg, 0.23 ± 0.04 and 0.02 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 5.11 kg, 0.23 kg, 0.23 kg, 17.13 kg, 22.70 kg, 0.23 ± 0.04, 0.01 ± 0.02 and 0.01 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent

environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 9.44 kg, 2.44 kg, -4.20, 0.56 kg, 14.60 kg, 22.83 kg, 0.41 ± 0.06, 0.11 ± 0.04, -0.88, 0.03 ± 0.001 and 0.19 respectively.

4.2.6 Ewe's weight at service (EWTS)

Variance components and genetic parameters estimated by different models for EWTS are presented in Table 4.10

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 13.77 kg, 13.77 kg, 30.18 kg and 0.54 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 1.61 kg, 19.78 kg, 11.41 kg, 32.80 kg, 0.05 ± 0.02 and 0.60 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects (r_{am}) and total heritability (h^2_t) were 2.69 kg, 21.94 kg, -3.15, 10.53 kg, 32.01 kg, 0.08 ± 0.03, 0.69 ± 0.04, -0.41 and 0.28 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 1.61 kg, 19.51 kg, 11.18 kg, 32.30 kg, 0.05 ± 0.02 and 0.60 ± 0.02 respectively.

Table 4.9 Variance components and genetic parameters for 12WT of 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**	5.10	5.11	9.44
σ^2_m	-	0.46	**3.00**	-	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	**14.60**	17.13	17.13	14.60
σ^2_p	25.05	22.70	**22.83**	22.70	22.70	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	-	-	**0.20**	-	-	0.19
Log-L	-6037.71	-5926.42	**-5910.27**	-5926.42	-5926.42	-5910.27
BIC	12091.37	11876.76	**11852.42**	11876.76	11884.73	11860.39

Table 4.10 Variance components and genetic parameters for EWTS of Muzaffarnagari sheep

Trait: EWTS	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
σ^2_a	13.77	1.61	2.69	**1.61**	1.61	2.68
σ^2_m	-	19.78	21.94	-	9.76	5.51
σ_{am}	-	-	-3.15	-	-	-3.30
σ^2_c	-	-	-	**19.51**	9.76	16.60
σ^2_e	13.77	11.41	10.53	**11.18**	11.18	10.53
σ^2_p	30.18	32.80	32.01	**32.30**	32.30	32.02
h^2	0.54±0.04	0.05±0.02	0.08±0.03	**0.05±0.02**	0.05±0.02	0.08±0.03
m^2	-	0.60±0.02	0.69±0.04	-	0.30±0.03	0.17±0.05
r_{am}	-	-	-0.41	-	-	-0.86
c^2	-	-	-	**0.60±0.02**	0.30±0.01	0.52±0.02
h^2_t	-	-	0.28	-	-	0.02
Log-L	-5527.50	-5275.10	-4998.86	**-5000.07**	-5000.07	-4996.89
BIC	11070.72	10573.78	10028.94	**10023.56**	10031.38	10032.82

Table 4.11 Variance components and genetic parameters for EWTL of Muzaffarnagari sheep

Trait: EWTL	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	17.91	**0.78**	1.13	0.78	0.77	1.13
σ^2_m	-	**20.24**	21.67	-	10.12	3.97
σ_{am}	-	-	-1.74	-	-	-1.74
σ^2_c	-	-	-	20.24	10.12	17.70
σ^2_e	14.23	**12.72**	12.49	12.72	12.71	12.50
σ^2_p	32.14	**33.74**	33.55	33.74	33.74	33.55
h^2	0.56±0.04	**0.02±0.02**	0.03±0.02	0.02±0.02	0.02±0.02	0.03±0.02
m^2	-	**0.60±0.02**	0.65±0.04	-	0.30± 0.01	0.12±0.01
r_{am}	-	-	-0.35	-	-	-0.82
c^2	-	-	-	0.60±0.02	0.30±0.03	0.53±0.04
h^2_t	-	-	0.28	-	-	0.02
Log-L	-5296.85	**-5060.21**	-5059.13	-5060.21	-5060.21	-5059.13
BIC	10609.3	**10143.84**	10149.48	10143.84	10151.64	10157.28

Table 4.12 Variance components and genetic parameters for ADG1 of Muzaffarnagari sheep

Trait: ADG1	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	657.82	446.71	**605.10**	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**	-	-	-1.00
c^2	-	-	-	0.02±0.02	0.01±0.00	0.04±0.03
h^2_t	-	-	**0.22**	-	-	0.20
Log-L	-17505.17	-17334.16	**-17325.29**	-17334.16	-17334.16	-17325.29
BIC	35026.99	34693.29	**34683.89**	34693.29	34701.62	34692.22

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 1.61 kg, 9.76 kg, 9.76 kg, 11.18 kg, 32.30 kg, 0.05 ± 0.02, 0.30 ± 0.03 and 0.30 ± 0.01 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 2.68 kg, 5.51 kg, -3.30, 16.60 kg, 10.53 kg, 32.02 kg, 0.08 ± 0.03, 0.17 ± 0.05, -0.86, 0.52 ± 0.02 and 0.02 respectively.

4.2.7 Ewe's weight at lambing (EWTL)

Variance components and genetic parameters estimated by different models for EWTL are presented in Table 4.11

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 17.91 kg, 14.23 kg, 32.14 kg and 0.56 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 0.78 kg, 20.24 kg, 12.72 kg, 33.74 kg, 0.02 ± 0.02 and 0.60 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 1.13 kg, 21.67 kg, -1.74, 12.49 kg, 33.55 kg, 0.03 ± 0.02, 0.65 ± 0.04, -0.35 and 0.28 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 0.78 kg, 20.24 kg, 12.72 kg, 33.74 kg, 0.02 ± 0.02 and 0.60 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 0.77 kg, 10.12 kg, 10.12 kg, 12.71 kg, 33.74 kg, 0.02 ± 0.02, 0.30 ± 0.01 and 0.30 ± 0.03 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2), maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 1.13 kg, 3.97 kg, -1.74, 17.70 kg, 12.50 kg, 33.55 kg, 0.03 ± 0.02, 0.12 ± 0.01, -0.82, 0.53 ± 0.04 and 0.02 respectively.

4.2.8 Average daily gain from birth to 3 months (pre weaning) (ADG1)

Variance components and genetic parameters estimated by different models for ADG1 are presented in Table 4.12

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 657.82 kg, 1167.59 kg, 1825.41 kg and 0.36 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 446.71 kg, 25.72 kg, 1195.83 kg, 1668.26 kg, 0.27 ± 0.04 and 0.02 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance

(σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 605.10 kg, 133.17 kg, -210.34, 1128.23 kg, 1656.17 kg, 0.37 ± 0.06, 0.080 ± 0.03, -0.74 and 0.22 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 446.71 kg, 25.72 kg, 1195.83 kg, 1668.26 kg, 0.27 ± 0.04 and 0.02 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 446.76 kg, 12.87 kg, 12.87 kg, 1195.78 kg, 1668.28 kg, 0.27 ± 0.04, 0.01 ± 0.02 and 0.01 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2), maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 605.01 kg, 73.48 kg, -210.83, 59.93 kg, 1128.46 kg, 1656.04 kg, 0.37 ± 0.06, 0.04 ± 0.001, -1, 0.04 ± 0.03 and 0.2 respectively.

4.2.9 Average daily gain from 3 to 6 months (ADG2)

Variance components and genetic parameters estimated by different models for ADG2 are presented in Table 4.13

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 236.31 kg, 874.81 kg, 1111.11 kg and 0.21 ± 0.03 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 209.65 kg, 20.19 kg, 876.79 kg, 1106.63 kg, 0.19 ± 0.03 and 0.02 ± 0.01 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 504.009 kg, 173.65 kg, -263.44, 710.99 kg, 1125.22 kg, 0.45 ± 0.07, 0.15 ± 0.03, -0.89 and 0.18 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 209.65 kg, 20.19 kg, 876.79 kg, 1106.63 kg, 0.19 ± 0.03 and 0.02 ± 0.01 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 209.48 kg, 10.08 kg, 10.08 kg, 876.93 kg, 1106.58 kg, 0.19 ± 0.03, 0.01 ± 0.01 and 0.01 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 504.10 kg, 137.50 kg, -263.27, 35.99 kg, 710.91 kg, 1125.24 kg, 0.45 ± 0.07, 0.12 ± 0.03, -1, 0.03 ± 0.001 and 0.16 respectively.

4.2.10 Average daily gain from 6 to 9 months (ADG3)

Variance components and genetic parameters estimated by different models for ADG3 are presented in Table 4.14

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 54.46 kg, 608.10 kg, 662.56 kg and 0.08 ± 0.03 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 53.89 kg, 0.00 kg, 609.04 kg, 662.93 kg, 0.08 ± 0.03 and 0.00 ± 0.01 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 169.48 kg, 60.45 kg, -95.58, 538.04 kg, 672.39 kg, 0.25 ± 0.06, 0.09 ± 0.03, -0.94 and 0.08 respectively.

Table 4.13 Variance components and genetic parameters for ADG2 of Muzaffarnagari sheep

Trait: ADG2	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
σ^2_a	236.31	209.65	**504.01**	209.65	209.48	504.10
σ^2_m	-	20.19	**173.65**	-	10.08	137.50
σ_{am}	-	-	**-263.44**	-	-	-263.27
σ^2_c	-	-	-	20.19	10.08	36.00
σ^2_e	874.81	876.79	**711.00**	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**	-	-	-1.00
c^2	-	-	-	0.02±0.01	0.01± 0.00	0.03±0.001
h^2_t	-	-	**0.18**	-	-	0.16
Log-L	-17505.17	-17334.16	**-17325.29**	-17334.16	-17334.16	-17325.29
BIC	29294.71	29221.04	**29174.66**	29221.04	29229.24	29182.86

Table 4.14 Variance components and genetic parameters for ADG3 of Muzaffarnagari sheep

Trait: ADG3	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	54.46	53.89	**169.48**	53.89	53.88	169.54
σ^2_m	-	0.00	**60.45**	-	0.00	53.95
σ_{am}	-	-	**-95.58**	-	-	-95.62
σ^2_c	-	-	-	0.00	0.00	6.54
σ^2_e	608.10	609.04	**538.04**	609.04	609.05	538.00
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**	-	-	-1.00
c^2	-	-	-	0.00±0.01	0.00±0.00	0.01±0.03
h^2_t	-	-	**0.08**	-	-	0.08
Log-L	-11355.30	-11326.48	**-11317.70**	-11326.48	-11326.48	-11317.70
BIC	22726.72	22677.00	**22667.46**	22677.00	22685.01	22675.47

Table 4.15 Variance components and genetic parameters for ADG4 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	-	0.00	**42.49**	-	0.00	42.53
σ_{am}	-	-	**-83.74**	-	-	-83.78
σ^2_c	-	-	-	0.00	0.00	0.00
σ^2_e	565.77	569.48	**513.03**	569.48	569.48	513.01
σ^2_p	629.41	631.42	**636.80**	631.42	631.42	636.80
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}	-	-	**-1.00**	-	-	-1.00
c^2	-	-	-	0.00±0.01	0.00±0.00	0.00±0.03
h^2_t	-	-	**0.09**	-	-	0.09
Log-L	-9956.49	-9932.19	**-9920.51**	-9932.19	-9932.19	-9920.51
BIC	19928.76	19888.05	**19872.57**	19888.05	19895.94	19880.46

Table 4.16 Variance components and genetic parameters for ADG5 of Muzaffarnagari sheep

Trait: ADG5	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	48.52	45.46	**97.75**	45.46	45.50	97.72
σ^2_m	-	5.43	**37.18**	-	2.70	26.64
σ_{am}	-	-	**-51.02**	-	-	-51.01
σ^2_c	-	-	-	5.43	2.70	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**	-	-	-1.00
c^2	-	-	-	0.02±0.02	0.01±0.00	0.05±0.001
h^2_t	-	-	**0.17**	-	-	0.15
Log-L	-9335.50	-9309.00	**-9290.13**	-9309.00	-9309.00	-9290.13
BIC	18686.95	18641.91	**18612.14**	18641.91	18649.88	18620.11

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 53.89 kg, 0.01 kg, 609.04 kg, 662.93 kg, 0.08 ± 0.03 and 0.00 ± 0.01 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 53.88 kg, 0.00 kg, 0.00 kg, 609.05 kg, 662.93 kg, 0.08 ± 0.03, 0.00 ± 0.01 and 0.00 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2), maternal heritability (m^2), genetic correlation between additive and maternal genetic effects (r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 169.54

kg, 53.95 kg, -95.62, 6.54 kg, 537.99 kg, 672.39 kg, 0.25 ± 0.06, 0.08 ± 0.002, -1, 0.01 ± 0.03 and 0.08 respectively.

4.2.11 Average daily gain from 9 to 12 months (ADG4)

Variance components and genetic parameters estimated by different models for ADG4 are presented in Table 4.15

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 63.64 kg, 565.77 kg, 624.41 kg and 0.10 ± 0.03 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 61.94 kg, 0.00 kg, 569.48 kg, 631.42 kg, 0.10 ± 0.03 and 0.00 ± 0.01 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 165.02 kg, 42.49 kg, -83.74, 513.03 kg, 636.79 kg, 0.26 ± 0.06, 0.07 ± 0.03, -1 and 0.09 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 61.94 kg, 0.001 kg, 569.48 kg, 631.42 kg, 0.10 ± 0.03 and 0.00 ± 0.01 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 61.94 kg, 0.00 kg, 0.001 kg, 569.48 kg, 631.42 kg, 0.10 ± 0.03, 0.00 ± 0.01 and 0.00 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 165.04 kg, 42.53 kg, -83.78, 0.001 kg, 513.01 kg, 636.80 kg, 0.26 ± 0.06, 0.07 ± 0.002, -1, 0.00 ± 0.03 and 0.09 respectively.

4.2.12 Average daily gain from 3 to 12 months (ADG5)

Variance components and genetic parameters estimated by different models for ADG5 are presented in Table 4.16

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 48.2 kg, 185.01 kg, 233.52 kg and 0.21 ± 0.03 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 45.46 kg, 5.43 kg, 183.33 kg, 234.22 kg, 0.19 ± 0.04 and 0.02 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 97.75 kg, 37.18 kg, -51.02, 152.67 kg, 236.58 kg, 0.41 ± 0.07, 0.16 ± 0.04, -0.85 and 0.17 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 45.46 kg, 5.43 kg, 183.33 kg, 234.22 kg, 0.19 ± 0.04 and 0.02 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 45.50 kg, 2.70 kg, 2.70 kg, 183.32 kg, 234.22 kg, 0.19 ± 0.04, 0.01 ± 0.02 and 0.01 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 97.72 kg, 26.64 kg, -51.01, 10.54 kg, 152.69 kg, 236.58 kg, 0.41 ± 0.07, 0.11 ± 0.04, -1, 0.05 ± 0.001 and 0.15 respectively.

4.2.13 Relative growth rate from birth to 3 months (pre weaning) (RGR1)

Variance components and genetic parameters estimated by different models for RGR1 are presented in Table 4.17

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 4147.48 kg, 10635.5 kg, 14783 kg and 0.28 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 3913.46 kg, 193.06 kg, 10654.7 kg, 14761.2 kg, 0.27 ± 0.04 and 0.01 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 4553.02 kg, 694.64 kg, -1094.90, 10473.3 kg, 14626.00 kg, 0.31 ± 0.06, 0.05 ± 0.02, -0.62 and 0.22 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 3913.46 kg, 193.06 kg, 10654.7 kg, 14761.2 kg, 0.27 ± 0.04 and 0.01 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 3906.06 kg, 96.28 kg, 96.28 kg, 10660.2 kg, 14758.8 kg, 0.27 ± 0.04, 0.01 ± 0.00 and 0.01 ± 0.02 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 4553.54 kg, 262.89 kg, -1094.05, 431.18 kg, 10472.8 kg, 14626.3 kg, 0.31 ± 0.06, 0.02 ± 0.00, -1, 0.03 ± 0.02 and 0.21 respectively.

4.2.14 Relative growth rate from 3 to 6 months (RGR2)

Variance components and genetic parameters estimated by different models for RGR2 are presented in Table 4.18

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 64.35 kg, 387.31 kg, 451.67 kg and 0.14 ± 0.03 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 68.29 kg, 3.15 kg, 375.67 kg, 447.11 kg, 0.15 ± 0.03 and 0.01 ± 0.01 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance

(σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 146.34 kg, 34.82 kg, -58.32, 331.41 kg, 454.25 kg, 0.32 ± 0.07, 0.08 ± 0.03, -0.82 and 0.17 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 68.31 kg, 3.15 kg, 375.65 kg, 447.12 kg, 0.15 ± 0.03 and 0.01 ± 0.01 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 68.31 kg, 1.57 kg, 1.57 kg, 375.66 kg, 447.11 kg, 0.15 ± 0.03, 0.004 ± 0.00 and 0.004 ± 0.01 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2), maternal heritability (m^2), genetic correlation between additive and maternal genetic effects (r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 146.43 kg, 23.30 kg, -58.37, 11.54 kg, 331.37 kg, 454.26 kg, 0.32 ± 0.07, 0.05 ± 0.001, -0.99, 0.03 ± 0.03 and 0.16 respectively.

Table 4.17 Variance components and genetic parameters for RGR1 of Muzaffarnagari sheep

Trait: RGR1	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
σ^2_a	4147.48	**3913.46**	4553.02	3913.46	3906.06	4553.54
σ^2_m	-	**193.055**	694.638	-	96.275	262.892
σ_{am}	-	-	-1094.9	-	-	-1094.05
σ^2_c	-	-	-	193.055	96.275	431.183
σ^2_e	10635.5	**10654.7**	10473.3	10654.7	10660.2	10472.8
σ^2_p	14783	**14761.2**	14626	14761.2	14758.8	14626.3
h^2	0.28±0.04	**0.27±0.04**	0.31±0.06	0.27±0.04	0.27±0.04	0.31±0.06
m^2	-	**0.01± 0.02**	0.05±0.02	-	0.01±0.00	0.02±0.00
r_{am}	-	-	-0.62	-	-	-1
c^2	-	-	-	0.01±0.02	0.01± 0.02	0.03±0.02
h^2_t	-	-	0.22	-	-	0.21
Log-L	-21900.5	**-21843.1**	-21840.2	-21843.1	-21843.1	-21840.2

Table 4.18 Variance components and genetic parameters for RGR2 of Muzaffarnagari sheep

Trait: RGR2	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
σ^2_a	64.35	**68.29**	146.34	68.31	68.31	146.43
σ^2_m	-	**3.15**	34.82	-	1.57	23.3
σ_{am}	-	-	-58.32	-	-	-58.37
σ^2_c	-	-	-	3.15	1.57	11.54
σ^2_e	387.31	**375.67**	331.41	375.65	375.66	331.37
σ^2_p	451.67	**447.11**	454.25	447.12	447.11	454.26
h^2	0.14±0.03	**0.15±0.03**	0.32±0.07	0.15±0.03	0.15±0.03	0.32±0.07
m^2	-	**0.01±0.014**	0.08±0.03	-	0.004±0.00	0.05±0.001
r_{am}	-	-	-0.82	-	-	-0.99
c^2	-	-	-	0.01±0.01	0.004±0.01	0.03±0.03
h^2_t	-	-	0.17	-	-	0.16
Log-L	-13022.1	**-12963.4**	-12955.2	-12963.4	-12963.4	-12955.2
BIC	26060.62	**25951.38**	25943.22	25951.38	25959.58	25951.42

Table 4.19 Variance components and genetic parameters for RGR3 of Muzaffarnagari sheep

Trait: RGR3	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	9.45	9.75	**44.4**	140	9.76	44.4
σ^2_m	-	0	**14.76**	-	0	14.14
σ_{am}	-	-	**-25.05**	-	-	-25.06
σ^2_c	-	-	-	0	0	0.62
σ^2_e	141.13	140	**118.88**	140	140	118.88
σ^2_p	150.58	149.75	**152.98**	149.75	149.76	152.98
h^2	0.06±0.02	0.07±0.03	**0.29±0.07**	0.07±0.03	0.07±0.03	0.29 ±0.07
m^2	-	0.00±0.01	**0.10±0.03**	-	0.00±0.01	0.09±0.03
r_{am}	-	-	**-0.98**	-	-	-1
c^2	-	-	-	0.00±0.01	0.00±0.00	0.004±0.00
h^2_t	-	-	**0.09**	-	-	0.09
Log-L	-9118.38	-9088.21	**-9077.13**	-9088.21	-9088.21	-9077.13
BIC	18252.78	18200.46	**18186.32**	18200.46	18208.48	18194.33

Table 4.20 Variance components and genetic parameters for RGR4 of Muzaffarnagari sheep

Trait: RGR4	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	8.87	9.01	**75.89**	9.01	9.01	26.66
σ^2_m	-	0	**6.59**	0	0	6.6
σ_{am}	-	-	**75.89**	-	-	-13.26
σ^2_c	-	-	-	0	0	0
σ^2_e	85.9	85.71	**75.89**	85.71	85.71	75.89
σ^2_p	94.77	94.72	**95.89**	94.72	94.73	95.89
h^2	0.09±0.03	0.10±0.03	**0.28±0.07**	0.10±0.03	0.10±0.03	0.28±0.07
m^2	-	0.00±0.02	**0.07±0.03**	-	0.00±0.00	0.07±0.03
r_{am}	-	-	**-1**	-	-	-1
c^2	-	-	-	0.00 ±0.02	0.00±0.02	0.00±0.00
h^2_t	-	-	**0.1**	-	-	0.1
Log-L	-7432.28	-7409.05	**-7397.58**	-7409.05	-7409.06	-7397.58
BIC	14880.33	14841.77	**14826.71**	14841.77	14849.66	14834.6

4.2.15 Relative growth rate from 6 to 9 months (RGR3)

Variance components and genetic parameters estimated by different models for RGR3 are presented in Table 4.19

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 9.45 kg, 141.13 kg, 150.58 kg and 0.06 ± 0.02 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 9.75 kg, 0.00 kg, 140 kg, 149.75 kg, 0.07 ± 0.03 and 0.00 ± 0.01 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 44.39 kg, 14.76 kg, -25.05, 118.88 kg, 152.98 kg, 0.29 ± 0.07, 0.10 ± 0.03, -0.98 and 0.09 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 140.004 kg, 0.001 kg, 140.004 kg, 149.75 kg, 0.07 ± 0.03 and 0.00 ± 0.01 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 9.76 kg, 0.00 kg, 0.001 kg, 139.99 kg, 149.76 kg, 0.07 ± 0.03, 0.00 ± 0.01 and 0.00 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent

environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 44.40 kg, 14.14 kg, -25.06, 0.62 kg, 118.88 kg, 152.98 kg, 0.29 ± 0.07, 0.09 ± 0.03, -1, 0.004 ± 0.00 and 0.09 respectively.

4.2.16 Relative growth rate from 6 to 9 months (RGR4)

Variance components and genetic parameters estimated by different models for RGR4 are presented in Table 4.20

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 8.87 kg, 85.90 kg, 94.77 kg and 0.09 ± 0.03 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 9.01 kg, 0.00 kg, 85.71 kg, 94.72 kg, 0.10 ± 0.03 and 0.00 ± 0.01 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 75.89 kg, 6.59 kg, -1 , 75.89 kg, 95.89 kg, 0.28 ± 0.07, 0.07 ± 0.03, -1 and 0.1 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 9.01 kg, 0.00 kg, 0.001 kg, 85.71 kg, 94.73 kg, 0.10 ± 0.03, 0.00 ± 0.00 and 0.00 ± 0.02 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent

environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 26.66 kg, 6.60 kg, -13.26, 0.00 kg, 75.89 kg, 95.89 kg, 0.28 ± 0.07, 0.07 ± 0.03, -1, 0.00 ± 0.00 and 0.1 respectively.

4.2.17 Relative growth rate from 3 to 12 months (RGR5)

Variance components and genetic parameters estimated by different models for RGR5 are presented in Table 4.21.

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 294.18 kg, 1165.23 kg, 1459.40 kg and 0.20 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 316.36 kg, 25.71 kg, 1091.31 kg, 1433.38 kg, 0.22 ± 0.04 and 0.02 ± 0.02 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 704.77 kg, 246.03 kg, -354.44, 865.33 kg, 1461.68 kg, 0.48 ± 0.08, 0.17 ± 0.04, -0.85 and 0.21 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 316.31 kg, 25.71 kg, 1091.35 kg, 1433.36 kg, 0.22 ± 0.04 and 0.02 ± 0.02 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 316.30 kg, 12.86 kg, 12.86 kg, 1091.35 kg, 1433.36 kg, 0.22 ± 0.04, 0.01 ± 0.00 and 0.01 ± 0.02 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 704.77 kg, 178.99 kg, -354.56, 67.15 kg, 865.33 kg, 1461.68 kg, 0.48 ± 0.08, 0.12 ± 0.004, -0.99, 0.05 ± 0.04 and 0.18 respectively.

4.3 Genetic parameters for reproduction traits using REML

4.3.1 Age at first lambing (AFL)

Variance components and genetic parameters estimated by different models for AFL are presented in Table 4.23

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 9177.45 kg, 100097.00 kg, 109274.00 kg and 0.08 ± 0.05 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 2576670 kg, 2603910 kg, 2482030 kg, 7662610 kg, 0.34 ± 0.10 and 0.34 ± 0.10 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , and total heritability (h^2_t) were 52505.80 kg, 31857.70 kg, -40891.80, 67056.90 kg, 110529.00 kg, 0.48 ± 0.02, 0.29 ± 0.07, -1 and 0.06 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability

(h^2) and maternal permanent environmental heritability (c^2) were 17.93 kg, 1832.53 kg, 36831.10 kg, 38681.10 kg, 0.00 ± 0.05 and 0.05 ± 0.04 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), and maternal permanent environmental heritability (c^2) were 82.00 kg, 42.79 kg, 1787.54 kg, 36774.80 kg, 38687.10 kg, 0.002 ± 0.04, 0.001 ± 0.04 and 0.05 ± 0.002 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 37408.20 kg, 6802.58 kg, -15952.10, 2571.61 kg, 17216.40 kg, 48046.60 kg, 0.78 ± 0.14, 0.14 ± 0.07, -1, 0.05 ± 0.07 and 0.04 respectively.

Table 4.21 Variance components and genetic parameters for RGR5 of Muzaffarnagari sheep

Trait: RGR5	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
σ^2_a	294.18	316.36	**704.77**	316.31	316.3	704.77
σ^2_m	-	25.71	**246.03**	-	12.86	178.99
σ_{am}	-	-	**-354.44**	-	-	-354.56
σ^2_c	-	-	-	25.71	12.86	67.15
σ^2_e	1165.23	1091.31	**865.33**	1091.35	1091.35	865.33
σ^2_p	1459.4	1433.38	**1461.68**	1433.36	1433.36	1461.68
h^2	0.20±0.04	0.22±0.04	**0.48±0.08**	0.22±0.04	0.22±0.04	0.48±0.08
m^2	-	0.02±0.02	**0.17±0.04**	-	0.01±0.00	0.12±0.004
r_{am}	-	-	**-0.85**	-	-	-0.1
c^2	-	-	-	0.02±0.02	0.01±0.02	0.05±0.04
h^2_t	-	-	**0.21**	-	-	0.18
Log-L	-11996	-11920.8	**-11904**	-11920.8	-11920.8	-11904
BIC	24008.02	23865.44	**23839.79**	23865.44	23873.41	23847.76

Table 4.22 Variance components and genetic parameters for AFS of Muzaffarnagari sheep

Trait: AFS	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
σ^2_a	**0.66**	0.7	1640.77	0.7	0.02	25050.5
σ^2_m	-	183.14	2114.39	-	105.67	4051.42
σ_{am}	-	-	-1862.57	-	-	-10074.2
σ^2_c	-	-	-	183.14	105.67	1205.75
σ^2_e	**34139.1**	33958.5	32261.1	33958.5	33931.5	19589.2
σ^2_p	**34139.8**	34142.4	2114.39	34142.4	34142.8	39822.8
h^2	**0.00±0.04**	0.0± 0.04	0.045±0.06	0.0± 0.04	0.0±0.04	0.63±0.13
m^2	-	0.005±0.04	0.062±0.06	-	0.003±0.04	0.102±0.01
r_{am}	-	-	-1	-	-	-1
c^2	-	-	-	0.005±0.04	0.003±0.0	0.03±0.07
h^2_t	-	-	0.04	-	-	0.3
Log-L	**-6162.47**	-6162.46	-6161.55	-6162.46	-6162.46	-6219.24
BIC	**12338.9**	12345.85	12351.01	12345.85	12352.83	12473.39

Table 4.23 Variance components and genetic parameters for AFL of Muzaffarnagari sheep

Trait: AFL	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
σ^2_a	9177.45	**2576670**	52505.8	17.93	82	37408.2
σ^2_m	-	**2603910**	31857.7	-	42.79	6802.58
σ_{am}	-	-	-40891.8	-	-	-15952.1
σ^2_c	-	-	-	1832.53	1787.54	2571.61
σ^2_e	100097	**2482030**	67056.9	36831.1	36774.8	17216.4
σ^2_p	109274	**7662610**	110529	38681.5	38687.1	48046.6
h^2	0.08±0.05	**0.34±0.10**	0.48 ± 0.02	0.00±0.05	0.002±0.04	0.78±0.14
m^2	-	**0.34±0.10**	0.288 ±0.07	-	0.001±0.04	0.14±0.07
r_{am}	-	-	-1.00	-	-	-1.00
c^2	-	-	-	0.05±0.04	0.05±0.002	0.05±0.07
h^2_t	-	-	0.06	-	-	0.04
Log-L	-6910.82	**-4291.57**	-6890.63	-5945.56	-5945.57	-6025.61
BIC	13835.64	**8602.02**	13809.26	11911.92	11918.87	12085.92

Table 4.24 Variance components and genetic parameters for LS of Muzaffarnagari sheep

Trait: LS	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	188710	199804	79181	2277170	2313670	**219994**
σ^2_m	-	2260.7	1942.13	-	2354080	**31463.4**
σ_{am}	-	-	-12375.2	-	-	**-83197**
σ^2_c	-	-	-	2296860	2354080	**1252.8**
σ^2_e	32510.7	22474.2	139804	2180670	2230480	**27068.3**
σ^2_p	221221	224539	208552	6754700	9252300	**196581**
h^2	0.853±0.04	0.890±0.03	0.380±0.02	0.337±0.01	0.250±0.01	**0.59±0.24**
m^2	-	0.01±0.0	0.009±0.0	-	0.254±0.01	**0.16±0.01**
r_{am}	-	-	-0.99	-	-	**-1**
c^2	-	-	-	0.34±0.01	0.254±0.01	**0.006±0.00**
h^2_t	-	-	0.34	-	-	**0.56**
Log-L	-3555.66	-3555.41	-3571.25	-4238.23	-4308.75	**-3529.95**
BIC	7123.91	7129.68	7167.66	8495.34	8642.67	**7091.35**

4.3.2 Age at first service (AFS)

Variance components and genetic parameters estimated by different models for AFS are presented in Table 4.22

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 0.66 kg, 34139.1 kg, 34139.8 kg and 0.00 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 0.70 kg, 183.14 kg, 33958.5 kg, 34142.4 kg, 0.00 ± 0.04 and 0.01 ± 0.04 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were

1640.77 kg, 2114.39 kg, -1862.57, 32261.1 kg, 2114.39 kg, 0.05 ± 0.06, 0.06 ± 0.06, -1 and 0.04 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 0.70 kg, 183.14 kg, 33958.5 kg, 34142.4 kg, 0.00 ± 0.04 and 0.005 ± 0.04 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 0.02 kg, 105.67 kg, 105.67 kg, 33931.5 kg, 34142.8 kg, 0.00 ± 0.04, 0.003 ± 0.04 and 0.003 ± 0.00 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects (r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 25050.5 kg, 4051.42 kg, -10074.2, 1205.75 kg, 19589.2 kg, 39822.8 kg, 0.63 ± 0.13, 0.10 ± 0.01, -1, 0.03 ± 0.07 and 0.30 respectively.

4.3.3 Litter size (LS)

Variance components and genetic parameters estimated by different models for LS are presented in Table 4.24

In model 1, the estimate of additive genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) were 188710.00 kg, 32510.70 kg, 221221.00 kg and 0.85 ± 0.04 respectively.

In model 2, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal heritability (m^2) were 199804.00 kg, 2260.70 kg, 22474.20 kg, 224539.00 kg, 0.89 ± 0.03 and 0.01 ± 0.00 respectively.

In model 3, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}) and total heritability (h^2_t) were 79181.00 kg, 1942.13 kg, -12375.20, 139804.00 kg, 208552.00 kg, 0.38 ± 0.02, 0.009 ± 0.00, -0.99 and 0.34 respectively.

In model 4, the estimate of additive genetic variance (σ^2_a), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) and maternal permanent environmental heritability (c^2) were 2277170.00 kg, 2296860.00 kg, 2180670.00 kg, 6754700.00 kg, 0.25 ± 0.01 and 0.25 ± 0.01 respectively.

In model 5, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2) and maternal permanent environmental heritability (c^2) were 2313670.00 kg, 2354080.00 kg, 2354080.00 kg, 2230480.00 kg, 9252300.00 kg, 0.25 ± 1, 0.25 ± 1and 0.25 ± 1 respectively.

In model 6, the estimate of additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), direct heritability (h^2) , maternal heritability (m^2), genetic correlation between additive and maternal genetic effects(r_{am}), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were 219994.00 kg, 31463.40 kg, -83197.00, 1252.80 kg, 27068.30 kg, 196581.00 kg, 1.12 ± 0.05, 0.16 ± 0.01, -1, 0.006 ± 0.00 and 0.56 respectively.

4.4 Genetic and phenotypic correlations among different traits

Genetic and phenotypic correlations among various traits were given in the Table from 4.25 to 4.33

4.4.1 Correlations of birth weight (BWT) with other traits

The genetic and phenotypic correlation among growth traits are indicated in the Table 4.25 to 4.30. The genetic correlations of BWT with WWT, 6WT, 9WT, 12WT, ADG1,

ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.41 ± 0.08, 0.31 ± 0.09, 0.39 ± 0.09, 0.23 ± 0.02, 0.27 ± 0.09, 0.14 ± 0.10, -0.04 ± 0.16, 0.05 ± 0.15, 0.03 ± 0.11, -0.17 ± 0.09, -0.01 ± 0.11, - 0.19 ± 0.6, -0.14 ± 0.14 and -0.20 ± 0.10 respectively.

The phenotypic correlations of BWT with WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.33 ± 0.02, 0.29 ± 0.02, 0.28 ± 0.02, 0.33 ± 0.09, 0.18 ± 0.02, 0.07 ± 0.02, 0.01 ± 0.02, -0.01 ± 0.02, -0.01 ± 0.02, -0.31 ± 0.02, -0.10 ± 0.02, -0.07 ± 0.02, -0.09 ± 0.02 and -0.19 ± 0.02 respectively.

4.4.2 Correlations of weaning weight (WWT) with other traits

The genetic correlations of WWT with BWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.41 ± 0.08, 0.88 ± 0.03, 0.77 ± 0.0, 0.70 ± 0.06, 0.99 ± 0.002, 0.38 ± 0.10, -0.58 ± 0.12, 0.04 ± 0.15, -0.13 ± 0.11, 0.80 ± 0.04, -0.31 ± 0.10, -0.91 ± 0.08, -0.31 ± 0.13 and -0.72 ± 0.05 respectively.

The phenotypic correlations of WWT with BWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.33 ± 0.02, 0.80 ± 0.01, 0.68 ± 0.01, 0.58 ± 0.01, 0.99 ± 0.00, 0.17 ± 0.02, -0.23 ± 0.02, -0.06 ± 0.02, -0.21 ± 0.02, 0.77 ± 0.01, -0.42 ± 0.02, -0.44 ± 0.02, -0.24 ± 0.02 and -0.73 ± 0.01 respectively.

4.4.3 Correlations of 6 months weight (6WT) with other traits

The genetic correlations of 6WT with BWT, WWT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.31 ± 0.09, 0.88 ± 0.03, 0.90 ± 0.02, 0.73 ± 0.05, 0.88 ± 0.002, 0.79 ± 0.04, -0.37 ± 0.14, -0.03 ± 0.15, 0.22 ± 0.11, 0.73 ± 0.05, 0.35 ± 0.10, -0.78 ± 0.09, -0.36 ± 0.13 and -0.29 ± 0.10 respectively.

The phenotypic correlations of 6WT with BWT, WWT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.29 ± 0.02, 0.80 ± 0.01, 0.84 ± 0.01, 0.70 ± 0.01, 0.79 ± 0.01, 0.74 ± 0.01, -0.21 ± 0.02, -0.11 ± 0.02, 0.20 ± 0.02, 0.61 ± 0.01, 0.27 ± 0.02, -0.51 ± 0.01, -0.34 ± 0.02 and -0.32 ± 0.02 respectively.

Table 4.25 Genetic (above diagonal) and phenotypic (below diagonal) correlation among growth traits

	BWT	WWT	6WT	9WT	12WT	ADG1	ADG2	ADG3	ADG4	ADG5	RGR1	RGR2	RGR3	RGR4	RGR5
BWT		0.41 ±0.08	0.31 ±0.09	0.39 ±0.09	0.23 ±0.02	0.27 ±0.09	0.14 ±0.10	-0.04 ±0.16	0.05 ±0.15	0.03 ±0.11	-0.17 ±0.09	-0.01 ±0.11	-0.19 ±0.16	-0.14 ±0.14	-0.20 ±0.10
WWT	0.33 ±0.02		0.88 ±0.03	0.77 ±0.05	0.70 ±0.06	0.99 ±0.002	0.38 ±0.10	-0.58 ±0.12	0.04 ±0.15	-0.13 ±0.11	0.80 ±0.04	-0.31 ±0.10	-0.91 ±0.08	-0.31 ±0.13	-0.72 ±0.05
6WT	0.29 ±0.02	0.80 ±0.01		0.90 ±0.02	0.73 ±0.05	0.88 ±0.03	0.79 ±0.04	-0.37 ±0.14	-0.03 ±0.15	0.22 ±0.11	0.73 ±0.05	0.35 ±0.10	-0.78 ±0.09	-0.36 ±0.13	-0.29 ±0.10
9WT	0.28 ±0.02	0.68 ±0.01	0.84 ±0.01		0.91 ±0.03	0.74 ±0.05	0.79 ±0.05	0.13 ±0.16	-0.04 ±0.16	0.60 ±0.09	0.53 ±0.08	0.43 ±0.11	-0.36 ±0.18	-0.41 ±0.14	-0.03 ±0.03
12WT	0.33 ±0.09	0.58 ± 0.01	0.70 ±0.01	0.84 ±0.01		0.68 ±0.06	0.62 ±0.08	0.19 ±0.16	0.34 ±0.14	0.74 ±0.05	0.50 ±0.09	0.28 ±0.12	-0.22 ±0.17	0.34 ±0.14	0.23 ±0.11
ADG1	0.18 ±0.02	0.99 ±0.00	0.79 ±0.01	0.67 ±0.01	0.57 ±0.01		0.37 ±0.10	-0.59 ±0.12	0.04 ±0.15	-0.14 ±0.11	0.87 ±0.03	-0.32 ±0.11	-0.91 ±0.08	-0.29 ±0.13	-0.72 ±0.05
ADG2	0.07 ±0.02	0.17 ±0.02	0.74 ±0.01	0.63 ±0.01	0.51 ±0.02	0.17 ±0.02		-0.09 ±0.17	-0.16 ±0.16	0.52 ±0.09	0.28 ±0.11	0.84 ±0.04	-0.46 ±0.14	-0.41 ±0.14	0.23 ±0.11
ADG3	0.01 ±0.02	-0.23 ±0.02	-0.21 ±0.02	0.32 ±0.02	0.24 ±0.02	-0.24 ±0.02	-0.08 ±0.02		0.06 ±0.21	0.76 ±0.11	-0.59 ±0.12	0.30 ±0.19	0.90 ±0.04	0.04 ±0.21	0.88 ±0.08
ADG4	-0.01 ±0.02	-0.06 ±0.02	-0.11 ±0.02	-0.16 ±0.02	0.35 ±0.02	-0.06 ±0.02	-0.10 ±0.02	-0.06 ±0.02		0.36 ±0.14	0.05 ±0.16	-0.16 ±0.17	0.06 ±0.23	0.91 ±0.03	0.22 ±0.15
ADG5	-0.01 ±0.02	-0.21 ±0.02	0.20 ±0.02	0.50 ±0.02	0.75 ±0.01	-0.22 ±0.02	0.50 ±0.02	0.47 ±0.02	0.47 ±0.02		-0.18 ±0.12	0.61 ±0.09	0.42 ±0.16	0.09 ±0.17	0.82 ±0.04
RGR1	-0.31 ±0.02	0.77 ±0.01	0.61 ±0.01	0.46 ±0.02	0.39 ±0.02	0.85 ±0.01	0.12 ±0.02	-0.24 ±0.02	-0.06 ±0.02	-0.22 ±0.02		-0.35 ±0.11	-0.84 ±0.09	-0.19 ±0.15	-0.65 ±0.07
RGR2	-0.10 ±0.02	-0.42 ±0.02	0.27 ±0.02	0.22 ±0.02	0.17 ±0.02	-0.42 ±0.02	0.82 ±0.01	0.03 ±0.02	-0.05 ±0.02	0.53 ±0.01	-0.35 ±0.02		0.13 ±0.20	-0.19 ±0.17	0.65 ±0.07
RGR3	-0.07 ±0.02	-0.44 ±0.02	-0.51 ±0.01	-0.01 ±0.02	-0.02 ±0.02	-0.45 ±0.02	-0.32 ±0.02	0.91 ±0.003	0.001 ±0.02	0.32 ±0.02	-0.40 ±0.02	-0.06 ±0.02		0.22 ±0.22	0.90 ±0.10
RGR4	-0.09 ±0.02	-0.24 ±0.02	-0.34 ±0.02	-0.43 ±0.02	0.36 ±0.02	-0.24 ±0.02	-0.26 ±0.02	-0.14 ±0.02	0.93 ±0.003	0.27 ±0.02	-0.18 ±0.02	-0.11 ±0.02	0.01 ±0.02		0.19 ±0.15
RGR5	-0.19 ±0.02	-0.73 ±0.01	-0.32 ±0.02	-0.002 ±0.02	0.24 ±0.02	-0.73 ±0.01	0.27 ±0.02	0.47 ±0.02	0.37 ±0.02	0.79 ±0.01	-0.61 ±0.01	0.64 ±0.01	0.51 ±0.02	0.33 ±0.02	

4.4.4 Correlations of 9 months weight (9WT) with other traits

The genetic correlations of 9WT with BWT, WWT, 6WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.39 ± 0.09, 0.77 ± 0.05, 0.90 ± 0.02, 0.91 ± 0.03, 0.74 ± 0.05, 0.79 ± 0.05, 0.13 ± 0.16, -0.04 ± 0.16, 0.60 ± 0.09, 0.53 ± 0.08, 0.43 ± 0.11, -0.36 ± 0.18, -0.41 ± 0.14 and -0.03 ± 0.03 respectively.

The phenotypic correlations of 9WT with BWT, WWT, 6WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.28 ± 0.02, 0.68 ± 0.01, 0.84 ± 0.01, 0.84 ± 0.01, 0.67 ± 0.01, 0.63 ± 0.01, 0.32 ± 0.02, -0.16 ± 0.02, 0.50 ± 0.02, 0.46 ± 0.02, 0.22 ± 0.02, -0.01 ± 0.02, -0.43 ± 0.02 and -0.002 ± 0.02 respectively.

4.4.5 Correlations of 12 months weight (12WT) with other traits

The genetic correlations of 12WT with BWT, WWT, 6WT, 9WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.23 ± 0.02, 0.70 ± 0.06, 0.73 ± 0.05, 0.91 ± 0.03, 0.68 ± 0.06, 0.62 ± 0.08, 0.19 ± 0.16, 0.34 ± 0.14, 0.74 ± 0.05, 0.50 ± 0.09, 0.28 ± 0.12, -0.22 ± 0.17, 0.34 ± 0.14 and 0.23 ± 0.11 respectively.

The phenotypic correlations of 12WT with BWT, WWT, 6WT, 9WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.33 ± 0.09, 0.58 ± 0.01, 0.70 ± 0.0, 0.84 ± 0.01, 0.57 ± 0.01, 0.51 ± 0.02, 0.24 ± 0.02, 0.36 ± 0.02, 0.75 ± 0.01, 0.39 ± 0.02, 0.17 ± 0.02, -0.02 ± 0.02, 0.36 ± 0.02 and 0.24 ± 0.02 respectively.

4.4.6 Correlations of ewe’s weight at service (EWTS) with other traits

The genetic correlations of EWTS with BWT, WWT, 6WT, 9WT, 12WT and EWTL were 0.60 ± 0.06, 0.56 ± 0.06, 0.54 ± 0.07, 0.67 ± 0.07, 0.69 ± 0.06 and 0.89 ± 0.02 respectively

The phenotypic correlations of EWTS with BWT, WWT, 6WT, 9WT, 12WT and EWTL were 0.28 ± 0.02, 0.25 ± 0.02, 0.22 ± 0.02, 0.25 ± 0.02, 0.26 ± 0.02 and 0.71 ± 0.01 respectively.

4.4.7 Correlations of ewe's weight at lambing (EWTL) with other traits

The genetic correlations of EWTL with BWT, WWT, 6WT, 9WT, 12WT and EWTS were 0.64 ± 0.06, 0.62 ± 0.06, 0.55 ± 0.07, 0.65 ± 0.07, 0.70 ± 0.06 and 0.89 ± 0.02 respectively

Table 4.26 Estimates of Genetic (above diagonal) and phenotypic (below diagonal) correlation among body weight traits

	BWT	WWT	6WT	9WT	12WT	EWTS	EWTL
BWT		0.41±0.08	0.31±0.09	0.39±0.09	0.23±0.02	0.60±0.06	0.64±0.06
WWT	0.33±0.02		0.88±0.03	0.77±0.05	0.70±0.06	0.56±0.06	0.62±0.06
6WT	0.29±0.02	0.80±0.01		0.90±0.02	0.730±0.05	0.54±0.07	0.55±0.07
9WT	0.28±0.02	0.68±0.01	0.84±0.01		0.91±0.03	0.67±0.07	0.65±0.07
12WT	0.33±0.09	0.58±0.01	0.70±0.01	0.84±0.01		0.69±0.06	0.70±0.06
EWTS	0.28±0.02	0.25±0.02	0.22±0.02	0.25±0.02	0.26±0.02		0.89±0.02
EWTL	0.40±0.02	0.36±0.02	0.26±0.02	0.26±0.02	0.26±0.02	0.71±0.01	

Table 4.27 Estimates of Genetic (above diagonal) and phenotypic (below diagonal) correlation among ADG

	ADG1	ADG2	ADG3	ADG4	ADG5
ADG1		0.37±0.10	-0.59±0.12	0.04±0.15	-0.14±0.11
ADG2	0.17± 0.02		-0.09±0.17	-0.16±0.16	0.52±0.09
ADG3	-0.24±0.02	-0.08±0.02		0.06±0.21	0.76±0.11
ADG4	-0.06±0.02	-0.10±0.02	-0.06±0.02		0.36±0.14
ADG5	-0.22±0.02	0.50±0.02	0.46±0.02	0.47±0.02	

Table 4.28 Estimates of Genetic (above diagonal) and phenotypic (below diagonal) correlation among RGR

	RGR1	RGR2	RGR3	RGR4	RGR5
RGR1		-0.35±0.11	-0.84±0.09	-0.19±0.15	-0.65±0.07
RGR2	-0.35±0.02		0.13±0.20	-0.19±0.17	0.65±0.07
RGR3	-0.40±0.02	-0.06±0.02		0.22±0.22	0.90±0.10
RGR4	-0.18±0.02	-0.11±0.02	0.01±0.02		0.19±0.15
RGR5	-0.61±0.01	0.64±0.01	0.51±0.02	0.33±0.02	

Table 4.29 Estimates of Genetic correlation of body weight traits with weight gain traits

	ADG1	ADG2	ADG3	ADG4	ADG5	RGR1	RGR2	RGR3	RGR4	RGR5
BWT	0.27 ±0.09	0.14 ±0.10	-0.04 ±0.16	0.05 ±0.15	0.03 ±0.11	-0.17 ±0.09	-0.01 ±0.11	-0.19 ±0.16	-0.14 ±0.14	-0.20 ±0.10
WWT	0.99 ±0.002	0.38 ±0.10	-0.58 ±0.12	0.04 ±0.15	-0.13 ±0.11	0.80 ± 0.04	-0.31 ±0.10	-0.91 ±0.08	-0.31 ±0.13	-0.72 ±0.05
6WT	0.88 ±0.03	0.79 ±0.04	-0.37 ±0.14	-0.03 ±0.15	0.22 ±0.11	0.73 ±0.05	0.35 ±0.10	-0.78 ±0.09	-0.36 ±0.13	-0.29 ±0.10
9WT	0.74 ±0.05	0.79 ±0.05	0.13 ±0.16	-0.04 ±0.16	0.60 ±0.09	0.53 ±0.08	0.43 ±0.11	-0.36 ±0.18	-0.41 ±0.14	-0.03 ±0.03
12WT	0.68 ±0.06	0.62 ±0.08	0.19 ±0.16	0.34 ±0.14	0.74 ±0.05	0.50 ±0.09	0.28 ±0.12	-0.22 ±0.17	0.34 ±0.14	0.23 ±0.11

Table 4.30 Estimates of Phenotypic correlation of body weight traits with weight gain traits

	BWT	WWT	6WT	9WT	12WT
ADG1	0.18±0.02	0.99±0.00	0.79±0.01	0.67±0.01	0.57±0.01
ADG2	0.07±0.02	0.17±0.02	0.74±0.01	0.63±0.01	0.51±0.02
ADG3	0.01±0.02	-0.23±0.02	-0.21±0.02	0.32±0.02	0.24±0.02
ADG4	-0.01± 0.02	-0.06±0.02	-0.11±0.02	-0.16±0.02	0.36±0.02
ADG5	-0.01±0.02	-0.21±0.02	0.20±0.02	0.50±0.02	0.75±0.01
RGR1	-0.31±0.02	0.77±0.01	0.61±0.01	0.46±0.02	0.39±0.02
RGR2	-0.10±0.02	-0.42±0.02	0.27±0.02	0.22±0.02	0.17±0.02
RGR3	-0.07±0.02	-0.44±0.02	-0.51±0.01	-0.01±0.02	-0.02±0.02
RGR4	-0.09±0.02	-0.24±0.02	-0.34±0.02	-0.43±0.02	0.36±0.02
RGR5	-0.19±0.02	-0.73±0.01	-0.32±0.02	-0.002±0.02	0.24±0.02

Table 4.31 Estimates of Genetic (above diagonal) and phenotypic (below diagonal) correlation among reproduction traits

	AFL	AFS	LS
AFL		0.99±0.08	0.87±0.00
AFS	0.99±0.07		0.82±0.00
LS	0.04±0.03	0.03±0.03	

The phenotypic correlations of EWTL with BWT, WWT, 6WT, 9WT, 12WT and EWTS were 0.40 ± 0.02, 0.36 ± 0.02, 0.26 ± 0.02, 0.26 ± 0.02, 0.26 ± 0.02 and 0.71 ± 0.01 respectively.

4.4.8 Correlations of Average Daily Gain from birth to 3months (ADG1) with other traits

The genetic correlations of ADG1 with BWT, WWT, 6WT, 9WT, 12WT, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.27 ± 0.09, 0.99 ± 0.002, 0.88 ± 0.03, 0.74 ± 0.05, 0.68 ± 0.06, 0.37 ± 0.10, -0.59 ± 0.12, 0.04 ± 0.15, -0.14 ± 0.11, 0.87 ± 0.03, -0.32 ± 0.10, -0.91 ± 0.08, -0.30 ± 0.13, -0.72 ± 0.05 respectively.

The phenotypic correlations of ADG1 with BWT, WWT, 6WT, 9WT, 12WT, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.81 ± 0.02, 0.99 ± 0.00, 0.79 ± 0.01, 0.67 ± 0.01, 0.57 ± 0.01, 0.17 ± 0.02, -0.24 ± 0.02, -0.06 ± 0.02, -0.22 ± 0.02, 0.85 ± 0.01, -0.42 ± 0.02, -0.45 ± 0.02, -0.24 ± 0.02, -0.73 ± 0.01 respectively.

4.4.9 Correlations of Average Daily Gain from 3 to 6months (ADG2) with other traits

The genetic correlations of ADG2 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.14 ± 0.10, 0.38 ± 0.10, 0.79 ± 0.04, 0.79 ± 0.05, 0.62 ± 0.08, 0.37 ± 0.10, -0.09 ± 0.17, -0.16 ± 0.16, 0.52 ± 0.09, 0.28 ± 0.11, 0.84 ± 0.04, -0.46 ± 0.14, -0.41 ± 0.14, 0.23 ± 0.11 respectively.

The phenotypic correlations of ADG2 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.07 ± 0.02, 0.17 ± 0.02, 0.74 ± 0.01, 0.63 ± 0.01, 0.51 ± 0.02, 0.17 ± 0.02, -0.08 ± 0.02, -0.10 ± 0.02, 0.50 ± 0.01, 0.12 ± 0.02, 0.82 ± 0.01, -0.32 ± 0.02, -0.26 ± 0.02, and 0.27 ± 0.02 respectively.

4.4.10 Correlations of Average Daily Gain from 6 to 9months (ADG3) with other traits

The genetic correlations of ADG3 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were -0.04 ± 0.16, -0.58 ± 0.12, 0.37 ± 0.14, 0.13 ± 0.16, 0.19 ± 0.16, -0.59 ± 0.12, -0.09 ± 0.17, 0.06 ± 0.21, 0.76 ± 0.11, -0.59 ± 0.12, 0.30 ± 0.19, 0.90 ± 0.04, 0.04 ± 0.21, 0.88 ± 0.08 respectively.

The phenotypic correlations of ADG3 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.01 ± 0.02, -0.23 ± 0.02, -0.21 ± 0.02, 0.32 ± 0.02, 0.24 ± 0.02, -0.24 ± 0.02, -0.08 ± 0.02, -0.06 ± 0.02, 0.47 ± 0.02, -0.24 ± 0.02, 0.03 ± 0.02, 0.91 ± 0.003, -0.14 ± 0.02 and 0.47 ± 0.02 respectively.

4.4.11 Correlations of Average Daily Gain from 9 to 12months (ADG4) with other traits

The genetic correlations of ADG4 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.05 ± 0.15, 0.04 ± 0.15, -0.03 ± 0.15, -0.04 ± 0.16, 0.34 ± 0.14, 0.04 ± 0.15, -0.16 ± 0.16, 0.06 ± 0.21, 0.36 ± 0.14, 0.05 ± 0.16, -0.16 ± 0.17, 0.06 ± 0.23, 0.91 ± 0.03 and 0.22 ± 0.15 respectively.

The phenotypic correlations of ADG4 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG5, RGR1, RGR2, RGR3, RGR4 and RGR5 were -0.01 ± 0.02, -0.06 ± 0.02, -0.11 ± 0.02, -0.16 ± 0.02, 0.36 ± 0.02, -0.06 ± 0.02, -0.10 ± 0.02, -0.06 ± 0.02, 0.47 ± 0.02, -0.06 ± 0.02, -0.05 ± 0.02, 0.001 ± 0.02, 0.93 ± 0.003 and 0.37 ± 0.02 respectively.

4.4.12 Correlations of Average Daily Gain from 3 to 12months (ADG5) with other traits

The genetic correlations of ADG5 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, RGR1, RGR2, RGR3, RGR4 and RGR5 were 0.03 ± 0.11, -0.13 ± 0.11, 0.22 ± 0.11, 0.60 ± 0.09, 0.74 ± 0.05, -0.14 ± 0.11, 0.52 ± 0.09, 0.76 ± 0.11, 0.36 ± 0.14, -0.18 ± 0.12, 0.61 ± 0.09, 0.42 ± 0.16, 0.09 ± 0.17 and 0.82 ± 0.04 respectively.

The phenotypic correlations of ADG5 with with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, RGR1, RGR2, RGR3, RGR4 and RGR5 were -0.01 ± 0.02, -0.21 ± 0.02, 0.20 ± 0.02, 0.50 ± 0.02, 0.75 ± 0.01, -0.22 ± 0.02, 0.50 ± 0.02, 0.47 ± 0.02, 0.47 ± 0.02, -0.22 ± 0.02, 0.53 ± 0.01, 0.32 ± 0.02, 0.27 ± 0.02 and 0.79 ± 0.01 respectively.

4.4.13 Correlations of Relative Growth Rate from birth to 3months (RGR1) with other traits

The genetic correlations of RGR1 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR2, RGR3, RGR4 and RGR5 were -0.17 ± 0.09, 0.80 ± 0.04, 0.73 ± 0.05, 0.53 ± 0.08, 0.50 ± 0.09, 0.87 ± 0.03, 0.28 ± 0.11, -0.59 ± 0.12, 0.05 ± 0.16, -0.18 ± 0.12, -0.35 ± 0.11, -0.84 ± 0.09, -0.19 ± 0.15 and -0.65 ± 0.07 respectively.

The phenotypic correlations of RGR1 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR2, RGR3, RGR4 and RGR5 were -0.31 ± 0.02, 0.77 ± 0.01, 0.61 ± 0.01, 0.46 ± 0.02, 0.39 ± 0.02, 0.85 ± 0.01, 0.12 ± 0.02, -0.24 ± 0.02, -0.06 ± 0.02, -0.22 ± 0.02, -0.35 ± 0.02, -0.40 ± 0.02, -0.18 ± 0.02 and -0.61 ± 0.01 respectively.

4.4.14 Correlations of Relative Growth Rate from 3 to 6months (RGR2) with other traits

The genetic correlations of RGR2 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR3, RGR4 and RGR5 were -0.01 ± 0.11, -0.31 ± 0.10, 0.35 ± 0.10, 0.43 ± 0.11, 0.28 ± 0.12, -0.32 ± 0.10, 0.83 ± 0.04, 0.30 ± 0.19, -0.16 ± 0.17, 0.61 ± 0.09, -0.35 ± 0.11, 0.13 ± 0.20, -0.19 ± 0.17 and 0.65 ± 0.07 respectively.

The phenotypic correlations of RGR2 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR3, RGR4 and RGR5 were -0.10 ± 0.02, -0.42 ± 0.02, 0.27 ± 0.02, 0.22 ± 0.02, 0.17 ± 0.02, -0.42 ± 0.02, 0.82 ± 0.01, 0.03 ± 0.02, -0.05 ± 0.02, 0.53 ± 0.01, -0.35 ± 0.02, -0.06 ± 0.02, -0.11 ± 0.02 and 0.64 ± 0.01 respectively.

4.4.15 Correlations of Relative Growth Rate from 6 to 9months (RGR3) with other traits

The genetic correlations of RGR3 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR4 and RGR5 were -0.19 ± 0.16, -0.91 ± 0.08, -0.78 ± 0.09, -0.36 ± 0.18, -0.22 ± 0.17, -0.91 ± 0.08, -0.46 ± 0.14, 0.90 ± 0.04, 0.06 ± 0.23, 0.42 ± 0.16, -0.84 ± 0.09, 0.13 ± 0.20, 0.22 ± 0.22 and 0.90 ± 0.10 respectively.

The phenotypic correlations of RGR3 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR4 and RGR5 were -0.07 ± 0.02, -0.44 ± 0.02, -0.51 ± 0.01, -0.01 ± 0.02, -0.02 ± 0.02, -0.45 ± 0.02, -0.32 ± 0.02, 0.91 ± 0.003, 0.001 ± 0.02, 0.32 ± 0.02, -0.40 ± 0.02, -0.06 ± 0.02, 0.01 ± 0.02 and 0.51 ± 0.02 respectively.

4.4.16 Correlations of Relative Growth Rate from 9 to 12months (RGR4) with other traits

The genetic correlation of RGR4 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR5 were -0.14 ± 0.14, -0.31 ± 0.13, -0.36 ± 0.13, -0.41 ± 0.14, 0.34 ± 0.14, -0.29 ± 0.13, 0.41 ± 0.14, 0.04 ± 0.21, 0.91 ± 0.03, 0.09 ± 0.17, -0.19 ± 0.15, -0.19 ± 0.17, 0.22 ± 0.22 and 0.19 ± 0.15 respectively.

The phenotypic correlation of RGR4 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR5 were -0.09 ± 0.02, -0.24 ± 0.02, -0.34 ± 0.08, -0.43 ± 0.02, 0.36 ± 0.02, -0.24 ± 0.02, -0.26 ± 0.02, -0.14 ± 0.02, 0.93 ± 0.003, 0.27 ± 0.02, -0.18 ± 0.02, -0.11 ± 0.02, 0.01 ± 0.02 and 0.33 ± 0.02 respectively.

4.4.17 Correlations of Relative Growth Rate from 3 to 12months (RGR5) with other traits

The genetic correlation of RGR5 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 were -0.20 ± 0.10, -0.72 ± 0.05, -0.29 ± 0.10, -0.03 ± 0.03, 0.23 ± 0.11, -0.72 ± 0.05, 0.23 ± 0.11, 0.88 ± 0.08, 0.22 ± 0.15, 0.82 ± 0.04, -0.65 ± 0.07, 0.65 ± 0.07, 0.90 ± 0.10 and 0.19 ± 0.15 respectively.

The phenotypic correlation of RGR5 with BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4 were -0.19 ± 0.02, -0.73 ± 0.01, -0.32 ± 0.02, -0.002 ± 0.02, 0.24 ± 0.02, -0.73 ± 0.01, 0.27 ± 0.02, 0.47 ± 0.02, 0.37 ± 0.02, 0.79 ± 0.01, -0.61 ± 0.01, 0.64 ± 0.01, 0.51 ± 0.02 and 0.33 ± 0.02 respectively.

4.4.18 Correlation of Age at First Lambing (AFL) with other traits

The genetic and phenotypic correlation among reproduction traits are depicted in the table 4.31. The genetic correlation of AFL with AFS, LS, BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were 0.99 ± 0.08, 0.87 ± 0.00, -0.05 ± 0.17, -0.16 ± 0.34, -0.18 ± 0.39, -0.43 ± 0.38, -0.23 ± 0.33, -0.16 ± 0.33, -0.30 ± 0.66, -1 ± 0.00, -0.14 ± 0.61, -0.94 ± 0.00, -0.23 ± 0.36, -0.99 ± 0.00, -0.47 ± 0.94, 0.20 ± 0.60 and -1.00 ± 0.00 respectively.

The phenotypic correlation of AFL with AFS, LS, BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were 0.99 ± 0.07, 0.04 ± 0.03, 0.02 ± 0.03, -0.12 ± 0.04, -0.13 ± 0.03, -0.16 ± 0.03, -0.20 ± 0.03, -0.14 ± 0.04, -0.07 ± 0.03, -0.02 ± 0.04, -0.04 ± 0.04, -0.14 ± 0.03, -0.17 ± 0.04, -0.03 ± 0.03, 0.03 ± 0.03, 0.003 ± 0.03 and -0.06 ± 0.03 respectively.

4.4.19 Correlation of Age at First Service (AFS) with other traits

The genetic correlation of AFS with AFL, LS, BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were 0.99 ± 0.08, 0.82 ± 0.00, -0.04 ± 0.19, -0.84 ± 0.87, -0.73 ± 0.00, -0.99 ± 0.88, -0.76 ± 0.00, -0.83 ± 0.75, 0.46 ± 0.00, -0.98 ± 0.00, 0.37 ± 0.00, -1.00 ± 0.00, -0.88 ± 0.61, 0.71 ± 0.00, -1.00 ± 0.00, 0.95 ± 0.00 and -0.05 ± 0.00 respectively.

The phenotypic correlation of AFS with AFL, LS, BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were 0.99 ± 0.07, 0.03 ± 0.03, -0.01 ± 0.03, -0.09 ± 0.04, -0.08 ± 0.03, 0.13 ± 0.03, 0.18 ± 0.03, -0.10 ± 0.04, -0.03 ± 0.03, -0.05 ± 0.03, -0.07 ± 0.03, -0.14 ± 0.03, -0.10 ± 0.04, -0.001 ± 0.03, -0.01 ± 0.03, -0.03 ± 0.03 and -0.06 ± 0.03 respectively.

4.4.20 Correlation of Litter Size (LS) with other traits

The genetic correlation of LS with AFL, AFS, BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were 0.87 ± 0.00, 0.82 ± 0.00, -0.94 ± 0.07, 1.00 ± 0.00, -0.64 ± 0.17, -0.66 ± 0.23, -0.34 ± 0.24, -

0.69 ± 0.13, 0.27 ± 0.26, 1.00 ± 0.00, -0.02 ± 0.35, 0.61 ± 0.23, 0.04 ± 0.24, 0.82 ± 0.15, 0.18 ± 0.34, 0.47 ± 0.34 and 0.85 ± 0.14 respectively.

Table 4.32 Estimates of genetic correlation of reproduction traits with growth traits

	AFL	AFS	LS
BWT	-0.05±0.17	-0.04±0.19	-0.95±0.07
3WT	-0.16±0.34	-0.84±0.87	1.00±0.00
6WT	-0.18±0.39	-0.73±0.00	-0.64±0.17
9WT	-0.43±0.38	-0.99±0.88	-0.66±0.23
12WT	-0.23±0.33	-0.76±0.00	-0.34±0.24
ADG1	-0.16±0.33	-0.83±0.75	-0.69±0.13
ADG2	-0.30±0.66	0.46±0.00	0.27±0.26
ADG3	-1.00±0.00	-0.98±0.00	1.00±0.00
ADG4	-0.14±0.61	0.37±0.00	-0.02±0.35
ADG5	-0.94±0.00	-1.00±0.00	0.61±0.23
RGR1	-0.23±0.36	-0.88±0.61	0.04±0.24
RGR2	-0.99±0.00	0.71±0.00	0.82±0.15
RGR3	-0.47±0.94	-1.00±0.00	0.18±0.34
RGR4	0.20±0.60	0.95±0.00	0.47±0.34
RGR5	-0.99±0.00	-0.05±0.00	0.85±0.14

Table 4.33 Estimates of phenotypic correlation reproduction traits with growth traits

	AFL	AFS	LS
BWT	0.02±0.03	-0.01±0.03	-0.03±0.03
3WT	-0.12±0.04	-0.09±0.04	1.00±0.00
6WT	-0.13±0.03	-0.08±0.03	0.16±0.03
9WT	-0.16±0.03	-0.13±0.03	0.17±0.03
12WT	-0.20±0.03	-0.18±0.03	0.17±0.03
ADG1	-0.14±0.04	-0.10±0.04	0.13±0.04
ADG2	-0.07±0.03	-0.03±0.03	0.08±0.03
ADG3	-0.02±0.04	-0.05±0.03	1.00±0.00
ADG4	-0.04±0.04	-0.07±0.03	0.02±0.03
ADG5	-0.14±0.03	-0.14±0.03	0.08±0.03
RGR1	-0.17±0.04	-0.10±0.04	0.12±0.04
RGR2	-0.03±0.03	-0.001±0.03	0.02±0.03
RGR3	0.03±0.03	-0.01±0.03	-0.04±0.03
RGR4	0.003±0.03	-0.03±0.03	0.03±0.03
RGR5	-0.06±0.03	-0.06±0.03	0.001±0.04

The phenotypic correlation of LS with AFL, AFS, BWT, WWT, 6WT, 9WT, 12WT, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were 0.04 ±0.03, 0.03 ± 0.03, -0.03 ± 0.03, -1.00 ± 0.00, -0.16 ± 0.03, 0.17 ± 0.03, 0.17 ± 0.03, 0.13 ± 0.04, 0.08 ± 0.03, 1.00 ± 0.00, 0.02 ± 0.03, 0.08 ± 0.03, 0.12 ± 0.04, 0.02 ± 0.03, -0.04 ± 0.03, 0.03 ± 0.03 and 0.001 ± 0.04 respectively. The genetic and phenotypic correlation of reproduction traits with growth traits are given in the Table 4.32 and 4.33.

4.5 Genetic, phenotypic and environmental trends for growth and reproduction traits

Estimates of genetic, phenotypic and environmental trends for growth and reproduction traits are given in the Table 4.34. Graphical representation of genetic and phenotypic trends for all the traits were given in the Figure 4.1 to 4.20.

4.5.1 Growth traits

The genetic trends calculated for BWT, WWT, 6WT, 9WT, 12WT, EWTS and EWTL, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were 0.005 ± 0.001 kg, 0.18 ± 0.04 kg, 0.25 ± 0.08 kg, 0.12 ± 0.04 kg, 0.22 ± 0.06 kg, 0.008 ± 0.008 kg, 0.005 ± 0.66 kg, 1.78 ± 0.36 g, 0.56 ± 0.33 g, -0.09 ± 0.04 g, 0.10 ± 0.05 g, 0.18 ± 0.08 g, 2.33 ± 0.4, -0.10 ± 0.08, -0.06 ± 0.02, 0.01 ± 0.02 and -0.49 ± 0.16 respectively.

The phenotypic trends calculated for BWT, WWT, 6WT, 9WT, 12WT, EWTS, EWTL, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were 0.002 ± 0.06 kg, -0.54 ± 0.20 kg, -0.84 ± 0.34 kg, 0.03 ± 0.29 kg, 0.07 ± 0.20 kg, 1.67 ± 0.23 kg, 0.34 ± 0.90 kg, -6.11 ± 2.22 g, 0.33 ± 1.74 g, 9.17 ± 1.69 g, 1.69 ± 1.44 g, 2.46 ± 0.72 g, -18.18 ± 7.48, -0.38 ± 0.83, 4.43 ± 0.71, 0.55 ± 0.48 and 7.48 ± 1.78 respectively.

The environmental trends calculated by the method of difference for BWT, WWT, 6WT, 9WT, 12WT, EWTS, EWTL, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5 were -0.003 kg, -0.72 kg, -1.08 kg, -0.08 kg, -0.15 kg, 1.66 kg, 0.34 kg, -7.89 g, -0.23 g, 9.26 g, 1.59 g, 2.28 g, -20.50, -0.28, 4.50, 0.54 and 7.97 respectively.

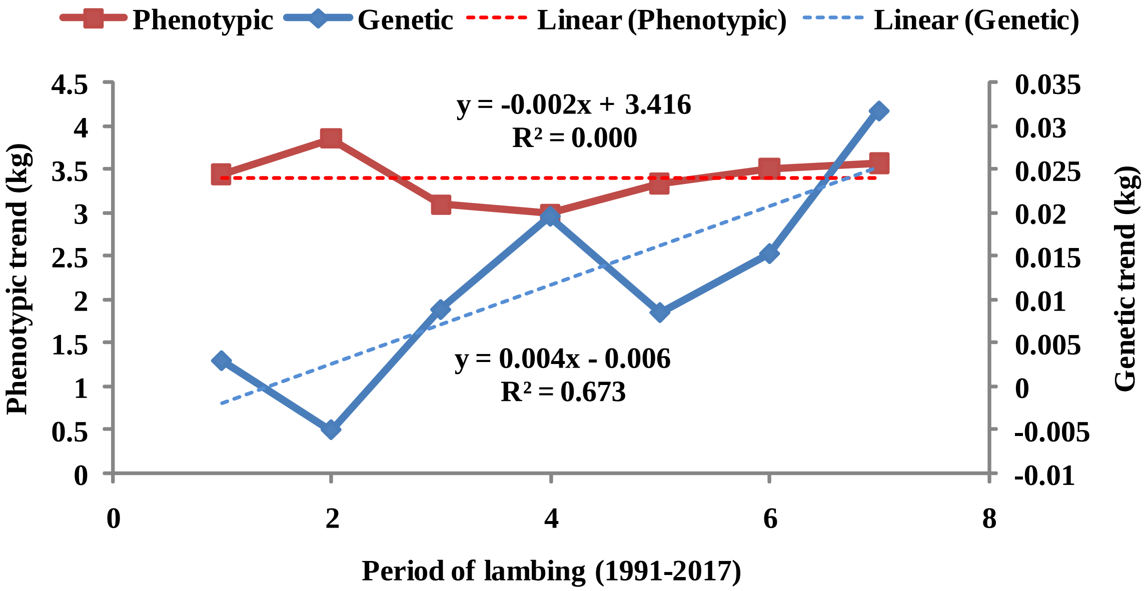


Fig. 4.1: Graphical representation of genetic and phenotypic trend of BWT

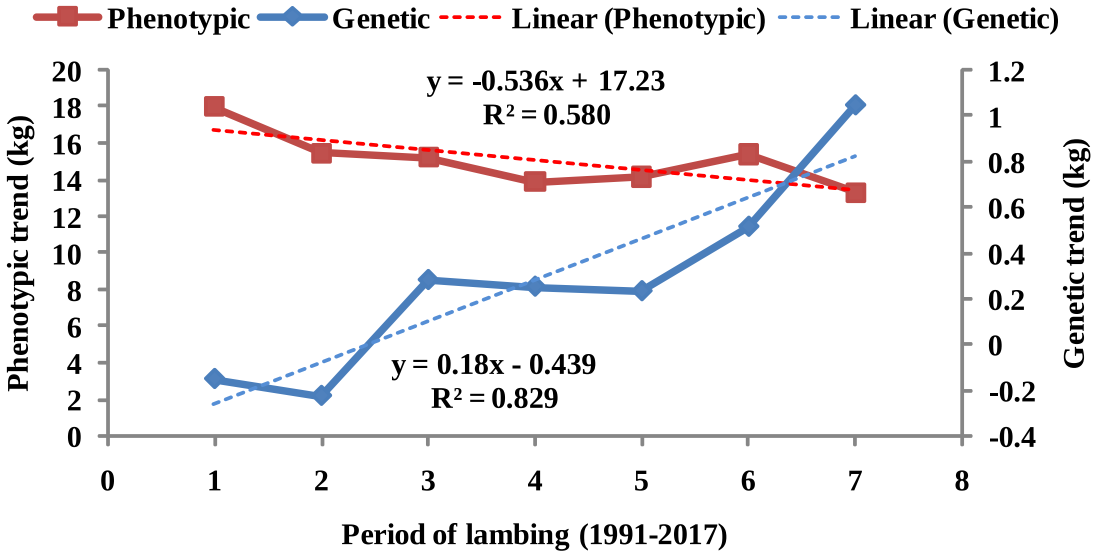


Fig. 4.2: Graphical representation of genetic and phenotypic trend of WWT

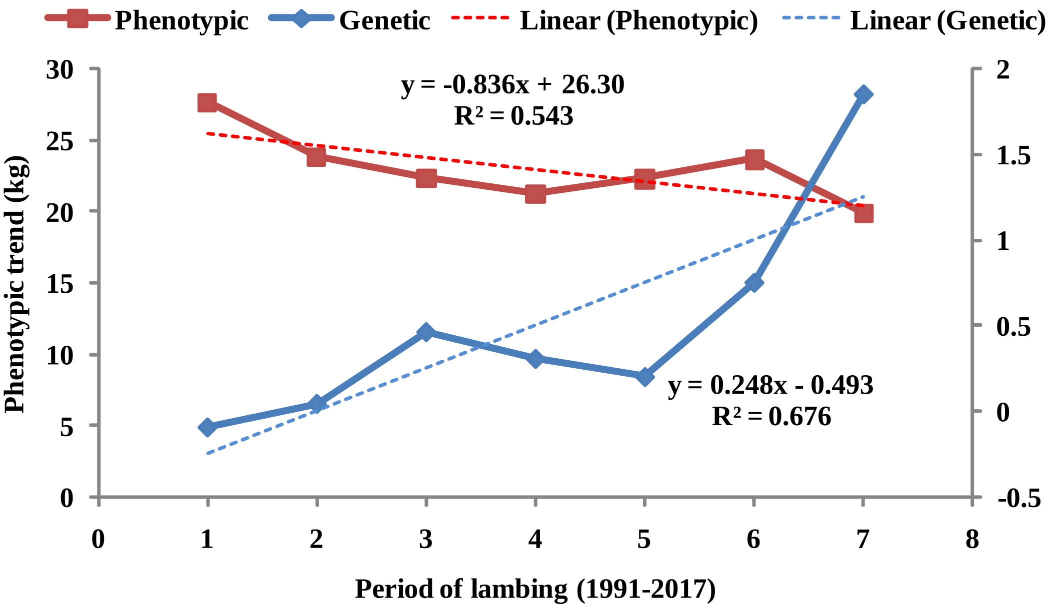


Fig. 4.3: Graphical representation of genetic and phenotypic trend of 6WT

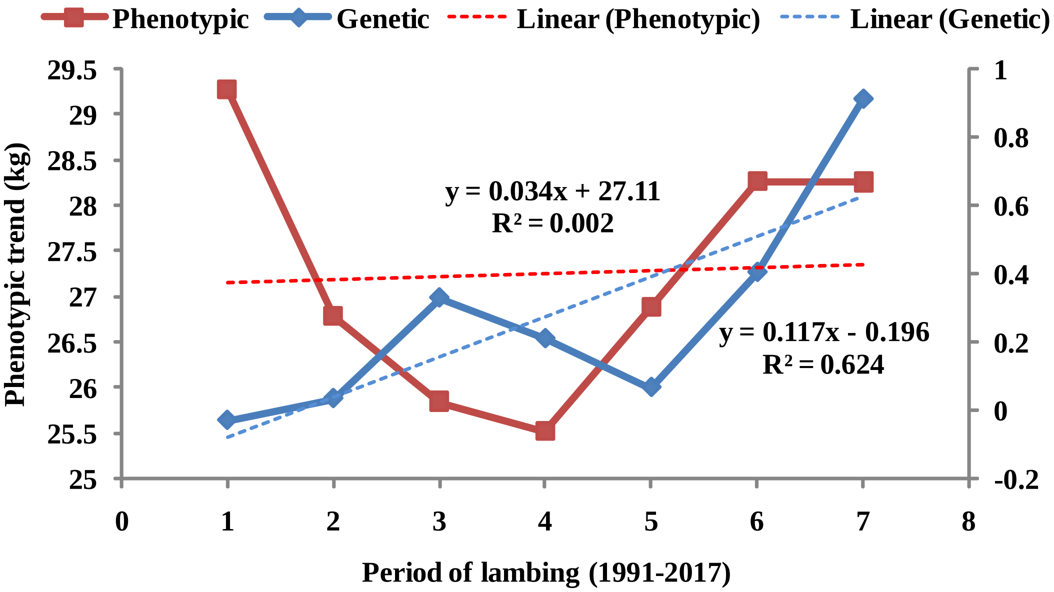


Fig. 4.4: Graphical representation of genetic and phenotypic trend of 9WT

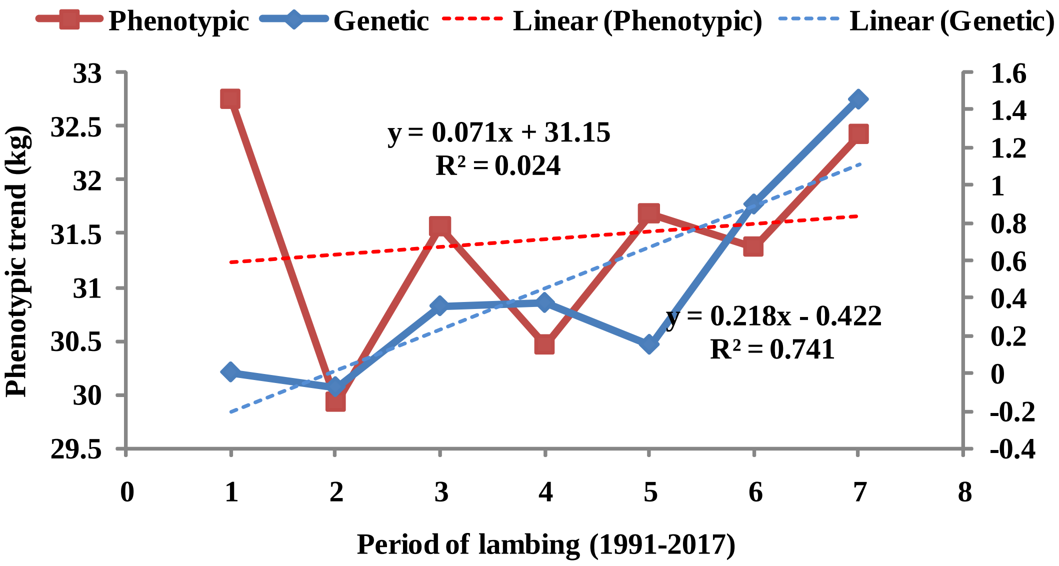


Fig. 4.5: Graphical representation of genetic and phenotypic trend of 12WT

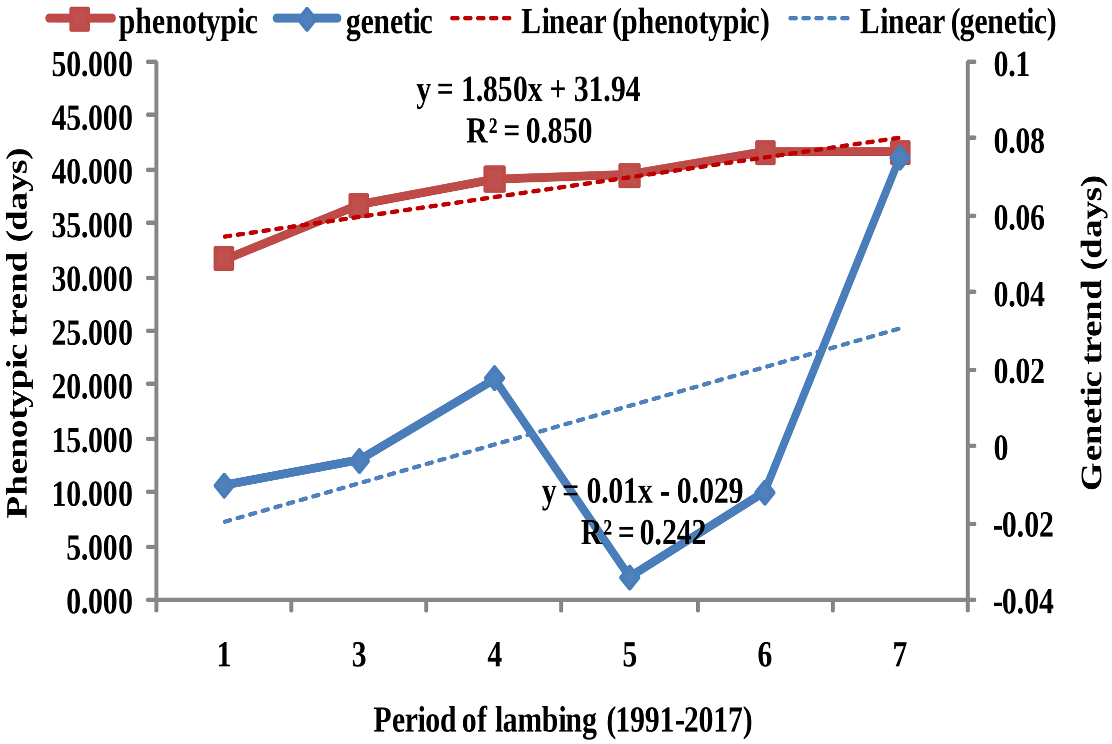


Fig. 4.6: Graphical representation of genetic and phenotypic trend of EWTS

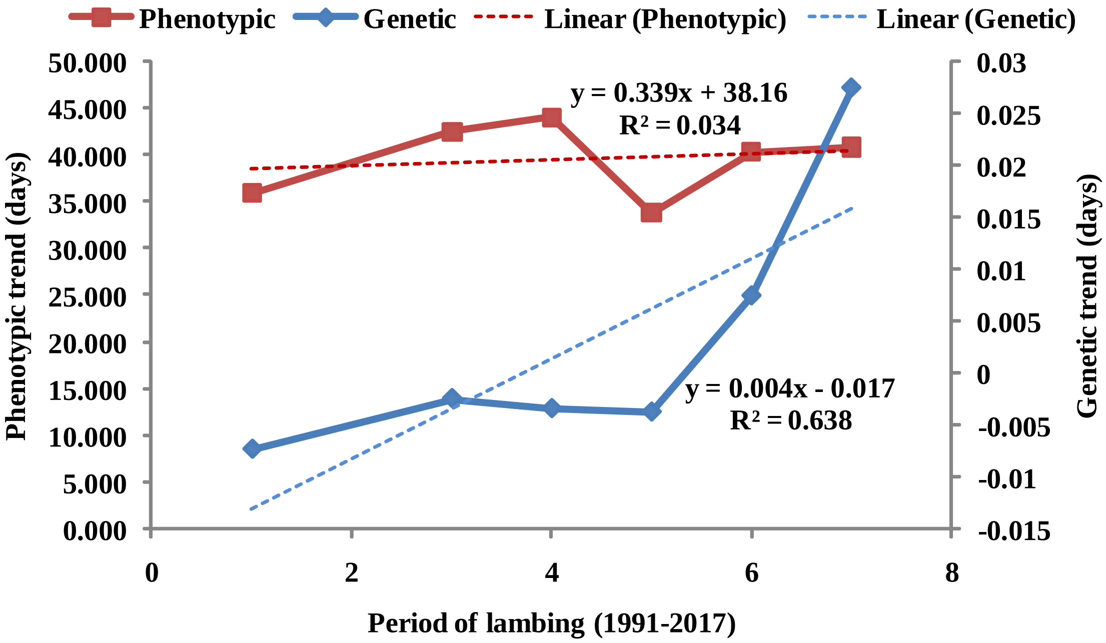


Fig. 4.7: Graphical representation of genetic and phenotypic trend of EWTL

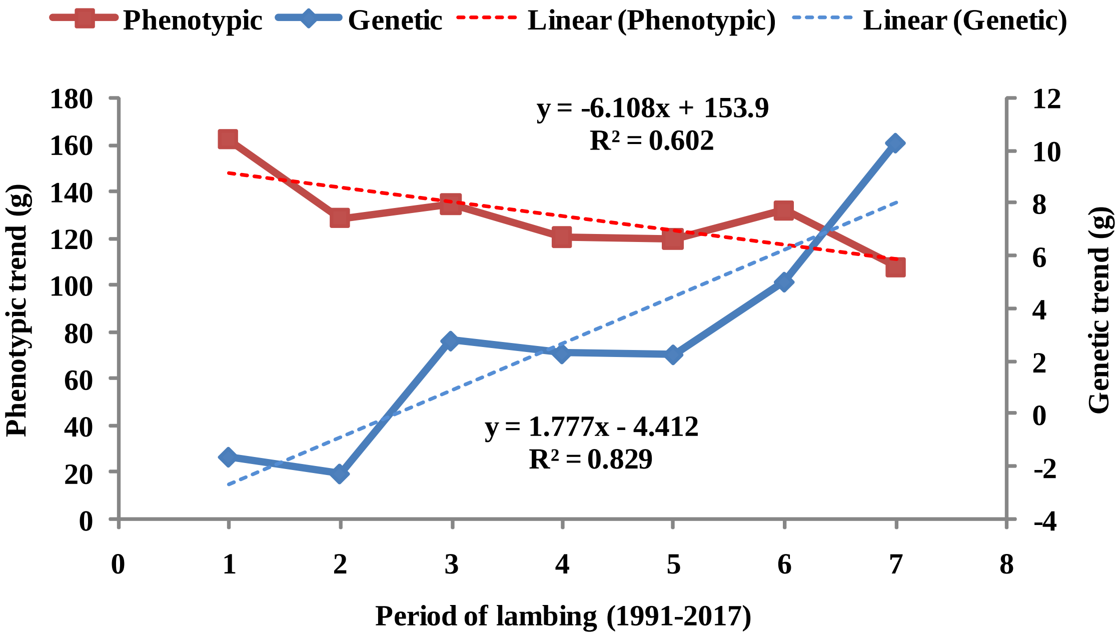


Fig. 4.8: Graphical representation of genetic and phenotypic trend of ADG1

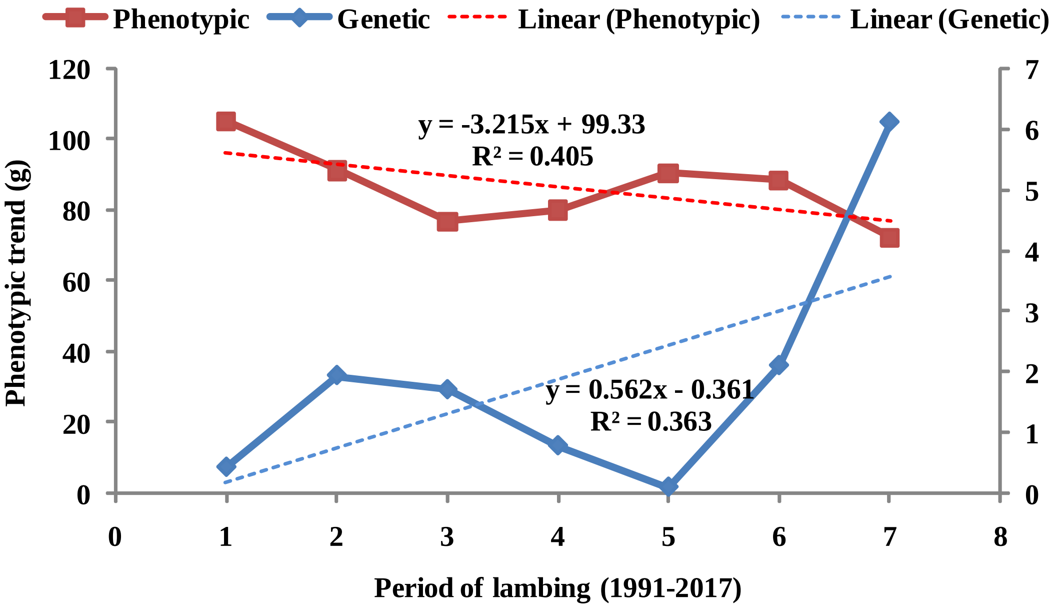


Fig. 4.9: Graphical representation of genetic and phenotypic trend of ADG2

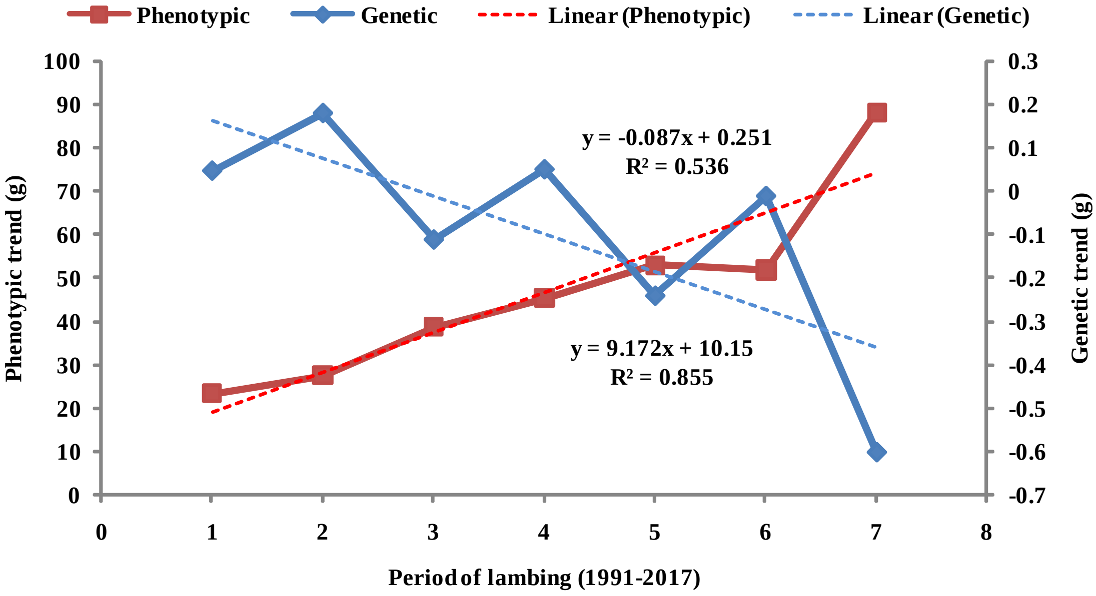


Fig. 4.10: Graphical representation of genetic and phenotypic trend of ADG3

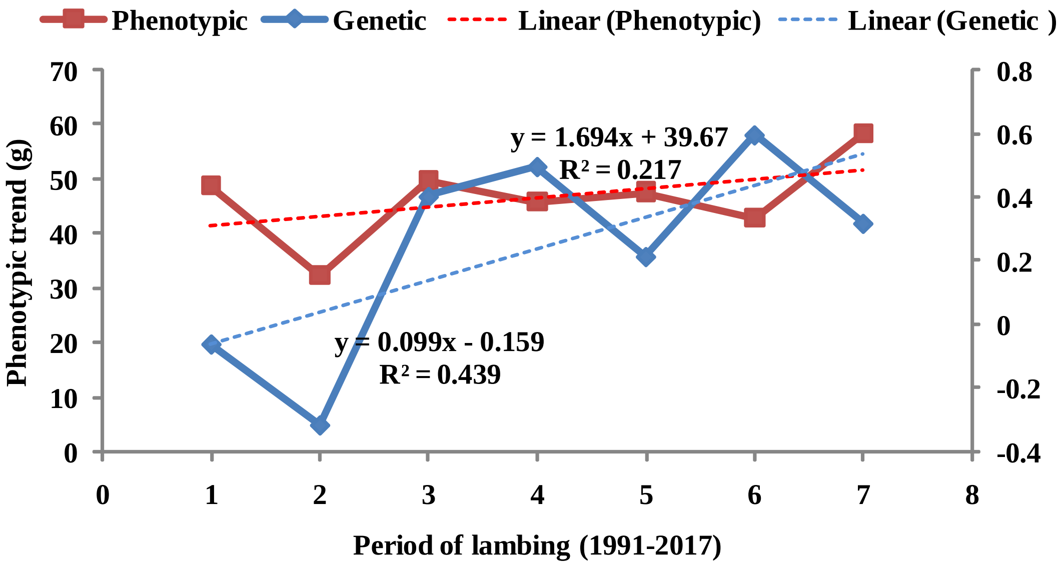


Fig. 4.11: Graphical representation of genetic and phenotypic trend of ADG4

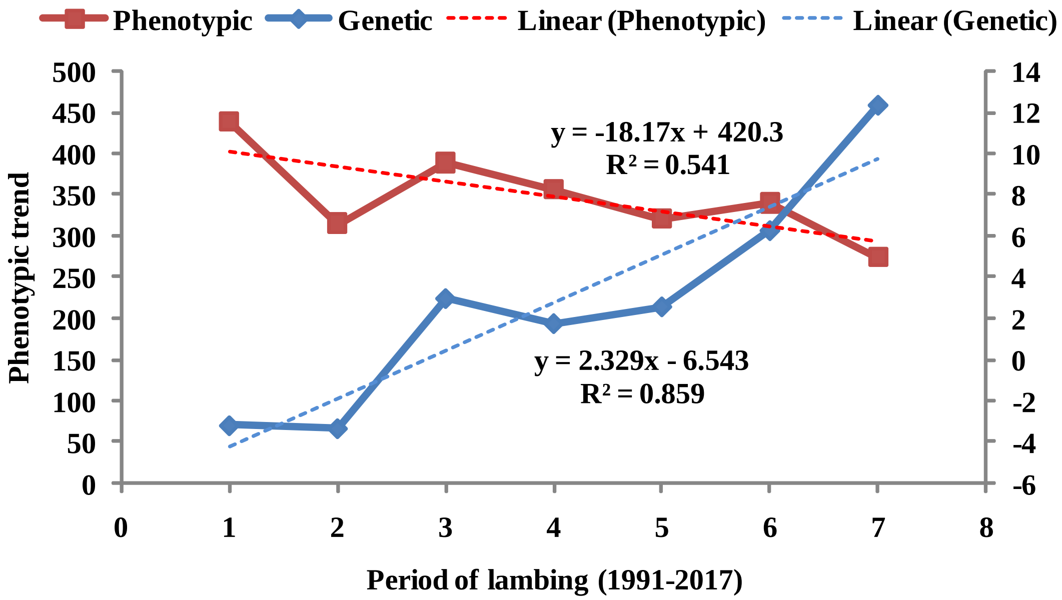


Fig. 4.12: Graphical representation of genetic and phenotypic trend of ADG5

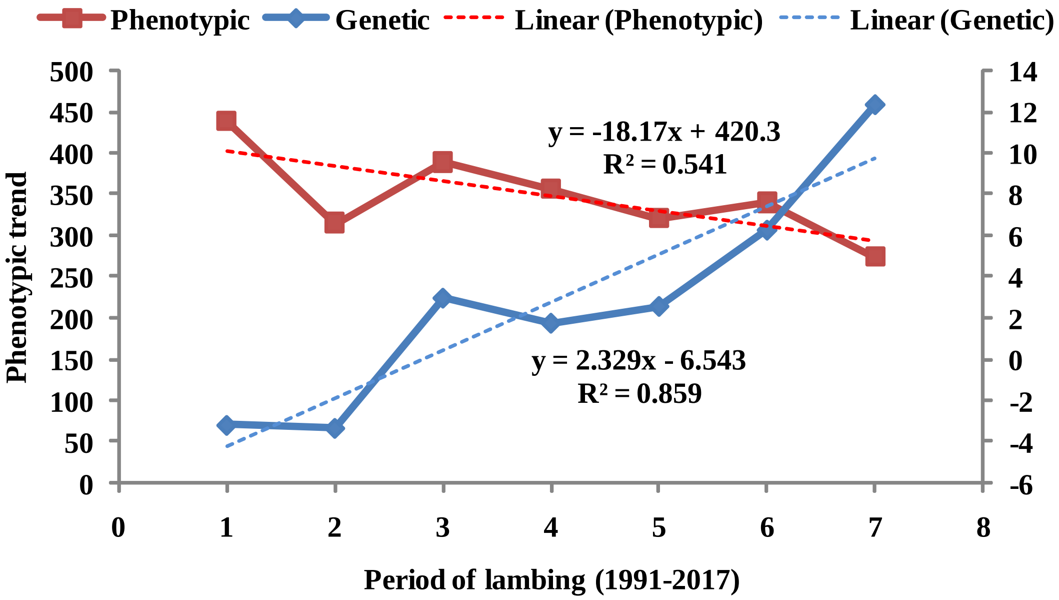


Fig. 4.13: Graphical representation of genetic and phenotypic trend of RGR1

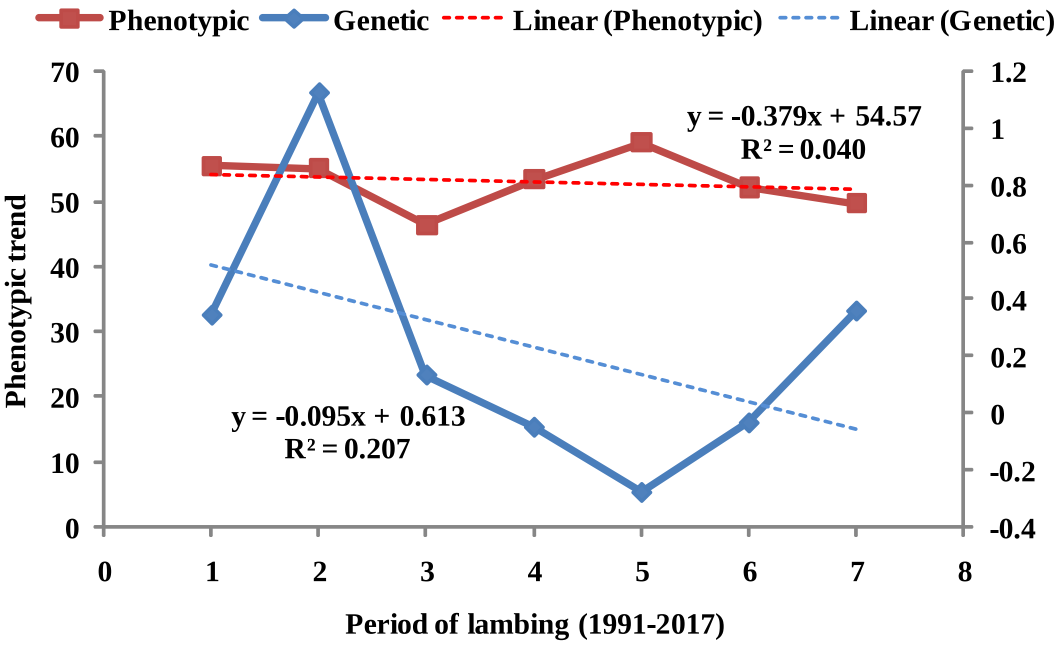


Fig. 4.14: Graphical representation of genetic and phenotypic trend of RGR2

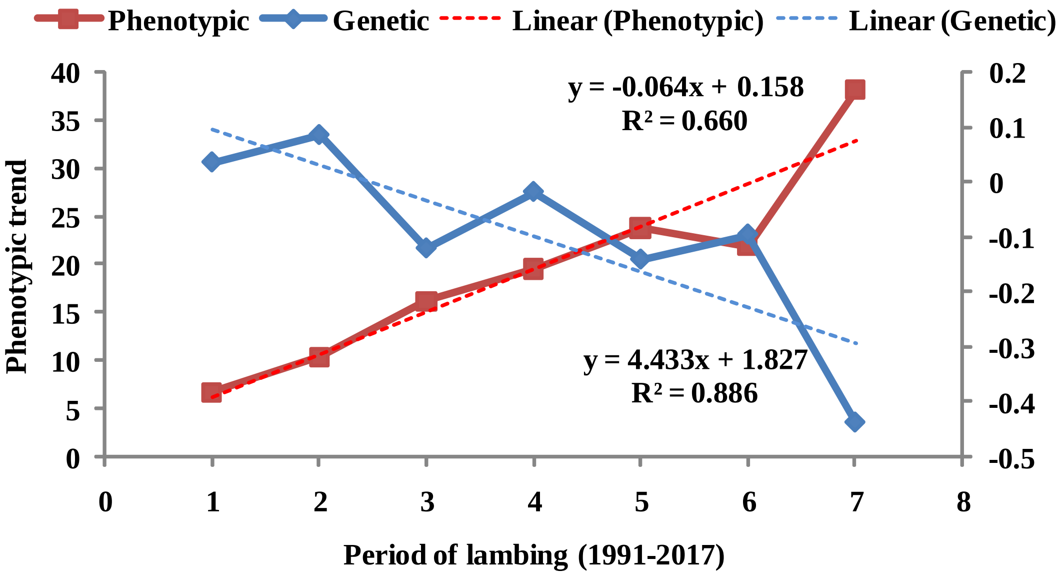


Fig. 4.15: Graphical representation of genetic and phenotypic trend of RGR3

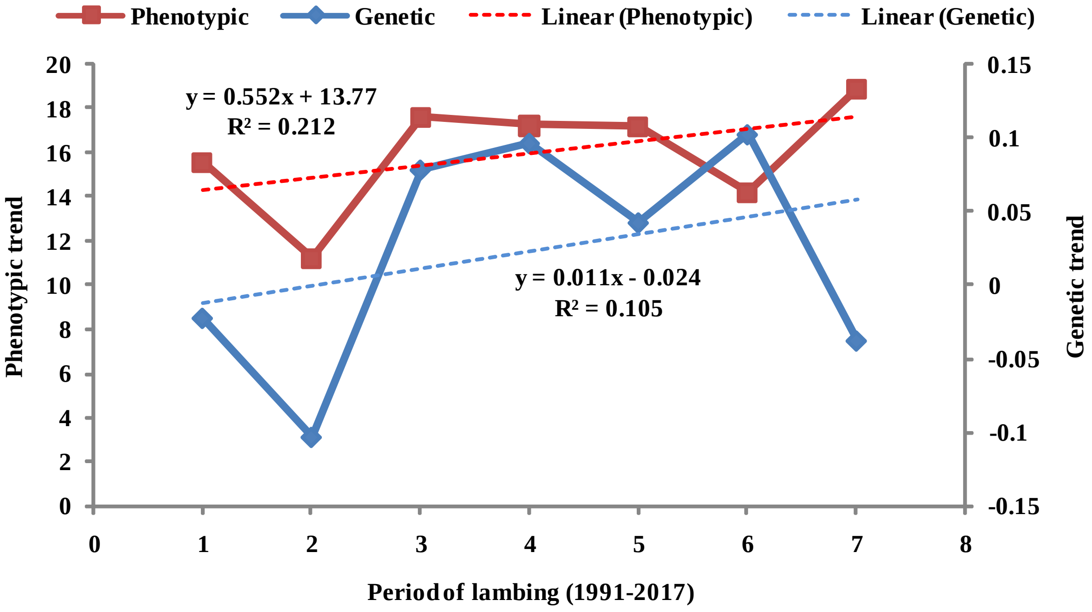


Fig. 4.16: Graphical representation of genetic and phenotypic trend of RGR4

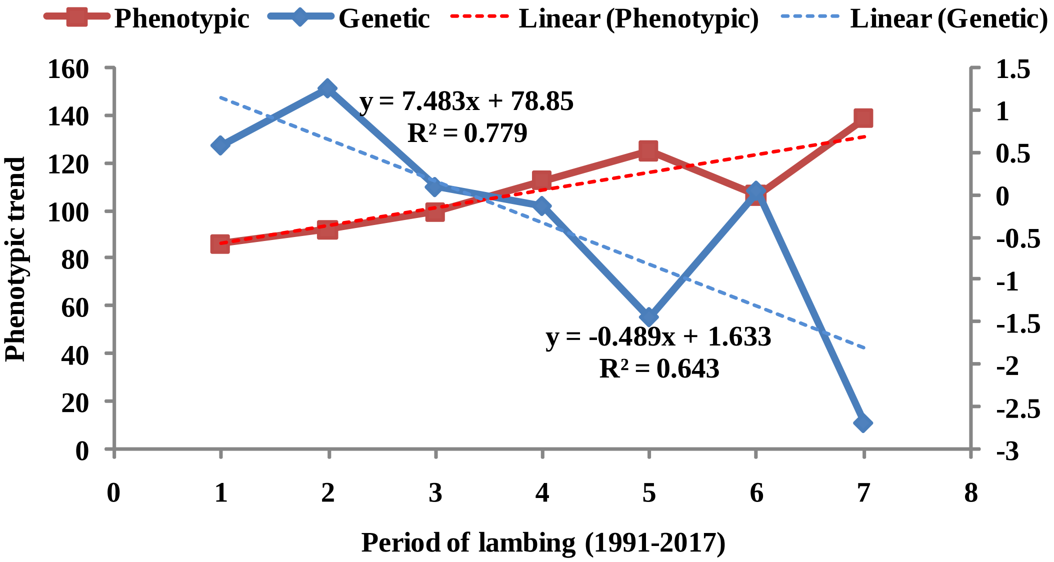


Fig. 4.17: Graphical representation of genetic and phenotypic trend of RGR5

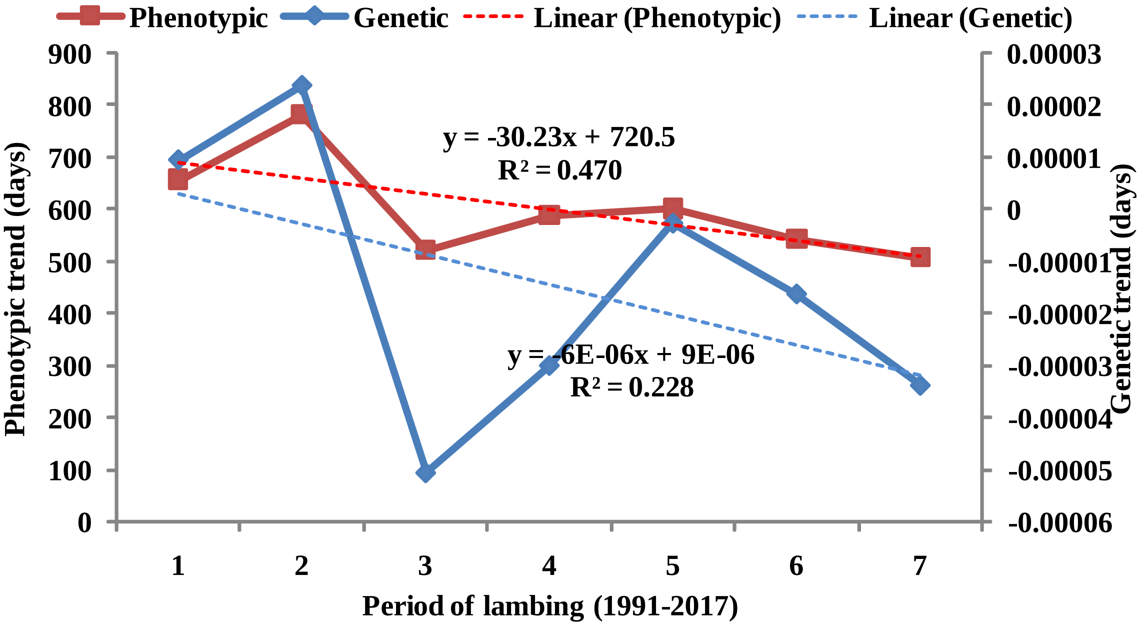


Fig. 4.18: Graphical representation of genetic and phenotypic trend of AFS

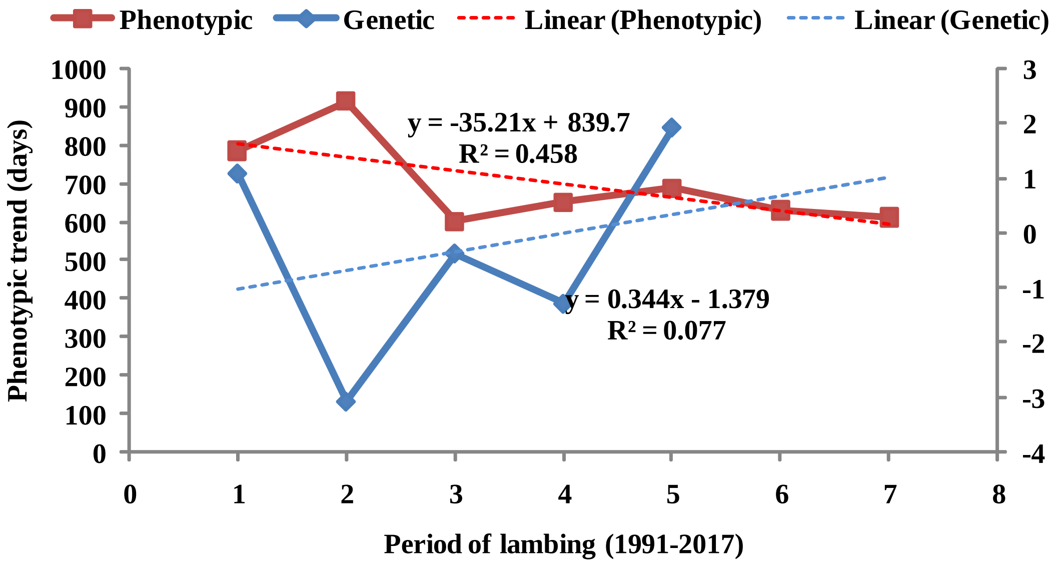


Fig. 4.19: Graphical representation of genetic and phenotypic trend of AFL

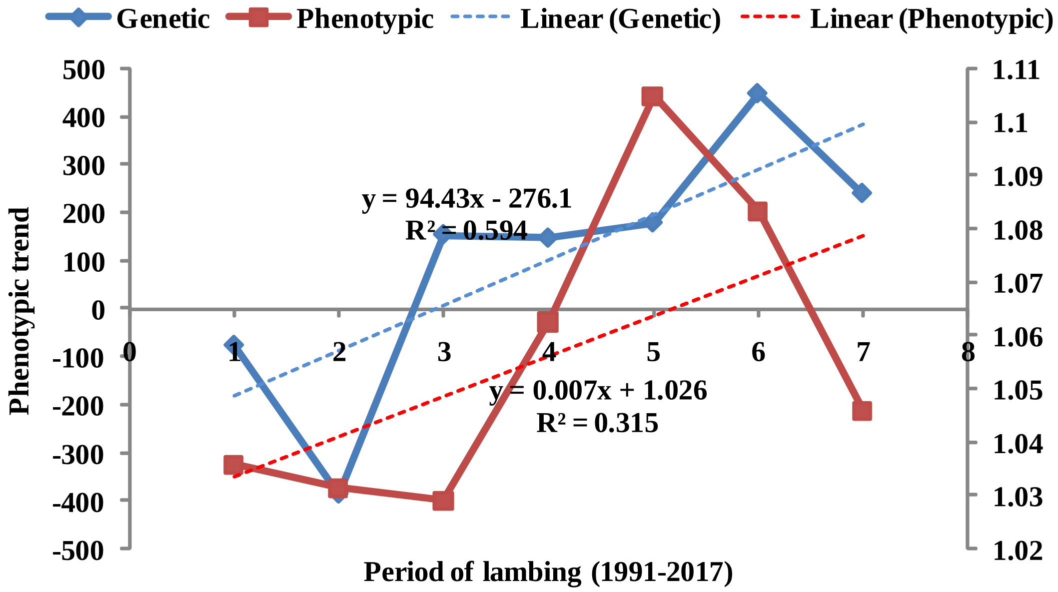


Fig. 4.20: Graphical representation of genetic and phenotypic trend of LS

4.5.2 Reproduction Traits

The genetic trends for AFL, AFS and LS were 0.34 ± 0.69 days, 0.00006 ± 0.00005 days and 136.00 ± 0.00 respectively.

The phenotypic trends for AFL, AFS and LS were -35.22 ± 17.13 days, -30.24 ± 14.34 days and 0.007 ± 0.005 respectively.

The environmental trends for AFL, AFS and LS were -35.56 days, -30.24 days and -135.99 respectively.

Table 4.34: Period wise genetic, phenotypic and environmental trends for all the traits

	Genetic	**Phenotypic**	**Environmental**
BWT	0.005±0.001 kg	0.002±0.06 kg	-0.003 kg
WWT	0.18±0.04 kg	-0.54±0.20 kg	-0.72 kg
6WT	0.25±0.08 kg	-0.84±0.34 kg	-1.08 kg
9WT	0.12±0.04 kg	0.03±0.29 kg	-0.08 kg
12WT	0.22±0.06 kg	0.07±0.20 kg	-0.15 kg
EWTS	0.008±0.008 kg	1.67±0.23 kg	1.66 kg
EWTL	0.005±0.66 kg	0.34±0.90 kg	0.34 kg
ADG1	1.78±0.36 g	-6.11±2.22 g	-7.89 g
ADG2	0.56±0.33 g	0.33±1.74 g	-0.23 g
ADG3	-0.09±0.04 g	9.17±1.69 g	9.26 g
ADG4	0.10±0.05 g	1.69±1.44 g	1.59 g
ADG5	0.18±0.08 g	2.46±0.72 g	2.28 g
RGR1	2.33±0.42	-18.18±7.48	-20.50
RGR2	-0.10±.08	-0.38±0.83	-0.28
RGR3	-0.06±0.02	4.43±0.71	4.50
RGR4	0.01±0.02	0.55±0.48	0.54
RGR5	-0.49±0.16	7.48±1.78	7.97
AFL	0.34±0.69 days	-35.22±17.13 days	-35.56 days
AFS	0.00006±0.00005 days	-30.24±14.34 days	-30.24 days
LS	-0.15±0.11	0.007±0.005	0.16

4.6 Genotyping the flock for *FecB* gene

Results of forced PCR-RFLP for all the samples were given in the Figure 4.21 to 4.32

Our present study found that all the 124 samples showed intact single band (140bp) under gel doc indicating that all the animals were non-carriers for *FecB*$^{++}$ gene and the frequency of non-carriers were found to be 100%. Since all the animals are non-carriers for *FecB* gene, there is no need for association studies.

* * *

Fig. 4.21-4.23: Genotypic pattern of 140 bp amplicon gene of *FecB* gene/*AvaII* forced PCR-RFLP from Muzaffarnagari sheep

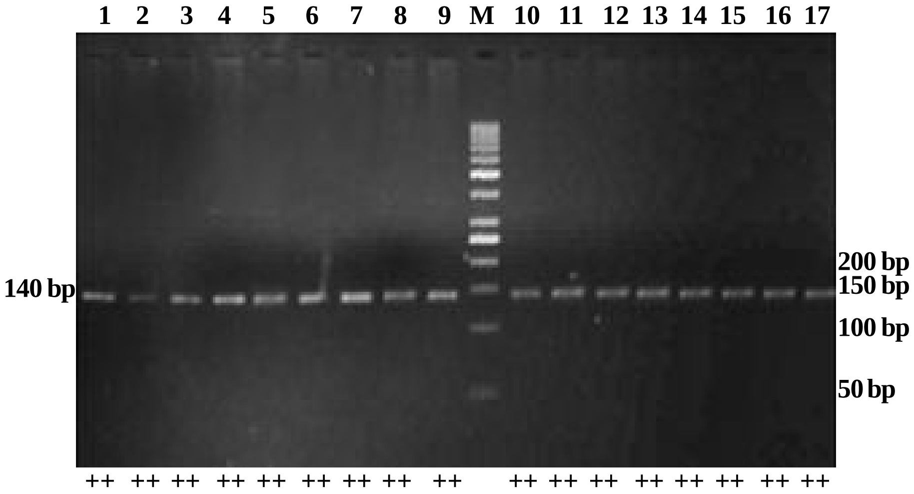


Fig. 4.21: **Lane M** : 50bp ladder
Lanes 1-17 : Homozygous non carrier (FecB^{++})

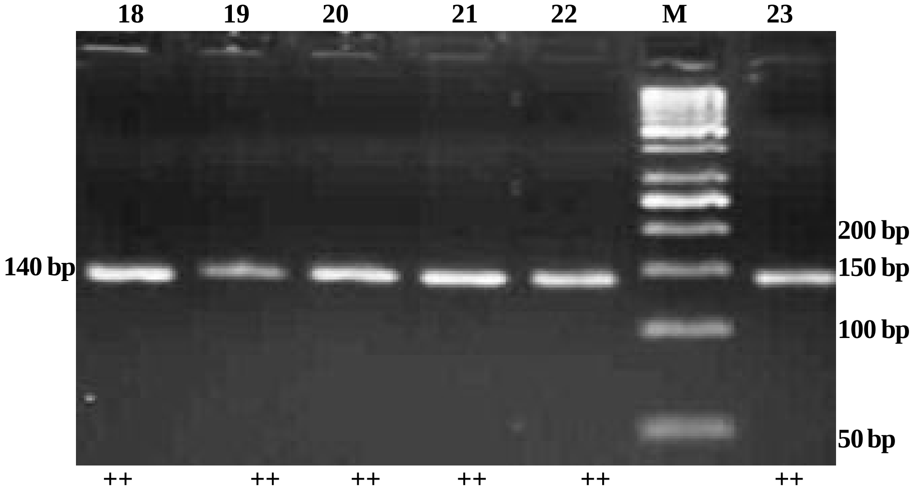


Fig. 4.22: **Lane M** : 50bp ladder
Lanes 18-23 : Homozygous non carrier (FecB^{++})

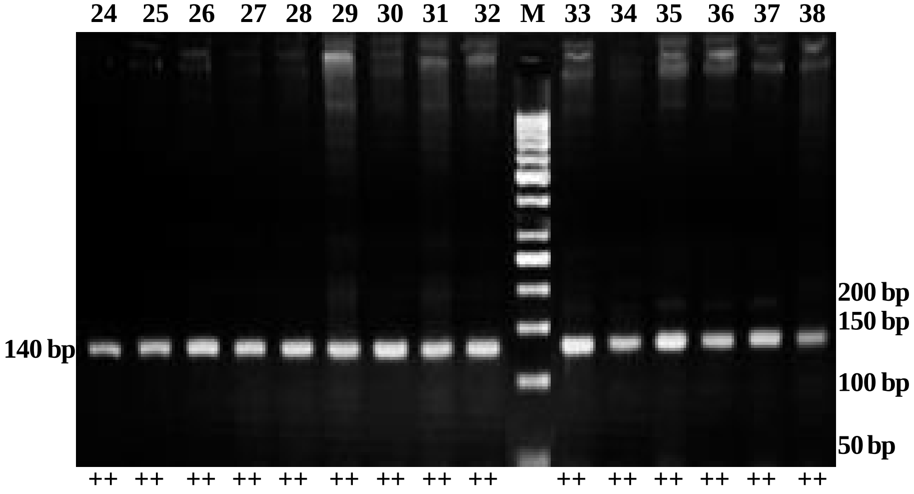


Fig. 4.23: **Lane M** : 50bp ladder
Lanes 24-38 : Homozygous non carrier (FecB^{++})

Fig. 4.24-4.26: **Genotypic pattern of 140 bp amplicon gene of *FecB* gene/*AvaII* forced PCR-RFLP from Muzaffarnagari sheep**

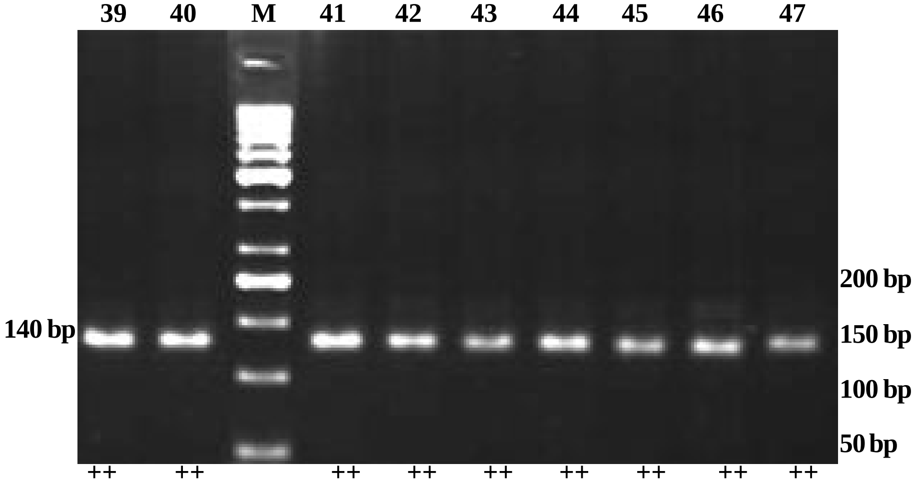


Fig. 4.24: Lane M : 50bp ladder
Lanes 39-47 : Homozygous non carrier (FecB^{++})

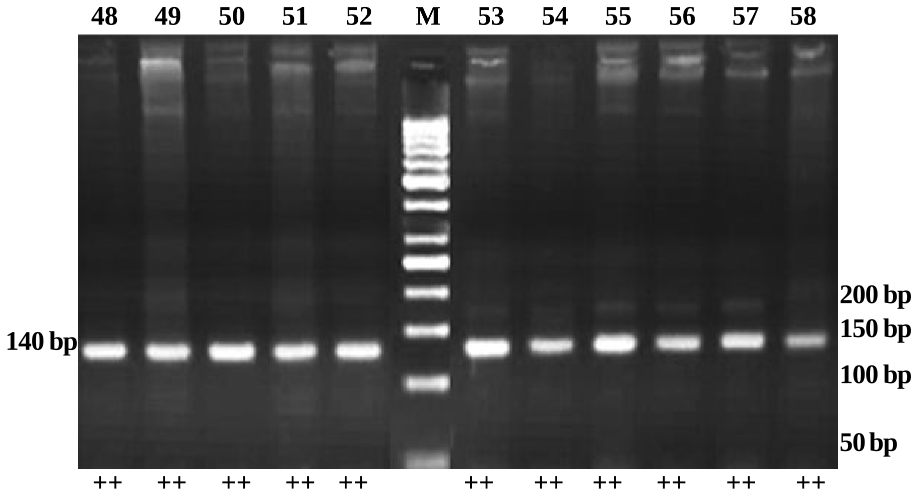


Fig. 4.25: Lane M : 50bp ladder
Lanes 48-58 : Homozygous non carrier (FecB^{++})

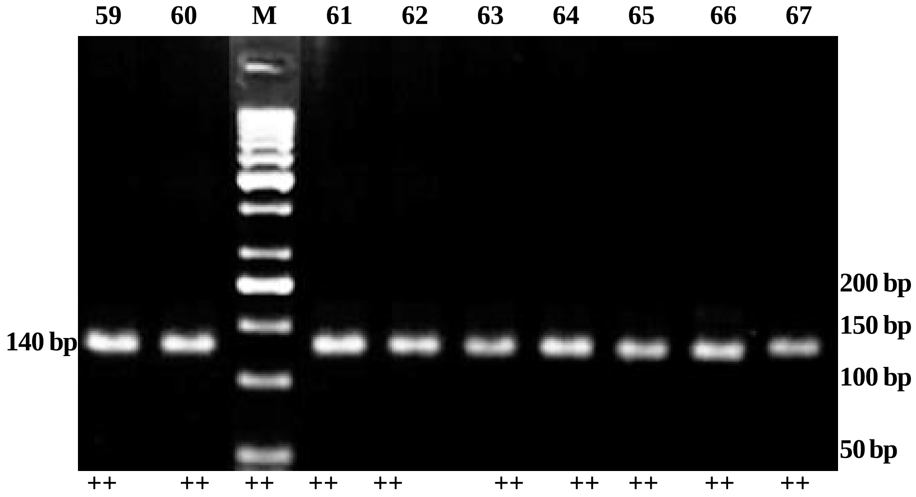


Fig. 4.26: Lane M : 50bp ladder
Lanes 59-67 : Homozygous non carrier (FecB^{++})

Fig. 4.27-4.29: Genotypic pattern of 140 bp amplicon gene of *FecB* gene/*AvaII* forced PCR-RFLP from Muzaffarnagari sheep

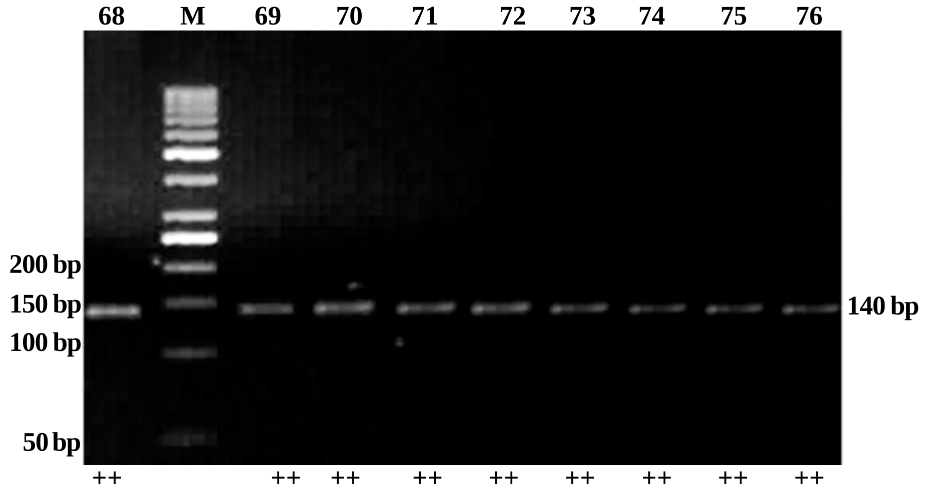


Fig. 4.27: **Lane M** : 50bp ladder
Lanes 68-76 : Homozygous non carrier (FecB^{++})

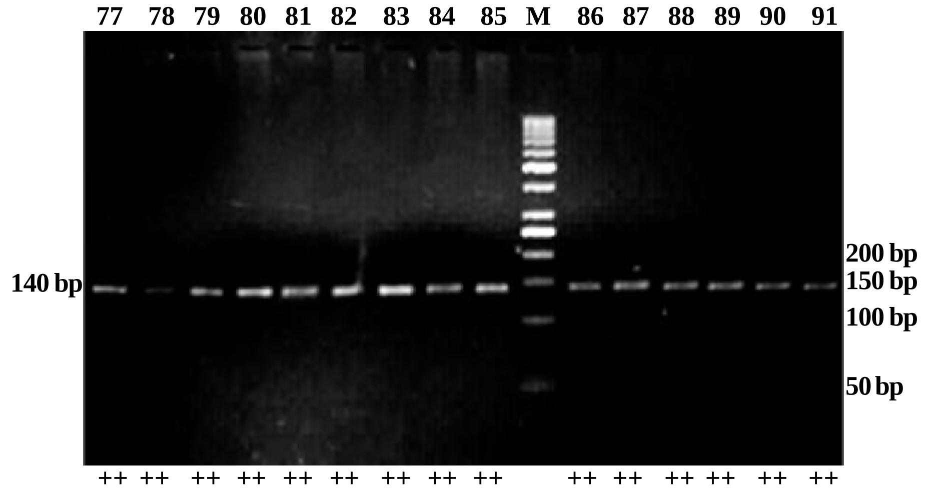


Fig. 4.28: **Lane M** : 50bp ladder
Lanes 77-91 : Homozygous non carrier (FecB^{++})

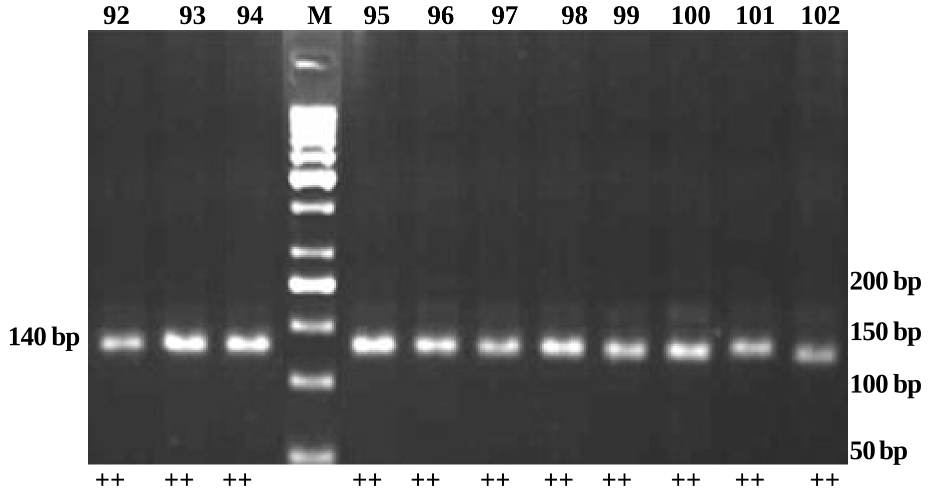


Fig. 4.29: **Lane M** : 50bp ladder
Lanes 92-102 : Homozygous non carrier (FecB^{++})

Fig. 4.30-4.32: Genotypic pattern of 140 bp amplicon gene of *FecB* gene/*AvaII* forced PCR-RFLP from Muzaffarnagari sheep

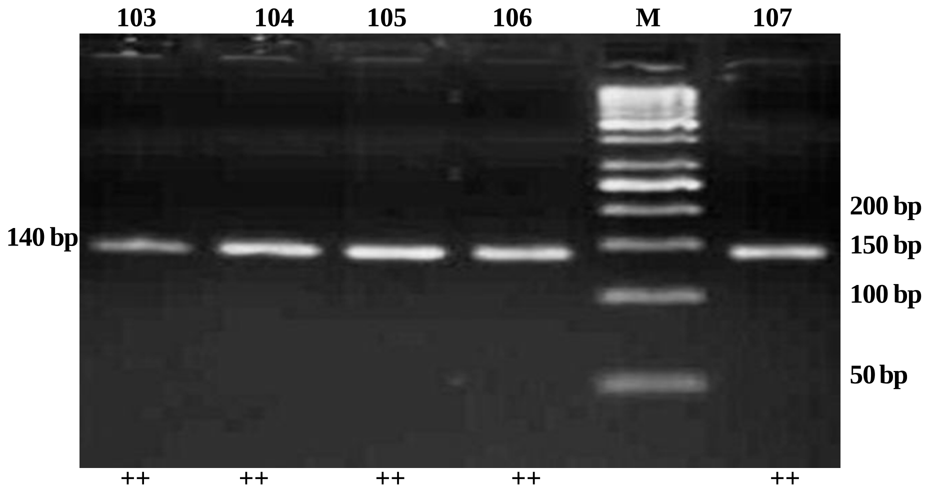


Fig. 4.30: Lane M : 50bp ladder
Lanes 103-107 : Homozygous non carrier (FecB^{++})

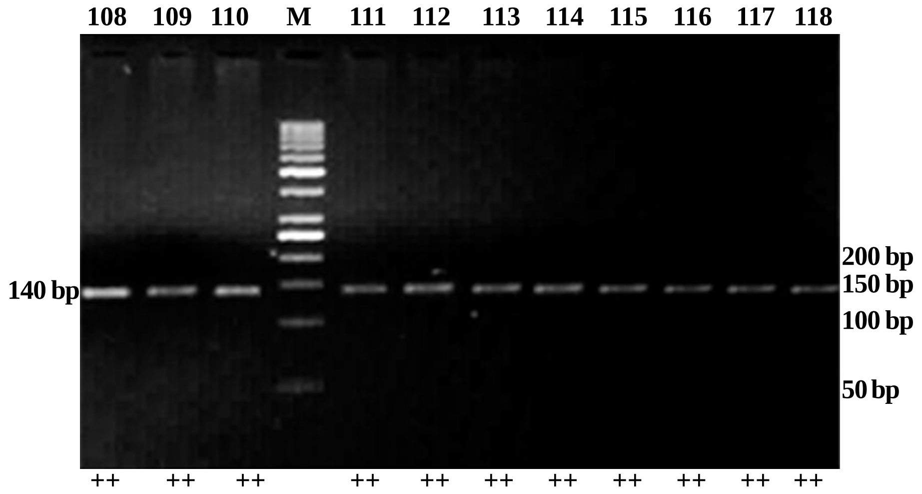


Fig. 4.31: Lane M : 50bp ladder
Lanes 108-118 : Homozygous non carrier (FecB^{++})

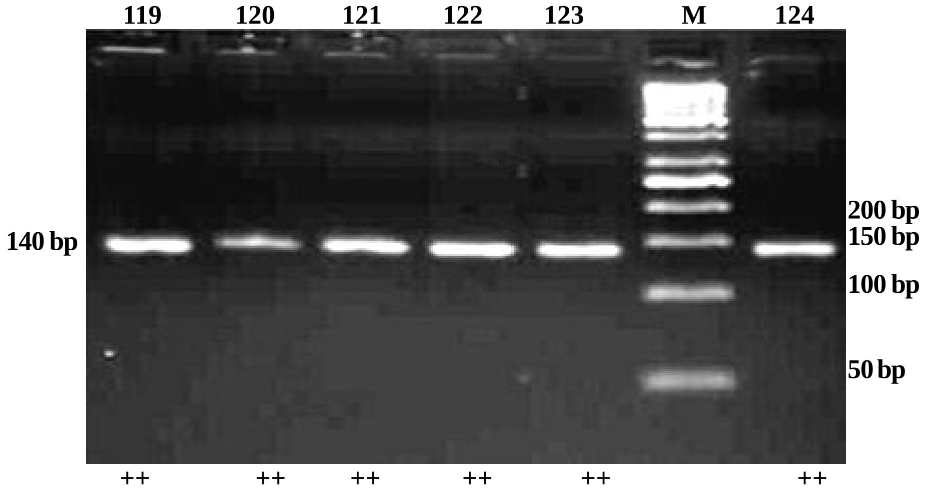
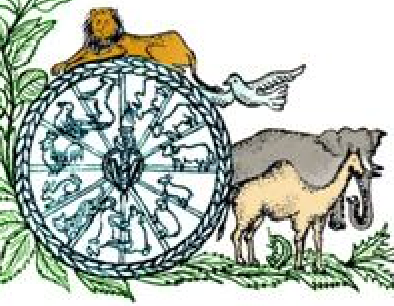


Fig. 4.32: Lane M : 50bp ladder
Lanes 119-124 : Homozygous non carrier (FecB^{++})

Discussion



5 DISCUSSION

5.1 Growth Performances

The least squares means along with standard error for growth traits are mentioned in the Table 4.1 to 4.3. It was observed that the increase in body weight during early ages was higher as compared with the later ages.

5.1.1 Weight at birth (BWT)

The least squares means along with standard error for BWT are presented in the Table 4.1. The overall least squares means for birth weight was 3.41±0.02 kg which was lower than the observation of Sinha and Singh (1997) (3.48±0.07 kg) and higher than the observation of Mandal *et al*. (2015) (3.14±0.01 kg) for this same breed.

On an average, the males were 0.14 kg heavier than the female lambs. Male lambs had shown increased weight 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 (Fourie *et al*., 1970). Similar findings was reported by Mandal *et al.* (2015) but Sinha and Singh (1997) showed no significance of sex on birth weight of animal.

Lambs born in S-1 (March-April) had significantly higher birth weight than lambs born in S-2 (October-November). It may be because of effect of the ambient temperature, since the ewes which gave birth on October-November had gestation during the hot and humid period of the year. This confirms the findings of Bhadula and Bhat (1980) and Mandal *et al.* (2015) and those of Carriedo *et al.* (1988) in a different breed of sheep.

The BWT was lowest in the period 4 (2003-2006) and highest in the period 2 (1995-1998). Due to the outbreak of sheep pox, performance of the flock had gone down in the mentioned period. As reported by Mandal *et al.* (2015), the significant differences in BWT among lambs born in different periods may be attributed to differences in management, selection of rams, and environmental conditions, such as the ambient temperature, humidity, rainfall etc. The latter affect the productivity of the pasture and the availability of the nutrients to the sheep grazing on the pasture. The periodic changes in the climate were reflected as differences in birth weight during different periods of the year. The significant effect of year of birth on the birth weight of lambs of this breed were reported by Sinha and Singh (1997) and Mandal *et al.* (2015). From the results of DMRT test as shown in the Table 4.1 it is depicted that period 1, 2, 3 and 6 are highly different from one another for birth weight. P-4 is similar to P-3 and P-7 is similar to P-6.

The relative competition between for nutrients between the still-growing ewes and the developing foetus may be the reason for the depression in birth weight in lambs born to younger ewes. The influence of the age of the ewe on her maternal effect on the birth weight of lamb i.e) fixed effect of parity had significant effect on birth weight. The maximum birth weight was in lambs born in parity 5. The change was largest from parity 1 to parity 2. A similar significant effect of parity of the dam on the body weights of lambs was observed by Mandal *et al.* (2015) in this breed. From DMRT test results in Table 4.1, it can be observed that only parity 1 is different from rest all other parities.

Single born lambs were heavier and significantly different from twins. This is because of maternal effect. Lambs born as single need not share its mother’s milk and time for caring is more, so that they are born as heavy lambs than twin born lambs. This finding is in accordance with the findings of Mandal *et al.* (2015) in this breed.

5.1.2 Weight at 3 months of age (WWT)

The least squares means along with standard error for WWT are shown in the Table 4.1. The overall least square means for WWT was lower (15.14 ± 0.17 kg) than the observation of Sinha and Singh (1997) which is 16.82 ± 0.37 kg and higher than the observation of Mandal *et al.* (2015) that is 14.70 ± 0.31 kg for this same breed.

Males had heavier weaning weight 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 (Fourie *et al.*, 1970). Same was reported by Mandal *et al.* (2015) and Sinha and Singh (1997) in this breed.

Lambs born in S-1 (March-April) had significantly higher WWT than lambs born in S-2 (October-November). This confirms the findings of Bhadula and Bhatt (1980) and Mandal *et al.* (2015) and those of Carriedo *et al.* (1988) in a different breed of sheep.

The WWT was lowest in the period 7 (2015-2017) and highest in the period 1 (1991-1994). Similar to the findings of Mandal in 2015, the significant differences in WWT among lambs born in different periods may be attributed to differences in management, selection of rams, and environmental conditions, such as the ambient temperature, humidity, rainfall and availability of feed and fodder along with the productivity of the pasture and the availability of the nutrients to the sheep grazing on the pasture. The periodic changes in the climate were reflected as differences in birth weight during different periods of the year. The effect of year of birth on the birth weight of lambs of this breed were reported by Sinha and Singh (1997) and Mandal *et al.* (2015).

The maximum WWT was in lambs born in 4th parity after which it decreases. The change was largest from parity 1 to parity 2. A similar significant effect of parity of the dam on the body weights of lambs was observed by Mandal *et al.* (2015) in this breed. According to Sezenler *et al.* (2016) parity of ewe had significant effect on the daily milk yield of ewes till 4th parity afterwards milk yield decreases because of ageing. This was one of the reason for higher growth of young ones upto 4th parity after which it decreases.

Single born lambs were heavier at weaning than multiple born lambs. This is because of maternal effect. Lambs born as single need not share its mother’s milk and time for caring is more, so that they are born as heavy lambs than twin born lambs. Mandal *et al.* (2015) also obtained the same result in Muzaffarnagari sheep.

5.1.3 Weight at 6 months of age (6WT)

The least squares means along with standard error for 6WT are depicted in the Table 4.1. The overall least squares means for 6WT was lower (22.91 ±0.22 kg) than the observation of Sinha and Singh (1997) which is 25.16 ± 0.41 kg and higher than the observation of Mandal *et al*. (2015) that is 21.39 ± 0.44 kg for this breed.

Males had heavier 6WT than females and it can be attributed to the differences in their endocrine system. Same was reported by Mandal *et al*. (2015) and Sinha and Singh (1997) in this breed.

Season had significant effect on 6WT ($P<0.05$).Lambs born in S-1 had significantly higher birth weights than lambs born in S-2, but by 6 months the lambs born in S-2 had significantly more weight than those born in S-1. The significant effect of the season of lambing on 6WT may be due to those lambs born in S-2 passing through a period with a favourable climate between January and April, when grazing of good quality fodder was available, while those born in S-1 spent the first 4 to 6 months of their life in a hot-humid climate and the rainy season (July-August), which confirms the findings of Bhadula and Bhat (1980), Sinha and Singh (1997) and Mandal *et al*. (2015) in this breed.

The 6WT was lowest in the period 7 (2015-2017) and highest in the period 1 (1991-1994). As reported by Mandal *et al.* (2015), the significant differences in 6WT among lambs born in different periods may be attributed to differences in management, selection of rams, and environmental conditions, such as the ambient temperature, humidity, rainfall etc. The latter affect the productivity of the pasture and the availability of the nutrients to the sheep grazing on the pasture. The periodic changes in the climate were reflected as differences in birth weight during different periods of the year. The effect of year of birth on the birth weight of lambs of this breed were reported by Sinha and Singh (1997) and Mandal *et al*. (2015).

Parity is non-significant on 6WT. The maximum 6WT was in lambs born in 4th parity after which it decreases. The change was largest from parity 1 to parity 2. A similar significant effect of parity of the dam on the body weights of lambs was observed by Mandal *et al*. (2015) in this breed. According to Sezenler *et al*. (2016) parity of ewe had significant effect on the daily milk yield of ewes till 4th parity afterwards milk yield decreases because of ageing. This was one of the reason for higher growth of young ones upto 4th parity after which it decreases.

Single born lambs were heavier at all body weights than multiple born lambs. This is because of maternal effect. Lambs born as single need not share its mother's milk and time for caring is more, so that they are born as heavy lambs than twin born lambs. Mandal *et al*. (2015) also got the same result in Muzaffarnagari sheep.

5.1.4 Weight at 9 months of age (9WT)

The least squares means along with standard error for 9WT are mentioned in the Table 4.1. The overall least squares means for 9WT was higher 27.25 ± 0.23 kg than the observation of Mandal *et al*. (2015) which is 24.69 ± 0.48 kg for this breed.

Males had heavier 9WT than females and it can be attributed to the differences in their endocrine system. Same was reported by Mandal *et al*. (2015) in this breed.

Season of birth had highly significant effect ($P<0.01$) on 9WT. Lambs born in S-1 had significantly higher birth weights than lambs born in S-2, but by 6 and 9 months the lambs born in S-2 had significantly more weight than those born in S-1. The significant effect of the season of lambing on 9WT may be due to those lambs born in S-2 passing through a period with a favourable climatic conditions between January and April, when grazing of good quality fodder was available, while those born in S-1 spent the first 4 to 6 months of their life in a hot-humid climate and the rainy season (July-August), which confirms the findings of Bhadula and Bhat (1980) and Mandal *et al*. (2015) in this breed.

The 9WT was lowest in the period 4 (2003-2006) and highest in the period 1 (1991-1994). As reported by Mandal *et al.* (2015), the significant differences in 9WT among lambs born in different periods may be attributed to differences in management, selection of rams, and environmental conditions, such as the ambient temperature, humidity, rainfall etc. and availability of feed and fodder along with the productivity of the pasture and the availability of the nutrients to the sheep grazing on the pasture. The periodic changes in the climate were reflected as differences in birth weight during different periods of the year. The effect of year of birth on the birth weight of lambs of this breed was reported by Mandal *et al*. (2015).

Parity is non-significant on 9WT. The maximum 9WT was in lambs born in 4th parity after which it decreases. The change was largest from parity 1 to parity 2. A similar significant effect of parity of the dam on the body weights of lambs was observed by Mandal *et al*. (2015) in this breed. According to Sezenler *et al*. (2016) parity of ewe had significant effect on the daily milk yield of ewes till 4th parity afterwards milk yield decreases because of ageing. This was one of the reason for higher growth of young ones upto 4th parity after which it decreases.

Single born lambs were heavier at all body weights than multiple born lambs. This is because of maternal effect. Lambs born as single need not share its mother's milk and time for caring is more, so that they are born as heavy lambs than twin born lambs. Mandal *et al*. (2015) also got the same result in Muzaffarnagari sheep.

5.1.5 Weight at 12 months of age (12WT)

The least squares means along with standard error for 12WT are mentioned in the Table 4.1. The overall least squares means for 12WT was higher 31.33 ± 0.24 kg than the observation of Mandal *et al*. (2015) which is 27.99 ± 0.58 kg for this breed.

Males had heavier 12WT than females and it can be attributed to the differences in their endocrine system. Same was reported by Mandal *et al*. (2015) in this breed.

Lambs born in S-1 had significantly higher birth weights than lambs born in S-2, but after 6 months the lambs born in S-2 had significantly more weight than those born in S-1. The significant effect of the season of lambing on 12WT may be due to those lambs born in S-2 passing through a period with a favourable climatic conditions between January and April, when grazing and stall feeding of good quality fodder was available, while those born in S-1 spent the first 4 to 6 months of their life in a hot-humid climate and the rainy season (July-August), which confirms the findings of Bhadula and Bhat (1980) and Mandal *et al*. (2015) in this breed.

The 12WT was lowest in the period 2 (1995-1998) and highest in the period 1 (1991-1994), still as a break in the increasing trend, low performance was noticed in the period 4

(2003-2006). As reported by Mandal *et al*. (2015), the significant differences in 12WT among lambs born in different periods may be attributed to differences in management, selection of rams, and environmental conditions, such as the ambient temperature, humidity, rainfall etc. and availability of feed and fodder along with the productivity of the pasture and the availability of the nutrients to the sheep grazing on the pasture. The periodic changes in the climate were reflected as differences in birth weight during different periods of the year. The effect of year of birth on the birth weight of lambs of this breed was reported by Mandal *et al*. (2015).

Parity is non-significant on 12WT. The maximum 12WT was in lambs born in 4th parity after which it decreases. The change was largest from parity 1 to parity 2. A similar significant effect of parity of the dam on the body weights of lambs was observed by Mandal *et al*. (2015) in this breed. According to Sezenler *et al*. (2016) parity of ewe had significant effect on the daily milk yield of ewes till 4th parity afterwards milk yield decreases because of ageing. This was one of the reason for higher growth of young ones upto 4th parity after which it decreases.

Single born lambs were heavier at all body weights than multiple born lambs. This is because of maternal effect. Lambs born as single need not share its mother’s milk and time for caring is more, so that they are born as heavy lambs than twin born lambs. Mandal *et al*. (2015) also got the same result in Muzaffarnagari sheep.

5.1.6 Ewe’s weight at service (EWTS)

The least squares means along with standard error for EWTS are mentioned in the Table 4.1. No information regarding EWTS was available in the literature for this breed. The overall least squares mean for EWTS was 38.42±0.32 days. Sex and season of lambing had no significant effect on EWTS and no significant differences could be observed among the values.

Almost increasing least square means was observed for various periods in ascending order. Highest value observed in the period 6 (2011-2014) and lowest being period 1 (1991-1994). As reported by Mandal *et al*. (2015), the significant differences in EWTS among lambs born in different periods may be attributed to differences in management, selection of rams, and environmental conditions, such as the ambient temperature, humidity, rainfall etc. The latter affect the productivity of the pasture and the availability of the nutrients to the sheep grazing on the pasture. The periodic changes in the climate were reflected as differences in birth weight during different periods of the year.

Parity is highly significant on EWTS with highest least square mean observed in parity 5. Increasing performance can be observed for increasing parity. According to Sezenler *et al*. (2016) parity of ewe had significant effect on the daily milk yield of ewes till 4th parity afterwards milk yield decreases because of ageing. This was one of the reason for higher growth of young ones upto 4th parity after which it decreases.

Type of birth is highly significant on EWTS. It is obvious that ewes bearing twin lambs have increased weight than the one bearing single lamb.

5.1.7 Ewe's weight at lambing (EWTL)

The least squares means along with standard error for EWTL are mentioned in the Table 4.1. No information regarding EWTL was available in the literature for this breed. The overall least squares mean of EWTL was 39.64±0.38 days. Sex and season of lambing had no significant effect on EWTL and no significant differences could be observed among the values.

Highest value observed in the period 3 (1999-2002) and lowest being period 4 (2003-2006). Lowest performance observed during period 4 could be because of pox incidence. As reported by Mandal *et al*. (2015), the significant differences in EWTL among lambs born in different periods may be attributed to differences in management, selection of rams, and environmental conditions, such as the ambient temperature, humidity, rainfall etc. The latter affect the productivity of the pasture and the availability of the nutrients to the sheep grazing on the pasture. The periodic changes in the climate were reflected as differences in birth weight during different periods of the year.

Parity is highly significant on EWTL with highest least square mean observed in parity 4 after which it decreases. According to Sezenler *et al*. (2016) parity of ewe had significant effect on the daily milk yield of ewes till 4th parity afterwards milk yield decreases because of ageing. This was one of the reason for higher growth of young ones upto 4th parity after which it decreases.

Type of birth is highly significant on EWTL. It is obvious that ewes bearing twin lambs have increased weight than the one bearing single lamb.

5.1.8 Average daily gain from birth to 3 months (ADG1) (pre weaning)

The least squares means along with standard error for ADG1 are mentioned in the Table 4.2. The overall least squares means for ADG1 was lower (130.31 ± 1.78 g) than the observation of Sinha and Singh (1997) which is 148.2 ± 3.9 g and higher than the observation of Mandal *et al*. (2015) which is 127.8 ± 3.33g for this breed.

As reported by Mandal *et al*. (2015), except season of lambing, all fixed effects had significant effect on pre weaning ADG (ADG1) in this breed. Male animals had higher ADG1 than female animals. Lambs born in S-1 had higher ADG1 than lambs born in S-2.

ADG1 was lowest in period 7 (2015-2017) and highest in period 1 (1991-1994). As reported by Mandal *et al*. (2015), the significant differences in ADG1 among lambs born in different periods may be attributed to differences in management, selection of rams, and environmental conditions, such as the ambient temperature, humidity, rainfall etc. The latter affect on the productivity of the pasture and the availability of the nutrients to the sheep grazing on the pasture. The periodic changes in the climate were reflected as differences in birth weight during different periods of the year. The effect of year of birth on the birth weight of lambs of this breed was reported by Mandal *et al*. (2015) and Sinha and Singh (1997). From DMRT test results in Table 4.2, it can be seen that P-1, 2 and 3 are different from one another. P-3 and 4 are not different from each other and P-6 and 7 are not different from P-1.

The daily weight gain of the lambs born to the ewes born in their second parity was higher than that of lambs from younger or older ewes during the pre weaning stage. ADG1 increased from first to second parity and therafter it decreased substantially with each increment in the parity of dam. The results of DMRT in Table 4.2, revealed that only parity 1 is different from other parities.

Pre weaning average daily gain were inversely proportional to type of birth. Single born lambs were heavier and slightly different from twins. Difference in weights at different seasons will be due to the availability of fodder, environmental and managemental conditions that prevailed during that season. It is noticed from the Table 4.2, that ADG1 has highest and ADG4 has lowest overall least square means which indicates that from economic point of view farmers should not keep animals after 10 to 12 months.

5.1.9 Average daily gain from 3 to 6 months (ADG2)

The least squares means along with standard error for ADG2 are mentioned in the Table 4.2. The overall least square means for ADG2 was lower (86.48 ± 1.55 g) than the observation of Sinha and Singh (1997) which is 92.5 ± 3.7 g on this breed.

As reported by Mandal *et al*. (2015), sex, season and year had significant effect on ADG2, in addition type of birth also had significant effect on ADG2 and ADG5 and not on any other post weaning ADG.

Male animals had higher ADG2 than female animals. Lambs born in S-2 had higher ADG2 than the lambs born in S-1. The significant effect of the season of lambing on ADG2 may be due to those lambs born in S-2 passing through a period with a favourable climate between January and April, when grazing of good quality fodder was available, while those born in S-1 spent the first 4 to 6 months of their life in a hot-humid climate and the rainy season (July-August), which confirms the findings of Bhadula and Bhat (1980) and Mandal *et al*. (2015) in this breed. ADG2 was highest in period 1 (1991-1994) and lowest in period 7 (2015-2017).

The maximum ADG2 was in lambs born in 4th parity after which it decreases. A similar results was observed by Mandal *et al*. (2015) in this breed. As per lactation physiology, bovines and ovines expressed maximum genetic potential of production of milk yield generally in 3rd and 4th parity. According to Sezenler *et al*. (2016) parity of ewe had significant effect on the daily milk yield of ewes till 4th parity afterwards milk yield decreases because of ageing. This was one of the reason for higher growth of young ones upto 4th parity after which it decreases.

The difference in the rate of weight gain per day for single-born lambs compared to multiple-born lambs was 24.55 g up to weaning after which it had reduced. This report is in confirmation with the report given by Mandal *et al.* (2015) in the same breed. The differences of growth rate during the different phases might be due to the variation in environmental and managemental conditions. During post-weaning phase, lambs were deprived of maternal support and had to depend upon themselves in procuring the feed and also the experience stress during grazing. Further growth rate depended on the availability of pasture and competition from grazing mates.

5.1.10 Average daily gain from 6 to 9 months (ADG3)

The least squares means along with standard error for ADG3 are mentioned in the Table 4.2. The overall least squares means for ADG3 was higher (47.75 ± 1.31 g) than the observation of Arthy *et al.* (2018) which is 43.00 g in Madras Red sheep.

As reported by Mandal *et al.* (2015), sex, season and year only had significant effect on ADG3. Male animals had higher ADG3 than female animals. Lambs born in S-2 had higher ADG3 than the lambs born in S-1. ADG3 was highest in period 7 (2015-2017) and lowest in period 1 (1991-1994). The difference in the rate of weight gain per day for single-born lambs compared to multiple-born lambs was 24.55 g up to weaning after which it had reduced. This report is in confirmation with the report given by Mandal *et al.* (2015) in the same breed.

5.1.11 Average daily gain from 9 to 12 months (ADG4)

The least squares means along with standard error for ADG4 are given in the Table 4.2. The overall least squares means for ADG4 was higher (46.71 ± 1.33 g) than the observation of Arthy *et al.* (2018) which is 34.21 g in Madras Red sheep.

As reported by Mandal *et al.* (2015), sex, season and year only had significant effect on ADG4. Male animals had higher ADG4 than female animals. Lambs born in S-2 had higher ADG4 than the lambs born in S-1. Lambs born in S-2 had higher ADG2 than the lambs born in S-1. The significant effect of the season of lambing on ADG2 may be due to those lambs born in S-2 passing through a period with a favourable climate between January and April, when grazing of good quality fodder was available, while those born in S-1 spent the first 4 to 6 months of their life in a hot-humid climate and the rainy season (July-August), which confirms the findings of Bhadula and Bhat (1980) and Mandal *et al*. (2015) in this breed. ADG4 was highest in period 7 (2015-2017) and lowest in period 2 (1995-1998).

The difference in the rate of weight gain per day for single-born lambs compared to multiple-born lambs was 24.55 g up to weaning after which it had reduced. This report is in confirmation with the report given by Mandal *et al*. (2015) in the same breed.

5.1.12 Average daily gain from 3 to 12 months (ADG5) (post weaning)

The least squares means along with standard error for ADG5 are shown in the Table 4.2. The overall least squares means for ADG5 was higher (58.86 ± 0.77 g) than the observation of Mandal *et al*. (2015) which is 49.4 ± 1.60 g in the same breed.

As reported by Mandal *et al*. (2015), Sex, season, period and type of birth had significant effect on ADG5. Male animals had higher ADG5 than female animals. Lambs born in S-2 had higher post weaning daily gain than the lambs born in S-1. Highest ADG5 was observed in the period 7 (2015-2017) and lowest in the period 2 (1995-1998). Increase in ADG5 was observed till parity 5.

The difference in the rate of weight gain per day for single-born lambs compared to multiple-born lambs was 24.55 g up to weaning after which it had reduced to -3.36 g by 12 months of age. This report is in confirmation with the report given by Mandal *et al*. (2015) in the same breed.

5.1.13 Relative Growth Rate (RGR)

The least squares means along with standard error for RGR are mentioned in the Table 4.3. Pre (RGR1) and post weaning RGR (RGR5) of the breed were 353.32 ± 5.27 and 111.03 ± 1.91 respectively. Values observed in our present study is higher than the values obtained by Mandal *et al*. (2015). Male animals showed higher pre and post weaning RGR. Animals born in S-1 had higher RGR values at all the stages of development. The efficiency of pre weaning RGR decreased with increase in parity upto 5th parity. Animals of multiple births exhibited greater pre and post RGR than animals born as singles. These results were in accordance with the results obtained by Mandal *et al.* (2015) in the same breed.

5.2 Performance of reproduction traits

5.2.1 Age of ewe at first lambing (AFL)

The least squares means along with standard error for AFL are depicted in the Table 4.4. The overall least squares means of AFL observed from the present study was 698.87 ± 73.94 days which is lower than the value observed by Umeel *et al.* (2018) in Munjal sheep showing better performance of animals of Muzaffarnagri sheep. Year of birth alone had high significance over AFL which is same as observed by Umeel *et al.* (2018) in Munjal sheep.

Animals born in S-1 had higher AFL than the animals born in S-2 showing better performance of S-2 born animals. Lambs born in October-November pass through a favourable climate between January and April when grazing material of good quality was available, This might be the reason for S-2 born animals to attain lambing age faster than the S-1 born animals.

Highest AFL observed in period 2 (1995-1998) whereas lowest observed in period 3 (1999-2002) and better performance. The present finding were in close agreement with those reported by Gowane *et al.* (2015) in Malpura sheep and Umeel *et al.* (2018) in Munjal sheep

Single born animals had lower AFL than the multiple born animals. This is because of maternal effect. Lambs born as single need not share its mother’s milk and time for caring is more, so that they are born as heavy lambs than twin born lambs.

5.2.2 Age of ewe at first service (AFS)

The least squares means along with standard error for AFS are mentioned in the Table 4.4. The overall least squares means of AFS found from the present study was 599.54 ± 8.54 days which is higher than the observation of Umeel *et al.* (2018) in Munjal sheep (563.08 ± 14.43 days). Year of birth alone had high significance over AFS which is same as observed by Umeel *et al.* (2018) in Munjal sheep.

Animals born in S-2 had lower AFS than the animals born in S-1. Lowest AFS was observed in period 7 (2015-2017) and highest AFS was observed during the period 2 (1995-

1998). The present finding were in close agreement with those reported by Gowane *et al.* (2015) in Malpura sheep and Umeel *et al.* (2018) in Munjal sheep.

Single born animals had lower AFL than the multiple born animals. This is because of maternal effect. Lambs born as single need not share its mother's milk and time for caring is more, so that they are born as heavy lambs than twin born lambs.

5.2.3 Litter Size (LS)

The least squares means along with standard error for AFL are given in the Table 4.4. The overall least squares means of LS observed was 1.07 ± 0.02 lower than the one observed in by Handford (2006) in Polypay breed of USA (1.77 ± 0.86).

Season alone had significant effect on LS. Animals born in S-1 had slightly higher LS (1.08 ± 0.02) than the animals born in S-2 (1.06 ± 0.02). LS was highest in period 5 (1.1 ± 0.03) and lowest in period 2 and 3 (1995-2002).

5.3 Genetic and Phenotypic parameters

The genetic and phenotypic parameters that reflect the genetic architecture of a population are heritability, phenotypic and genetic correlations. The heritability, genetic and phenotypic correlations among different body weights were estimated and presented in Table 4.5 to 4.33. The heritability of trait gives an idea of the proportion of genetic variance in population for a particular trait. Many economic traits in sheep are correlated with each other. Phenotypic correlations among different traits are the results of combination of genetic and environmental correlations.

5.3.1 (Co) Variance components and heritability

Covariance and variance components using various REML models for growth and reproduction traits are depicted in Table 4.5 to 4.24.

5.3.1.1 Body weight traits

Generally, model 1 which includes only animal additive genetic effects give biased results, whereas model 2 consists both animal and maternal genetic effects may give better estimates of direct heritability. But in our study, we found that model 3 resulted in lowest BIC values for all the traits and considered as the best model in explaining the variability in all the traits. This model includes animal and dam genetic effects along with the covariance between the effects. Model 4 includes maternal permanent environment, model 5 includes both dam genetic and environmental effects, and model 6 includes all the effects along with the covariance between the effects. Model 6 like model 3 yielded better estimates, but based on the BIC values, model 3 is chosen as the best model.

The appropriate models for all the traits showed that maternal genetic effect is important in case of all the traits. The direct heritability estimates for all the body weights from the best model is almost high except for BWT (0.29), EWTS (0.05) and EWTL (0.02). The higher heritability estimates suggested that body weights was mostly affected by individual genes and less affected by environmental factors. The moderate heritability in case of BWT suggested that better nutritional status and body condition score of ewe at lambing time had resulted in favourable environmental conditions which allowed the expression of animal own genes. Adding value to the above mentioned point the only trait which has positive covariance (0.14) between animal and maternal effect in our study is BWT only. The reported direct (0.29) and maternal (0.31) heritability is much higher than the value reported by Mandal *et al*. (2015) as 0.15 and 0.12 and Mandal *et al.* (2006) in the same breed 0.09 and 0.07 respectively.

The direct heritability estimate of WWT in the present study was 0.37 which is higher than the value obtained by Mandal *et al*. (2015) as 0.16. Heritability estimate of 6WT, 9WT and 12WT in the present study were 0.47, 0.34 and 0.41 respectively and were higher than the observations of Mandal *et al.* (2003) in the same breed.

The estimates obtained in this study were almost moderate indicating response to selection and genetic gain will be moderate.

5.3.1.2 Growth rate traits (ADG and RGR)

Based on the BIC values model 3 seemed to be the best model for all the growth efficiency traits except for RGR1 for which model 2 holded the best.

The heritability of pre weaning ADG (ADG1) from our present study under best model was 0.37 which is higher than the observation of Mandal *et al.* (2003) (0.19) in the same breed. The heritability estimate of post weaning ADG (ADG5) in our study was 0.41 which is also higher than the report of Mandal *et al.* (2003) in the same breed.

The appropriate models for all the traits showed that maternal genetic effect is important in case of all the traits. The direct heritability estimates for all the traits were high except for some of post weaning growth efficiency traits such as ADG3 (0.25), ADG4(0.26), RGR3 (0.29) and RGR4 (0.28) all of which showed moderate heritability.

The higher heritability estimates suggested that body weights was mostly affected by individual genes and less affected by environmental factors. Moderate heritability of some of the post weaning growth efficiency traits indicated that moderate genetic progress would be possible from selection. The lower estimates of heritability for post weaning growth efficiency traits may be due to lack of favourable conditions during grazing and also, the lambs were deprieved of maternal support as the suckling of milk was stopped after weaning, further, animals weaned during summer may not gain body weight due to exposure to unfavourable conditions in the grazing field like scarcity of pasture and competition from grazing mates in the grazing area. During pre weaning period all the animals are reared almost under uniform favourable management conditions. Hence, the environmental differences among the animals were minimum leading to the better expression of animal genes and thus better heritability estimates could be obtained during this period. Whereas increased harsh environmental conditions in the environmental conditions in a population maximizes the residual variance and may yield lowered estimate of heritability during the post weaning period and in general the additive genetic variability of a quantitative trait in a population changes with the environmental differences, so the magnitude of heritability of metric traits changes. Falconer and Mackay (1996) opined that environmental variance is a property of genotype up to some extent, where certain genotypes are more sensitive to the environmental differences and it is concluded that post weaning phase may generate huge variation in terms of environment and results in lowered estimates of heritability than pre weaning phase.

The estimates obtained in this study were moderate to low indicating response to selection will be slow.

5.3.2 Genetic and phenotypic correlation among growth and reproduction traits

The genetic and phenotypic correlation among various studied traits are represented in Table 4.25 to 4.33. Precise estimates of genetic correlations are important to identify early available traits that could bring about change in desired traits through indirect selection. Indirect selection also provides scope for better intensity of selection by selection in both the sexes.

5.3.2.1 Genetic and phenotypic correlation among growth traits

The genetic and phenotypic correlation between BWT and WWT, 6WT, 9WT, 12WT, EWTS and EWTL were positive and varied from low to high. Our results are in agreement with the findings of Mandal *et al.* (2015), Sinha and Singh (1997), Bhadula and Bhat (1980) and Mandal *et al.* (2003) in the same breed. The genetic and phenotypic correlation of BWT with pre weaning ADG (ADG1) was low and positive which confirms the findings of Sinha and Singh (1997), Mandal *et al*. (2015) and Mandal *et al.* (2003). The genetic and phenotypic correlation of BWT with pre weaning RGR (RGR1) was low and negative and this is in confirmation with the results of Mandal *et al.* (2003) in the same breed.

The genetic and phenotypic correlation between WWT and 6WT, 9WT, 12WT, EWTS and EWTL were high and positive and this confirms the results of Mandal *et al*. (2015), Sinha and Singh (1997), Bhadula and Bhat (1980) and Mandal *et al.* (2003) in this breed. WWT had high and positive genetic and phenotypic correlation with pre weaning ADG (ADG1) and RGR (RGR1) and this is in accordance with the results of Mandal *et al*. (2015) and Mandal *et al*. (2003) in the same breed. Duguma *et al*. (2002) stated that WWT and ADG are phenotypically the same traits, thus selection can be performed based on one of these traits. The high and positive direct genetic and phenotypic correlations between WWT and other traits in the present study indicates that if selection is thus based on WWT, improvement in all the components of growth traits may follow. WWT was negatively correlated with post weaning ADG and this result is in slight modification with the findings of Mandal *et al.* (2003) in which WWT and post weaning ADG were phenotypically negatively correlated but genetically positively correlated. The high and positive direct genetic and phenotypic correlations between WWT and other traits in the present study indicates that if selection is thus based on WWT, improvement in all the components of growth traits may follow.

6WT had high and positive phenotypic and genetic correlation with 9WT and 12WT and similarly 9WT had high and positive genetic and phenotypic correlation with 12WT and it confirms the findings of Mandal *et al.* (2003) in the same breed.

6WT, 9WT and 12WT had high and positive correlation with pre and post weaning ADG and the same results were obtained by Mandal *et al*. (2003) in the same breed. 6WT and 9WT had positive genetic and phenotypic correlation with pre weaning RGR (RGR1) and had negative genetic and phenotypic correlation with post weaning RGR (RGR5) and this is in accordance with the results of Mandal *et al*. (2003) in the same breed. 12WT had positive genetic and phenotypic correlation with both pre and post weaning RGR and this confirms the results of Mandal *et al*. (2003) in the same breed.

Negative genetic and phenotypic correlation existed between pre and post weaning ADG. Abegaz *et al*. (2005) suggested that negative correlations between pre and post weaning ADGs would be resulted due to compensatory growth of some poorly nursed lambs in the post weaning period. This is in slight modification from the results obtained by Mandal *et al.* (2003) in the same breed where in which pre and post ADG had negative correlation phenotypically and positive correlation genetically.

The moderately high genetic correlations between BWT and other body weights in this study indicate that the selection for increased BWT can result in genetic improvement in the subsequent development of body weights. Since WWT has high and positive correlation with most of the traits, improvement in body weight could be attained by selection on WWT.

5.3.2.2 Reproduction Traits

The heritability estimates of AFS and AFL was 0.00 ± 0.04 and 0.34 ± 0.10 respectively as calculated from the best model. Heritability estimate of AFS is lower and heritability estimate of AFL is higher than the estimated value of Umeel *et al.* (2018) in Munjal breed of sheep. The heritability estimate of LS in the present study was 0.59 ± 0.24 which is higher than the estimate obtained by Handford (2006) in Polypay breed of USA. Low estimates of heritability for reproduction traits indicated that these traits are mostly influenced by managemental and environmental factors and it can be improved by better managemental practices.

The genetic correlation of AFS with AFL was high and positive (0.96 ± 0.01) and phenotypic correlation of AFS with AFL was also high and positive (0.97 ± 0.01). The genetic correlation of LS with AFS and AFL were high and positive (0.82 and 0.87) but phenotypic correlation was low (0.03 and 0.04) respectively. Results of AFS and AFL were in accordance with the findings of Umeel *et al.* (2018) in Munjal sheep. Genetic and phenotypic correlation of reproduction traits with growth traits were mostly negative.

The magnitude of association was more between AFS and AFL. The genetic correlations between traits pointed forward the conclusion that the early maturing ewes should be selected to have lower age at first lambing.

5.4 Genetic, phenotypic and environmental trends of all traits

The estimates of genetic, phenotypic and environmental trends are given in the Table 4.34. The genetic and phenotypic trends for all growth and reproduction traits are graphically represented in the Figure 4.1 to 4.20. The genetic trends of most of the traits were positive. Increasing genetic trends of BWT, WWT, 6WT, 9WT, 12WT, EWTS and EWTL indicate that the genetic improvement of flock has been attained for the mentioned traits from 1991 to 2017. Some of the traits showing negative trend such as ADG3, RGR2, RGR3 and RGR5 which might be because of the negative correlation between the body weight traits with these traits. The above findings were in confirmation with the findings of Balasubramaniyam *et al.* (2012) and Arthy *et al.* (2018) in Madras Red sheep.

The environmental trends was also mostly low indicating that the though genetic improvement takes place in the flock, since there is no parallel improvement in the environment in the flock, phenotypic trends when visualized, improvement cannot be observed to the expected response to selection for some traits. Traits showing high environmental trends such as ADG3 and RGR5 (post weaning traits) were highly influenced positively by the environment.

The results for phenotypic trends shows that most of the traits showed positive trend. Our results were in close conformity with the results of Balasubramaniyam *et al.* (2012) and Arthy *et al.* (2018) but in our present investigative negative phenotypic trend was present for WWT and 6WT. The phenotypic trends for most of the traits were positive indicating overall positive change in the Muzaffarnagari flock maintained at CIRG, Mukhdoom.

The genetic trends for AFS and AFL had increased and LS had slightly decreased. Negative correlation between growth traits and reproductive traits could be the reason for this. It might also be due to inbreeding because of small flock size, and the base population was a flock of elite animals selected and purchased from field. Undesirable trends for AFS and AFL were in accordance with the result obtained by Umeel *et al.* (2018) in munjal sheep.

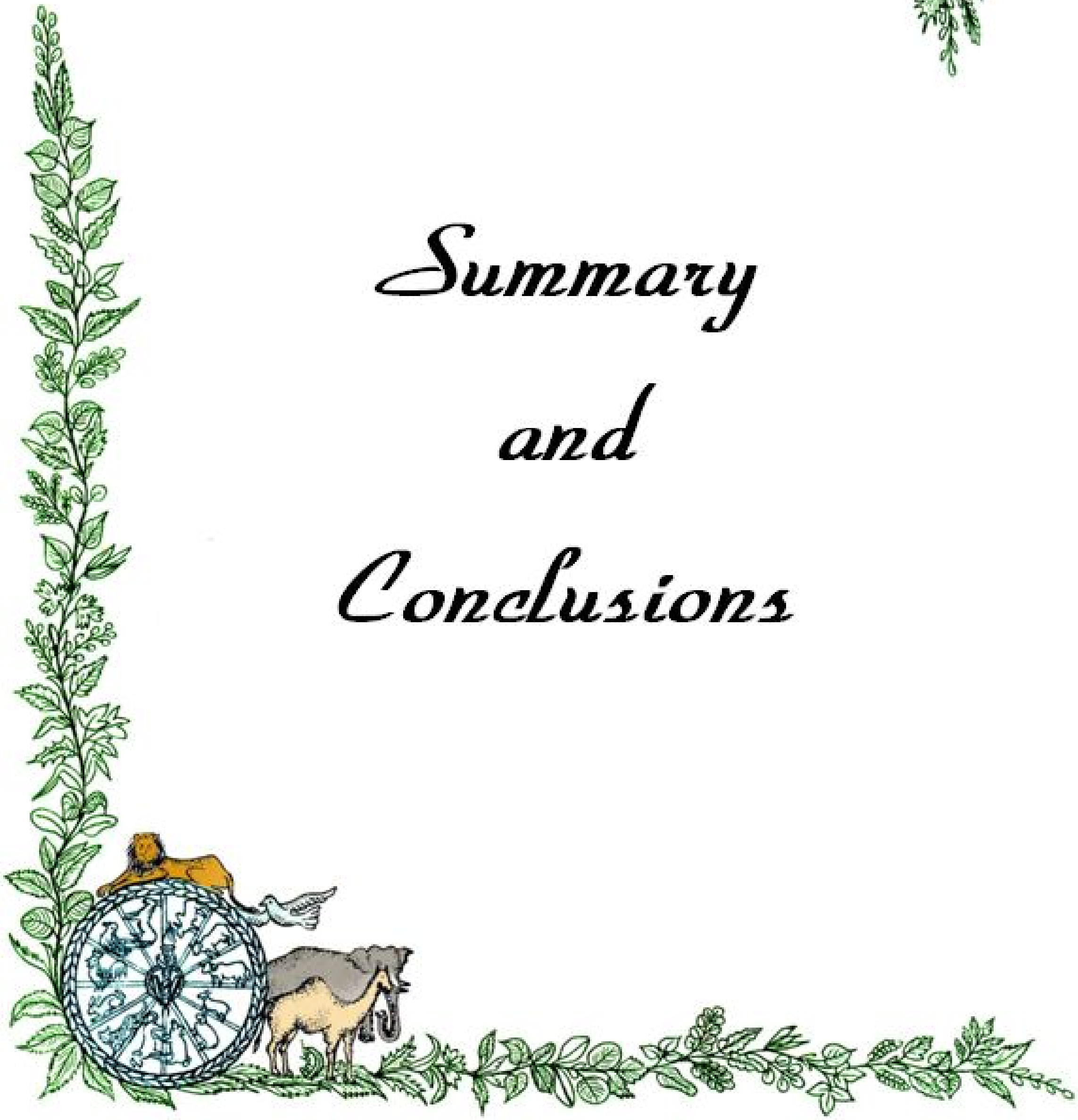
5.5 Genotyping the flock for *FecB* gene

Our present study found that all the 124 samples showed intact single band (140bp) under gel doc indicating that all the animals were non-carriers for *FecB*$^{++}$ gene (Fig. 4.21 to 4.32) and the frequency of non-carriers were found to be 100%. Our results were in agreement with the findings of some authors who reported *FecB* absence among various sheep breeds. Debnath and Singh RV (2014) in Balangir and Bonpala sheeps, Sudhakar *et al*. (2013) in Mecheri sheep, Yatoo *et al*. (2015) in Dorper sheep of Jammu and Mishra SK *et al*. (2018) in Kajali sheep among Indian sheep breeds. Amr *et al*. (2009) in five Egyptian sheep breeds.

Among analysed records (n=4525), 83.7% were singles and 16.3% were twins. This increased twinning rate in this flock may be due to the action of other prolificacy genes like *FecX*, *FecG* etc. which will also bring about increase in prolificacy.

* * *

Summary and Conclusions



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SUMMARY AND CONCLUSIONS

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. Being the heaviest and largest among the Indian sheep breeds, Muzaffarnagari is believed to be the most promising breed for meat and carpet wool production. In current decade, decline in wool demand can be observed leading to the decline in wool production. Hence, the focus of breeders and farmers is shifting towards improving the flock for meat production. Genetic parameter estimation and analysis of the relationship among them at different ages is important for formulating breeding programme successfully. 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 utmost importance. Fertility is one of the important parameters controlling the biological efficiency of sheep with regard to meat, milk and wool production. Mutations with major effects on ovulation rate and litter size have been identified in genes of the TGF-β super family namely and a TGF- receptor namely bone morphogenetic protein receptor (BMPR-1B) (*FecB*). Being the heaviest breed, twinning is very rare and almost nil (NBAGR) in this sheep, but Muzaffarnagari flock at CIRG, makhdoom has a twinning rate of 16.3% that points towards possible involvement of fecundity genes.. The present investigation was designed with the objectives to estimate variance and covariance components, genetic parameters and genetic, phenotypic and environmental trends for various growth and reproduction traits in Muzaffarnagari sheep over a period of 27 years (1991-2017) and to screen animals for *FecB* mutation and its association with litter size.

Phenotypic data was collected from Central Institute for Research on Goats (CIRG), Makhdoom. Pedigree cleaning was done and rams bearing <5 progenies and records of more than 5 parity were excluded from the data analysis). Standardized data was classified according to sex (male and female), season (March to April and October to November) , period of lambing (1991-94, 1995-98, 1999-2002, 2003-06, 2007-10, 2011-14 and 2015-17), parity (1,2,3,4 and 5) and type of birth (single born and twin born lambs). The traits analyzed were weight at birth (BWT), weight at 3 months or weaning (WWT), weight at 6 months (6WT), weight at 9 months (9WT), weight at 12 months (12WT), ewe’s weight at service (EWTS), ewe’s weight at lambing (EWTL), average daily gain from birth to 3 months (ADG1), average daily gain from 3 to 6 months (ADG2), average daily gain from 6 to 9 months (ADG3), average daily gain from 9 to 12 months (ADG4), average daily gain from 3 to 12 months (ADG5), relative growth rate from birth to 3 months (RGR1), relative growth rate from 3 to 6 months (RGR2), relative growth rate from 6 to 9 months (RGR3), relative growth rate from 9 to 12 months (RGR4), relative growth rate from 3 to 12 months (RGR5), age of ewe at first service (AFS), age of ewe at first lambing (AFL) and litter size (LS). Sex, season, year of lambing, parity and type of birth were included as fixed effects and dam’s weight at lambing as covariate for mixed model analysis. Least squares estimates of overall population mean ± SE (kg) for BWT, WWT, 6WT, 9WT, 12WT, EWTS, EWTL, ADG1, ADG2, ADG3, ADG4, ADG5, RGR1, RGR2, RGR3, RGR4, RGR5, AFL, AFS and LS were 3.41±0.02, 15.14±0.17, 22.19±0.22, 27.25±0.23, 31.33±0.24, 38.42±0.32, 39.64±0.38, 130.31 ± 1.78, 86.48 ± 1.55, 47.75 ± 1.31, 46.71 ± 1.33, 58.86 ± 0.77, 353.32 ± 5.27, 53.16 ± 1.01, 20.20 ± 0.63, 16.42 ± 0.52, 111.03 ± 1.91, 73.94, 599.54 ± 8.54 and 1.07 ± 0.02 respectively. 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 that included both animal and dam genetic effects along with the covariance between the effects was obtained as the best model in explaining variability for most of the traits. Period of lambing was found to have highly significant effect (P<0.01) on all the growth and reproduction traits except LS. The effect of sex was significant on almost all growth traits except EWTS and EWTL. Season of lambing had significant effect on all body weight traits (except 12WT, EWTS, EWTL), post weaning ADG, post weaning RGR and LS. The effect of parity was significant on BWT, WWT, EWTS, EWTL, pre weaning ADG and pre weaning RGR.

According to the best model, direct heritability estimates of the traits ranged from 0.004 (AFS) to 0.48 (RGR5). The maternal heritability estimates of the studied traits ranged from 0.01 (RGR1, RGR2) to 0.31 (BWT). It emphasized that ignoring maternal heritability estimates will lead to over estimation of direct heritability. Strong negative correlation was visualized between animal and maternal genetic effects for all the studied traits. 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. The genetic and phenotypic correlation among the growth traits ranged from -0.91 (ADG1-RGR3) to 0.99 (WWT-ADG1); -0.73 (12WT-RGR5) to 0.99 (WWT-ADG1) respectively. The genetic and phenotypic correlation among the reproduction traits ranged from 0.82 (AFS-LS) to 0.99 (AFS-AFL); 0.03 (AFS-LS) to 0.99 (AFS-AFL). Negative correlation exists between the pre and post weaning growth rate traits (ADG and RGR) which has to be taken into consideration during selection. All other parameters, additive genetic variance (σ^2_a), maternal genetic variance (σ^2_m), covariance between direct additive and maternal genetic effects (σ_{am}), maternal permanent environmental variance (σ^2_c), residual variance (σ^2_e), phenotypic variance (σ^2_p), maternal permanent environmental heritability (c^2) and total heritability (h^2_t) were also calculated for all the traits under investigation using all six models. Overall genetic and phenotypic trends for all the traits were in desired direction. Negative estimates were observed for environmental trends. Desired genetic improvement obtained through selection has been hampered by environmental interaction.

About 5ml of blood was collected from 124 animals randomly from the Muzaffarnagari flock maintained at CIRG, Makhdoom in a 5ml sterile anticoagulant (EDTA) coated tube and samples were transported to laboratory in ice. Genomic DNA was isolated from the blood samples by the standard Phenol-Chloroform-Isoamyl alcohol extraction method. (Sambrook and Russel 2001). Genotyping for *FecB* gene was performed by forced PCR RFLP technique with forward (5’-GTCGCTATGGGGAAGTTTGGATG-3’) and reverse (5’-CAAGATGTTTTCATGCCTCATCAACACGGTC-3’) primers to introduce a point mutation in the amplified product that creates *AvaII* restriction site (G↓GACC) and (C↓TCAG) in the DNA of *FecB* carrier animals. The present study found that all the 124 samples showed intact single band (140bp) under gel doc indicating that all the animals were non-carriers for *FecB*$^{++}$ gene and the frequency of non-carriers were found to be 100%.

Based on the above observations, following conclusions were drawn:

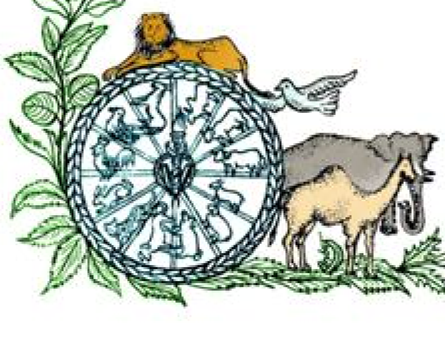
- Moderate to high heritability estimates of growth traits indicated that scope for response to selection for those traits.
- Low to moderate heritability estimates of reproduction traits indicated that response to selection will be slow in these traits.
- Ignoring maternal heritability estimates during genetic parameters estimation will lead to over estimation of direct heritability.
- Positive genetic correlation among body weight traits indicate indirect selection can bring correlated response in these traits.
- WWT had high and positive genetic and phenotypic correlation with other body weight traits, hence it can be considered as a better trait for selection.
- Negative correlation among pre and post weaning growth rate traits should be considered while planning breeding programme.
- High and positive correlation among reproduction traits indicates possibility of indirect selection.
- Positive and favourable genetic trends have been obtained for most of the studied traits indicating that effective breeding programme has been followed for 27 years.
- The increase in twinning rate (16.3%) in this flock of Muzaffarnagari could not be ascribed to *FecB* gene.

Future suggestions for improvement of Muzaffarnagari flock at CIRG, Makhdoom, Mathura:

- Weaning weight (weight at 3 months of age) can be used for selection among growth traits
- Fecundity (*FecB*) gene can be introgressed to increase the prolificacy in this flock to enhance the income of shepherd community.

* * *

Mini Abstract



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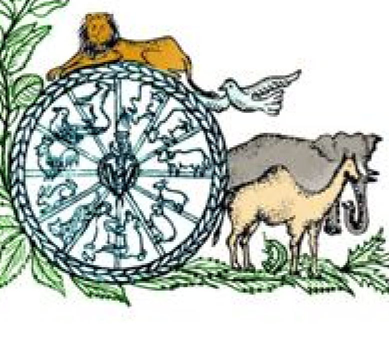
MINI ABSTRACT

The present investigation was designed to estimate variance and covariance components, genetic parameters and genetic, phenotypic and environmental trends for various growth and reproduction traits in Muzaffarnagari sheep over a period of 27 years (1991-2017) and to screen animals for *FecB* mutation and its association with litter size. Phenotypic data were collected from Central Institute for Research on Goats (CIRG), Makhdoom. The traits analyzed were birth weight (BWT), weaning weight (WWT), 6 months weight (6WT), 9 months weight (9WT), 12 months weight (12WT), ewe's weight at service (EWTS), ewe's weight at lambing (EWTL), average daily gain from birth to 3 months (ADG1), average daily gain from 3 to 6 months (ADG2), average daily gain from 6 to 9 months (ADG3), average daily gain from 9 to 12 months (ADG4), average daily gain from 3 to 12 months (ADG5), relative growth rate from birth to 3 months (RGR1), relative growth rate from 3 to 6 months (RGR2), relative growth rate from 6 to 9 months (RGR3), relative growth rate from 9 to 12 months (RGR4), relative growth rate from 3 to 12 months (RGR5), age of ewe at first service (AFS), age of ewe at first lambing (AFL) and litter size (LS). Sex, season, year of lambing, parity and type of birth were included as fixed effects and dam's weight at lambing as covariate 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 that included both animal and dam genetic effects along with the covariance between the effects was obtained as the best model in explaining variability for most of the traits. It emphasized that ignoring maternal heritability estimates will lead to over estimation of direct heritability. Direct heritability estimates of the traits ranged from 0.004 (AFS) to 0.48 (RGR5). The genetic and phenotypic correlation among the growth traits ranged from -0.91 (ADG1-RGR3) to 0.99 (WWT-ADG1); -0.73 (12WT-RGR5) to 0.99 (WWT-ADG1) respectively. The genetic and phenotypic correlation among the reproduction traits ranged from 0.82 (AFS-LS) to 0.99 (AFS-AFL); 0.03 (AFS-LS) to 0.99 (AFS-AFL). 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. Furthermore, a total of 124 Muzaffarnagari sheep maintained at CIRG, Makhdoom were genotyped for the presence of *FecB* mutation using polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP). Results revealed the absence of *FecB* mutation in this flock although among the analysed records (n=4525), 16.3% were twin births which is highly unusual for Muzaffarnagari sheep. The increased twinning rate in this flock may be due to some other prolificacy genes and warrants further investigation to pinpoint the cause for increased prolificacy in this flock of sheep.

लघु सारांश



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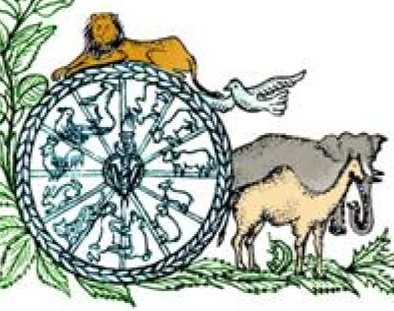
oreku v/;;u dk 27 o"k ¼1991&2017½ dh vof/k e et¶Qjuxjh HkkMk e fofHkUu of) vkj iu:Riknu y{k.kk d fy, ilj.k vkj lgilj.k ?kVdk] vkuokf'kd ekin.Mk vkj vkuokf'kd] ley{k.kk vkj i;koj.kh; :>kuk dk vueku yxku d fy, rFkk cgi trk o'kk.k mRifjoru dh tkp rFkk ,d C;kr d cPPkk ¼fyVj lkbt½ d lkFk bld lc/k dk n[ku d fy, fd;k x;k FkkA dUæh; cdjh vuql/kku lLFkku ¼d-c-v-l-½] e[kne l ley{k.kk d vkdM ,df=r fd; x; FkA fo'y"k.k fd, x, y{k.kk e tUe dk otu ¼BWT½] n/k NMku d le; dk otu ¼WWT½] 6 eghu dk otu ¼6 WT½] 9 eghu dk otu ¼9WT½] 12 eghu dk otu ¼12 WT½] iFke lEHkkx d le; eknk dk otu ¼EWTS½] eeu d tUe d le; eknk dk otu ¼EWTL½] tUe l 3 eghu rd vkl r nfud of) ¼ADG1½] 3 l 6 eghu rd vkl r nfud of) ¼ADG2½] 6 l 9 eghu rd vkl r nfud of) ¼ADG3½] 9 l 12 eghu rd vkl r nfud of) ¼ADG4½] 3 l 12 eghu rd vkl r nfud of) ¼ADGS½] tUe l 3 eghu ¼RGR1½ dh vkif{kd of) nj] 3 l 6 eghu ¼RGR2½ dh lkif{kd of) nj 6 l 9 eghu dh lkif{kd of) nj ¼RGR3½ 9 l 12 eghu dh lkif{kd of) nj ¼RGR4½] 3 l 12 eghu dh lkif{kd of) nj ¼RGR5½] iFke lEHkkx d le; eknk dh me ¼AFS½] igy eeu d tUe d le; eknk dh me ¼AFL½ vkj fyVj lkbt ¼LS½ 'kkfey FkA fefJr ekMy fo'y"K.k d fy, fyx _r] ilo dk lky] C;kr vkj tUe d idkj dk fuf'pr iHkko vkj eeu d tUe d le; eknk d otu dk ofLiV dkofj;V (covariate) d :i e 'kkfey fd;k x;kA iR;{k vkj ekr&lc/kh vkuokf'kd iHkkok d fofHkUu l;ktuk oky Ng i'k ekMy dk okecV lk¶Vo;j dk mi;kx djr g, REML fof/k }kjk fQV fd;k x;k FkkA lHkh y{k.kk d fy, loJ"B ekMy dk fu/kkj.k dju d fy, c;fl;u lpuk ekun.M dk mi;kx fd;k x;k FkkA fofo/krk dh 0;k[;k dju e lcl vPN ekMy d :i e ekMy 3 mHkjk ftl e iHkkok d chp lgilj.k d lkFk i'k vkj eknkuk d vkuof'kd iHkko Hkh 'kkfey FkA bl l bl rF; dk cy feyk fd ekrRo lc/kh o'kkxfrRo d vuekuk dh mi{kk dju l iR;{k c'kkxfrRo vueku 0-004 ¼AFS½ l ydj 0-048 ¼RGR5½ rd feykA of) y{k.kk d chp vkuof'kd vkj lEky{k.kh lgilj.k Øe'k% -0.91 (ADG1-RGR3) l 0.99 (WWT-ADG1); -0.73 (12WT-RGR5) l 0.99 (WWT-ADG1) rd FkkA iu:Riknd y{k.kk d chp vkuof'kd vkj lEy{k.kh lgilj.k Øe'k% 0-82 ¼AFS-LS½ l 0-99 ¼AFS-AFL½] 0-03 ¼AFS-LS½ l 0-99 ¼AFS-AFL½ rd FkkA lHkh y{k.kk d fy, dy feykdj vkuof'kd vkj ley{k.kh :>ku okfNr fn'kk e FkA i;koj.kh; :>kuk d fy, udkjkRed vueku n[k x;A p;u d ek/;e l ikIr okfNr vkuof'kd l/kkj i;koj.kh; lgHkkfxrk d dkj.k ckf/kr gA d-c-v-l-] e[kne e ektn et¶Qjuxjh uLy dh dy 124 HkMk dk ihlhvkj&vkj,Q,yih ¼PCR-RFLP½ dk mi;kx djd cgi trk c'kk.k mRifjoru d vkuof'kd :i dh tkp dh x;hA ifj.kkek l bl >M e cgi trk mRifjoru dh vuifLFkfr dk irk yxk gkykfd fo'yf"kr fjdkM ¼n=4525½ tMok tUe Fk tk fd et¶Qjuxjh HkM e vlkekU; gA bl >M e c<h gbl tMok nj dN vU; cgi trk o'kk.k d dkj.k gk ldrh gA HkM d bl >M e c<h cgi trk d dkj.k dk bfxr dju d fy, vkj tkp dh vko';drk gA

References



9 REFERENCES

Abegaz, S., Van Wyk, J.B. and Olivier, J.J., 2005. Model comparisons and genetic and environmental parameter estimates of growth and the Kleiber ratio in Horro sheep. South African Journal of Animal Science, **35**(1): 30-40.

Ahmad, M. 2002. Genetic evaluation of growth and wool yield traits using animal model in Avikalin crossbred sheep, Ph.D. Thesis submitted to G.B. Pant Univ. of Agri. and Tech, Uttaranchal, India.

Ahmad, M., Singh, C.V., Sharma, R.K., Kumar, S. and Arora, A.L. 2004. Genetic estimates of growth and wool yield in Avikalin sheep. The Indian Journal of Small Ruminants, **10**(2): 156-158.

Akhtar, P., Mabdullah, M. and Mirza Aslam, M. 2007. Heritability estimates of some growth traits of Hissardale sheep in Pakistan. Indian Journal of Animal Sciences, **77**(2): 181-183.

Amr, A., EL-Hanafy. and El-Saadani, M.A. 2009. Fingerprinting of *FecB* gene in five Egyptian sheep breeds. Biotechnology in Animal Husbandry **25**: 205-212.

Arora, A.L. and Kushwaha, B.P. 1996, Estimates of genetic and phenotypic parameters of some production traits in Avikalin sheep. Indian J. Small Ruminants, **2**(1): 40-42.

Arora, A.L. and Swarnkar, C.P. 1995. Factors affecting age and weight at first breeding and first lambing in Malpura ewes. The Indian Journal of Small Ruminants, **1**: 22-25.

Arora, A.L., Gowane, G.R., Prince, L.L.L., Prakash, V. 2010. Genetic trends for performance traits of Malpura sheep. Indian Journal of Animal Sciences, **80**(9): 937-939.

Arora, A.L., Sharma, R.C., Narula, H.K., Kumar, R. 1999. Comparative performance of Avikalin and Malpura Sheep. Indian Journal of Small Ruminants, **5**(1): 4-8.

Arora, C.L., Narula, H.K. 1996. Growth and wool production performance of Malpura lambs and their f_1 crosses of Awassi. The Indian Journal of Small Ruminants, **2**(1): 43-45.

Arthy, V., Venkataramanan, R., Sivaselvam, S. N., Sreekumar, C., and Balasubramanyam, D. 2018. Genetic evaluation of growth in farmers' flocks of Madras Red sheep under long-term selection in a group breeding scheme. Tropical animal health and production, 1-9.

Arya, P.K. 1997. Performance of Karakul Sheep in Arid Zone. M.V.Sc. thesis, Rajasthan Agricultural University, Bikaner.

Babar, M.E. and Javed, K. 2009. Non-genetic factors affecting reproductive traits in Lohi sheep. Acta Agriculture Scandinavica, Section-A-Animal Science, **59**(1): 48- 52.

Balasubramanyam, D., Raja, T.V., Kumarasamy, P., Sivaselvam, S.N. 2012. Estimation of genetic parameters and trends for body weight traits in Madras Red sheep. Indian Journal of Small Ruminants, **18**(2): 173-179.

Bhadula, S.K. and Bhat, P.N. 1980. Genetic and non-genetic factors affecting body weights in Muzaffarnagari sheep and their half-breds. Indian Journal of Animal Sciences, **50**: 852-856.

Bhasin, N.R. 1969. Selection for body weights at weaning and six months in Bikaneri sheep. Indian Journal of Animal Sciences, **39**: 497-502.

Bhat, M.R., Karim, M.A., Ganai, T.A.S., Bhat, A.S., Ganmai, N.A. and Risam, K.S. 1999. Factors affecting reproductive traits of Corriedale sheep. The Indian Journal of Small Ruminants, **512**: 87-89.

Bindon, B.M. and Piper, L.R. 1986. The reproductive biology of prolific sheep breeds. Oxford reviews of reproductive biology, **8**: 414.

Bohra, S.D.J., Nagarcenkar, R. and Sharma, K.N.S. 1979. Factors affecting pre-weaning body weights in Malpura sheep. Indian Veterinary Journal, **56**: 125-128.

Bradford, G.E., Inounu, I., Iniguez, L.C., Tiesnamurti, B. and Thomas, D.L. 1991. The prolificacy gene of Javanese sheep. Colloques de l'INRA (France).

Carriedo, J.A., Rio, A. and San Primitivo, F., 1988. Heritability of body weight and preweaning growth of single born lambs and environmental factors affecting these. In Anales de la Facultad de Veterinaria, **34**: 15-27.

Charyulu, E.K., Arora A.L. 1998. Breeding strategies for improving mutton production. Proceeding of Golden Jubilee Seminar- Sheep, Goat and Rabbit- Production and Utilization, 1998, 57.

Chikurdekar, A.A., Mandakmale, S.D., Birari, D.R., Bhoite, U.Y., Sakhare, P.S. 2012. Effects of factors affecting growth performance of Sangamneri strain of Deccani sheep. Indian Journal of Small Ruminants, **18**(2): 256-257.

Dass, G. 2007. Production performance and management practices of Pugal sheep in the home tract. Indian Journal of Animal Sciences, **77**(8): 763-766.

Dass, G. and Singh V.K 2002. Improvement of Marwari sheep in hot arid climate. Indian Journal of Animal Sciences, **72** (3): 253-256.

Dass, G., Mehta S.C., Sharma P.R. and Singh V.K. 2000. Selection in Marwari sheep:3. Response to selection and trends. The Indian Journal of Small Ruminants, **6**(1): 6-9.

Dass, G., Prasad, H., Mandal, A., Singh, M.K and Singh, N.P. 2008a. Growth characteristics of Muzaffarnagari sheep under semi intensive feeding management. Indian Journal of Animal Sciences, **78**(9): 1030-1033.

Dass, G., Sharma P.R. and Mehrotra, V. 2008b. Production performance of Marwari lambs under hot arid region of Rajasthan. Indian Journal of Animal Sciences, **78**(9): 1019-1022.

Dass, G., Singh V.K, Mehta S.C. and Sharma P.R. 1998. Selection in Marwari sheep: 2. Gain in body weight and growth efficiency. The Indian Journal of Small Ruminants, **4**(2): 47- 52.

Dass, G., Singh, V.K., Mehta, S.C. and Sharma, P.R. 2004. Reproductive traits of Marwari sheep in arid Rajasthan. The Indian Journal of Small Ruminants, **10**(1): 88-89.

Dass, G.S. and Acharya, R.M. 1970. Growth of Bikaneri sheep. Journal of Animal Sciences, **34**: 713-725.

Davis, G.H., Balakrishnan, L., Ross, I.K., Wilson, T., Galloway, S.M., Lumsden, B.M., Hanrahan, J.P., Mullen, M., Mao, X.Z., Wang, G.L. and Zhao, Z.S. 2006. Investigation of the Booroola (*FecB*) and Inverdale (FecXI) mutations in 21 prolific breeds and strains of sheep sampled in 13 countries. Animal Reproduction Science, **92**(1-2): 87-96.

Davis, G.H., Balakrishnan, L., Ross, I.K., Wilson, T., Galloway, S.M., Lumsden, B.M., Hanrahan, J.P., Mullen, M., Mao, X.Z., Wang, G.L. and Zhao, Z.S. 2006. Investigation of the Booroola (*FecB*) and Inverdale (FecXI) mutations in 21 prolific breeds and strains of sheep sampled in 13 countries. Animal Reproduction Science, **92**(1-2): 87-96.

Davis, G.H., Dodds, K.G. and Bruce, G.D. 1999. Combined effect of the Inverdale and Booroola prolificacy genes on ovulation rate in sheep. Change, **3**: 0-12.

Davis, G.H., Galloway, S.M., Ross, I.K., Gregan, S.M., Ward, J., Nimbkar, B.V., Ghalsasi, P.M., Nimbkar, C., Gray, G.D., Inounu, I. and Tiesnamurti, B. 2002. DNA tests in prolific sheep from eight countries provide new evidence on origin of the Booroola (*FecB*) mutation. Biology of Reproduction, **66**(6): 1869-1874.

Debnath, J. and Singh, R.V. 2014. Genetic polymorphism of Boorola *FecB* gene and its association with litter size in Balangir, Shahabadi and Bonpala sheep breeds. Indian Journal of Animal Research, **48**(4).

Devendarn S.P., Murli N. and Gajendran K. 2007. Comparative performance of farm and field in Madras Red sheep. Indian Veterinary Journal, **84**: 1002-1003.

Dey, B. 2004. Genetic Studies on Reproduction and Production Traits of Nali Sheep. M.V.Sc. Thesis submitted to Haryana Agricultural University, Hissar, Haryana.

Dey, B. and Poonia, J.S. 2005. Factors affecting growth traits in Nali sheep. The Indian Journal of Small Ruminants, **11**(1): 77-79.

Dey, B. and Poonia, J.S. 2006. Estimates of Phenotypic, Genetic and Environmental Trends in a flock of Nali sheep. The Indian Journal of Small Ruminants, **12**(2): 185-187.

Dixit, S.P., Dhillon, J.S. and Singh, G. 2002. Sources of variation in reproductive traits of Bharat Merino sheep. The Indian Journal of Animal Sciences, **72**(4): 328-331.

Duguma, G. and Schoeman, S.J., 2002. The influence of non-genetic factors on early growth traits in the Tygerhoek Merino lambs. Ethiopian Journal of Animal Production

Elvin, J.A., Clark, A.T., Wang, P., Wolfman, N.M. and Matzuk, M.M. 1999. Paracrine actions of growth differentiation factor-9 in the mammalian ovary. Molecular endocrinology, **13**(6): 1035-1048.

Fabre, S., Pierre, A., Pisselet, C., Mulsant, P., Lecerf, F., Pohl, J., Monget, P. and Monniaux, D. 2003. The Booroola mutation in sheep is associated with an alteration of the bone morphogenetic protein receptor-IB functionality. Journal of Endocrinology, **177**(3): 435-444.

Falconer, D.S. and Mackay, T.F.C. 1996. Introduction to quantitative genetics. Harlow, Essex, UK: Longmans Green, 3.

Feng, G.U.A.N., Shou-Ren, L.I.U., Guo-Qing, S.H.I., Jun-Tao, A.I., Da-Gan, M.A.O. and Li-Guo, Y.A.N.G. 2006. Polymorphism of *FecB* gene in nine sheep breeds or strains and its effects on litter size, lamb growth and development. Acta Genetica Sinica, **33**(2): 117-124.

Fourie, P.D., Kirton, A.H. and Jury, K.E. 1970. Growth and development of sheep; II. Effect of breed and sex on the growth and carcass composition of the south down and Romney and their cross. New Zealand Journal of Agricultural Research, **13**(4): 753-770.

Galloway, S.M., McNatty, K.P., Cambridge, L.M., Laitinen, M.P., Juengel, J.L., Jokiranta, T.S., McLaren, R.J., Luiro, K., Dodds, K.G., Montgomery, G.W. and Beattie, A.E. 2000. Mutations in an oocyte-derived growth factor gene (BMP15) cause increased ovulation rate and infertility in a dosage-sensitive manner. Nature genetics, **25**(3): 279.

Ganai, N.A. 1992. Selection indices for genetic improvement of Marwari sheep. M.V.Sc. thesis, Rajasthan Agricultural University, Bikaner.

Ganai, T.A.S. Mishra, S.S. and Sheikh, F.D. 2010. Genetic parameters and variance component estimates of body weight of Corriedale sheep. The Indian journal of small Ruminants, **16**(1): 236-239.

Ganesan, R., Dhanavanthan, P., Balasubramanyam, D. and Kumarasamy, P. 2013. Estimates of genetic parameters of growth traits in Madras Red sheep. IOSR Journal of Agriculture and Veterinary Science, **3**(5): 69-73.

Ghafouri-Kesbi, F., Abbasi, M.A., Afraz, F., Babaei, M., Baneh, H. and Abdollahi Arpanahi, R., 2011. Genetic analysis of growth rate and Kleiber ratio in Zandi sheep. Tropical Animal Health and Production, **43**: 1153-1159.

Gohil, G. 2010. Genetic evaluation of growth and reproduction of Marwari sheep. M.V.Sc. thesis, Rajasthan Agricultural University, Bikaner.

Gowane, G.R. and Arora, A.L. 2010. Performance evaluation of Malpura sheep in farmer's flock of eastern semi arid region of Rajasthan. The Indian journal of small Ruminants, **16**(1):87-91.

Gowane, G.R., Chopra, A., Ved Prakash, and Arora, A.L. 2010. Estimates of (co)variance components and genetic parameters for body weights and first greasy fleece weight in Malpura sheep, Livestock Science, **131**: 94-101.

Gowane, G.R., Prince, L.L.L., Lopes, F.B., Paswan, C., Sharma, R.C. 2015. Genetic and phenotypic parameter estimates of live weight and daily gain traits in Malpura sheep using Bayesian approach. Small Ruminant Research, **128**: 10-18.

Guan, F., Liu, S.R., Shi, G.Q. and Yang, L.G. 2006. Polymorphism of *FecB* gene in nine sheep breeds or strains and its effects on litter size, lamb growth and development. Acta Genetica Sinica, **33**: 117-124

Gupta, B.R. and Reddy K.K. 1988. Factors affecting birth weight in Nellore and Dorset * Nellore synthetic lambs. Indian Journal of Animal Sciences, **58**: 391-393.

Hanford, K.J., Van Vleck, L.D. and Snowder, G.D. 2006. Estimates of genetic parameters and genetic trend for reproduction, weight, and wool characteristics of Polypay sheep. Livestock Science, **102**(1-2): 72-82.

Hanrahan, J.P., Gregan, S.M., Mulsant, P., Mullen, M., Davis, G.H., Powell, R. and Galloway, S.M. 2004. Mutations in the genes for oocyte-derived growth factors GDF9 and BMP15 are associated with both increased ovulation rate and sterility in Cambridge and Belclare sheep (Ovis aries). Biology of reproduction, **70**(4): 900-909

Harvey, H.R. 1990. User’s guide for LSMLMW PC -I Version mixed model Least Squares and Maximum Likelihood computer programme. LOWA state university, USA.

Henderson, C.R. 1973. Sire evaluation and genetic trends. Journal of Animal Science (Symposium). 10-41.

Jagatheesan, P.N.R.; Arunachalam, S.; Sivkumar, T. and Selvaraju, M. 2003. Performacnes of Mecheri sheep in its breeding tract. Indian Journal of Animal Science. **73**(8): 909-912.

Jagtap, D.Z., Khanna, A.S., Narwade, V.S. and Deshmukh, A.P. 1988. Body weight up to twelve months and greasy fleece yield of Deccani and its half breeds with Dorset and Merino. Indian Journal of Animal Sciences, **58**: 1427-1431.

Jain, A., Singh, G. and Yadav, D.K. 2009. Chokla - an endangered sheep genetic resource. The Indian Journal of Animal Sciences, **79**(10): 1071-1072.

Jain, R.D., Quereshi, M.I., Khan, F.H. and Tripathi, G.S. 2001. Factors influencing age at first fertile service in Rambouillet sheep. The Indian Veterinary Journal, **78**(6): 547-548.

Joshi, R.K. 2001. Genetic trends in a population of Marwari sheep under continuous selection . PhD thesis, Rajasthan Agricultural University, Bikaner.

Joshi, R.K., Yadav S.B.S., Murdia C.K., Purohit G.N. and Singh V.K. 2003. Weight gain and growth efficiency in Marwari sheep under arid condition of Rajasthan. The Indian Journal of Small Ruminants, **9**(1): 25-28.

Kaila, O.P., Sinha, N.K. and Khan B.V. 1989. Body weight growth in Muzaffarnagari sheep and its exotic crossbreds. The Indian Journal of Animal Sciences, **59**: 877-880.

Khan, B.U. and Bhat, P.N. 1981. Genetic and non-genetic factors affecting live-lamb traits in Muzaffarnagari sheep and its half bred with Corriedale. The Indian Journal of Animal Sciences, **51**: 36-38.

Khan, H.M., Ganai, N.A., Bhakat, M., Mir, M.S. and Sheikh, B.A. 2011. Factors affecting birth weight and dam weight of Polled Dorset and cross bred sheep at an organized farm. The Indian Journal of Small Ruminants, **17**(2): 227-230.

Kramer, C.Y. 1957. Extension of multiple range tests to group correlated adjusted means. Biometrics, **13**(1): 13-18.

Kulkarni, A.P. and Deshpande, K.S. 1986. Genetic studies on weaning weight and subsequent body weight in Deccani sheep and its crosses. The Indian Journal of Animal Sciences, **56**: 1180-1181.

Kulkarni, A.P. and Deshpande, K.S. 1990. Factors affecting body weight at different stages and first clip fleece weight in Merino half bred sheep. Indian veterinary Journal, **67**: 929-933.

Kumar S., Kushwaha, B.P., Srivastava, M.K. and Arora A.L. 2001. Age and weight at first service in Chokla and their crossbred sheep. The Indian Journal of Small Ruminants, **7**(2): 106-109.

Kumar, A., Arora, A. L., Shrivastva, M. K. 2004, Genetic evaluation and improvement of Malpura sheep and enhancing its reproductive efficiency by introducing Garole inheritance, CSWRI Annual Report, 2003-04, 21.

Kumar, R. 2000, Genetic analysis of body weight and wool yield traits in Chokla sheep. Ph.D. Thesis submitted to G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, India.

Kumar, S., Dahiya, S. P., Malik, Z. S., Patil, C. S., and Magotra, A. 2017. Genetic analysis of performance traits in Harnali sheep. Indian Journal Of Animal Research, **52**(5): 643-648.

Kumar, S., Dahiya, S.P., Malik, Z.S., Patil, C.S. and Magotra, A. 2018. Genetic analysis of performance traits in Harnali sheep. Indian Journal of Animal Research. **52(**5).

Kumar, S., Kolte, A.P., Mishra, A.K., Arora, A.L. and Singh, V.K. 2006. Identification of the *FecB* mutation in Garole× Malpura sheep and its effect on litter size. Small Ruminant Research, **64**(3): 305-310.

Kumar, S., Kumar, V., Gangaraju, G., Nath, S., and Thiruvenkadan, A. K. 2017. Estimates of direct and maternal (co) variance components as well as genetic parameters of growth traits in Nellore sheep. Tropical animal health and production, **49**(7): 1431-1438.

Kumar, V.R.S., Shivkumar, K., Singh, D.A.P., Ramesh, V., Murlidharan, J. and Devendran, p. 2007. Non genetic factors affecting birth weight of Mechari lambs. The Indian Journal of Small Ruminants, **13**(2): 228-230.

Kushwaha, B.P., Jain A. and Singh G. 1995, Estimates of Genetic and phenotypic parameters of body weights and fleece weight in Avivastra sheep. Indian J. Animal Science, **65**(7): 812-813.

Kushwaha, B.P., Mehta B.S. and Kumar R. 1998, Chokla- A superior carpet wool sheep, in Animal Genetics Resources and Sustainable Development: Proced.6th World Congress Genetics Application for Livestock Production, UNE, Armidale, Australia, Jan.12-16, Vol.**26**: 11-17.

Lal, N., Mishra, B.S., Singh, P.K. and Shukla, S.M. 2000. Growth rate and wool production in Muzaffarnagari sheep and its exotic grades. The Indian Journal of Small Ruminants, **6**: 68-72.

Lalit, Z.S., Dalal, D.S., Dahiya, S.P., Patil, C.S. and Dahiya, R., 2016. Genetic analysis of growth traits in Harnali sheep. Veterinary world. **9**(2): 128.

Lanzoni, N.A., Queiroj, S.A., Albuquerque, L.G., Garcia Sobrinho, A. and Andrade, A.F. 1996. Factors affecting some important economic traits in a flock of Polwarth sheep in Sao. Ars Veterinaria, **12**(2): 178-187.

Lehmann, K., Seemann, P., Stricker, S., Sammar, M., Meyer, B., Süring, K., Majewski, F., Tinschert, S., Grzeschik, K.H., Müller, D. and Knaus, P. 2003. Mutations in bone morphogenetic protein receptor 1B cause brachydactyly type A2. Proceedings of the National Academy of Sciences, **100**(21): 12277-12282.

Liu, S.F., Jiang, Y.L. and Du, L.X. 2003. Studies of BMPR-IB and BMP15 as candidate genes for fecundity in Little Tailed Han sheep. Yi chuan xue bao= Acta genetica Sinica, **30**(8): 755-760.

Lush, J.L. 1935. Progeny test and individual performance as indicators of an animal's breeding value. Journal of Dairy Science, **18**: 1-19.

Malik, B.S., Singh, R.P. and Kanaujia, A.S. 1998. Effect of non-genetic factors on growth traits in Nali and its crosses with Corridale and Russian Merino. Indian Journal of Animal Research, **32**(2): 81-86.

Mandal A., Pant K.P., Nandy D.K., Rout P.K. and Roy R. 2003. Genetic analysis of growth traits in Muzaffarnagari sheep. Tropical Animal Health Production, **35**(3): 271-84.

Mandal, A., Karunakaran, M., Sharma, D. K., Baneh, H., and Rout, P. K. 2015. Variance components and genetic parameters of growth traits and Kleiber ratio in Muzaffarnagari sheep. Small Ruminant Research, **132**: 79-85.

Mandal, A., Neser, F.W.C., Rout, P.K., Roy, R. and Notter, D.R. 2006. Genetic parameters for direct and maternal effects on body weights of Muzaffarnagari sheep. Animal Science, **82**(2): 133-140.

McNatty, K.P., Juengel, J.L., Wilson, T., Galloway, S.M. and Davis, G.H. 2001. Genetic mutations influencing ovulation rate in sheep. Reproduction, Fertility and Development, **13**(8): 549-555.

McNatty, K.P., Lun, S., Heath, D.A., Ball, K., Smith, P., Hudson, N.L., McDiarmid, J., Gibb, M. and Henderson, K.M. 1986. Differences in ovarian activity between Booroola× Merino ewes which were homozygous, heterozygous and non-carriers of a major gene influencing their ovulation rate. Journal of reproduction and fertility, **77**(1): 193-205.

McNatty, K.P., Smith, P., Moore, L.G., Reader, K., Lun, S., Hanrahan, J.P., Groome, N.P., Laitinen, M., Ritvos, O. and Juengel, J.L. 2005. Oocyte-expressed genes affecting ovulation rate. Molecular and cellular endocrinology, **234**(1-2): 57-66.

Mehta, S.C., Vijay, P.K., Joshi, B.K. and Nivasarkar, A.E. 1995. Characterization and Conservation of Sonadi Sheep. Indian Journal of Animal Sciences, **65**(7): 804-808.

Meyer, K. 2013. WOMBAT—A program for mixed model analyses by restricted maximum likelihood. Animal Genetics and Breeding Unit, Armidale. 105 pp.

Mishra, A.K., Arora, A.L., Prince, L.L.L., Gowane, G.R. and Kumar, S. 2009a. Lifetime litter size and ewes productivity efficiency of Garole * Malpura cross bred sheep. Indian Journal of Animal Sciences, **79**(10): 1075-1077.

Mishra, A.K., Arora, A.L., Prince, L.L.L., Gowane, G.R. and Kumar, S. 2009b. Genetic analysis of performance traits of Malpura sheep. Indian veterinary Journal, **88**(5): 484-486.

Mishra, S.K., Mishra, A.K., Raja, K.N., Vohra, V., Singh, S., Singh, Y., Ahlawat, S. and Kataria, R.S., 2018. Polymorphism analysis at FecB locus in Kajali sheep of India. Indian Journal of Animal Research, **52**(3): 474-476.

Mohammadi, K., Beigi Nassiri, M.T., Roshanfekr, H., Mirzadeh, K., Aghaei, A. 2011. Estimation of genetic trend for body weights at post-weaning in Zandi sheep. Journal of Animal and Veterinary Advances, **10**(3): 272-274.

Montgomery, G.W., Galloway, S.M., Davis, G.H. and McNatty, K.P. 2001. Genes controlling ovulation rate in sheep. Reproduction, **121**(6): 843-852.

Montgomery, G.W., Penty, J.M., Sise, J.A. and Tou, H.M. 1992. Genes encoding the α and β chains of follicle-stimulating hormone are not sites for the Booroola (*FecB*) mutation in sheep. Journal of reproduction and fertility, **95**(3): 895-901.

Moore, L.G., McNatty, K.P., Isaacs, K.L., Lun, S., Chie, W.N., McNatty, S. and Hudson, N.L. 1995. Pituitary and plasma levels of growth hormone in Booroola sheep that are either homozygous carriers or non-carriers of the *FecB*B fecundity gene. Journal of endocrinology, **147**(2): 217-223.

Mulsant, P., Lecerf, F., Fabre, S., Schibler, L., Monget, P., Lanneluc, I., Pisselet, C., Riquet, J., Monniaux, D., Callebaut, I. and Cribiu, E. 2001. Mutation in bone morphogenetic protein receptor-IB is associated with increased ovulation rate in Booroola Merino ewes. Proceedings of the National Academy of Sciences, **98**(9): 5104-5109.

Murdia, C.K., Saharan, R., Joshi, R.K., Ramnani, K. and Yadav, S.B.S. 2003. Genetic improvement in greasy fleece yield of Magra sheep under field conditions. The Indian Journal of Small Ruminants, **9**(1): 35-38.

Naqvi, S.M.K., Maurya, V.P., Joshi, A., Sharma, R.C. and Mittal, J.P. 2002. Production of crossbred lambs through artificial insemination of non-prolific medium size Malpura and Avikalin ewes using fresh diluted semen of prolific micro size Garole rams. Asian Australian Journal of Animal Sciences, **15**(5): 633-636.

Narula, H.K., Kumar, A., Ayub, M. and Mehrotra, V. 2010. Growth rate and wool production of Marwari lambs under arid region of Rajasthan. Indian Journal of Animal Sciences, **80**(4): 350-353.

Narula, H.K., Yadav, S.B.S., Mehrotra, V. and Ayub, M. 2007. Performance evaluation of Magra sheep in an organized farm. Abstract compendium of National Symposium on Recent Trends in Technological Interventions for Rural Prosperity in Small Holder Livestock Production Systems, held at College of Veterinary Science, Tirupati from 20-22 June, 2007:49.

Narula, H.K., Yadav, S.B.S., Sharma, P.R. and Mehrotra, V. 2009. Growth and reproductive performance of Magra sheep of Rajasthan. The Indian Journal of Animal Sciences, **79**(6): 639-641.

Nawaj, M., Khan, M.A., Qureshi, M.A. and Rasoof, E. 1998. Production and reproductive performance of Kajli and Lohi ewes. Asian Australian Journal of Animal Sciences, **12** (1): 16-67; 19 ref.

Negi, P.R, Bhat, P.N. and Garg, R.C. 1987. Factors affecting pre weaning Body weights in Gaddi sheep and its crosses. The Indian Journal of Animal Sciences, **57**: 489-492.

Nehra, K.S. 1991. Study on Growth and Wool Production of Marwari Sheep in Arid Zone. M.V.Sc. Thesis, Rajasthan Agriculure University, Bikaner.

Nehra, K.S. and Singh, V.K. 2006. Genetic evaluation of Marwari sheep in arid zone. The Indian Journal of Small Ruminants, **12**: 91-94.

Nimbkar, C., Ghalsasi, P.M., Nimbkar, B.V., Walkden-Brown, S.W., Maddox, J.F., Gupta, V.S., Pardeshi, V.C., Ghalsasi, P.P. and Van der Werf, J.H.J. 2007. Reproductive performance of Indian crossbred Deccani ewes carrying the *FecB* mutation. In Proceedings of the Association for the Advancement of Animal Breeding and Genetics (Vol. **17**: 430-433).

Pannu, U. 1994. Genetic Evaluation of Performance of Marwari sheep in Different Selection Lines. M.V.Sc. Thesis, Rajasthan Agricultural University, Bikaner.

Pardeshi, V.C., Sainani, M.N., Maddox, J.F., Ghalsasi, P.M., Nimbkar, C. and Gupta, V.S., 2005. Assessing the role of FecB mutation in productivity of Indian sheep. Current Science. 887-890.

Parihar, K. 2012. Studies on genetic and phenotypic trends of growth and wool traits in Magra sheep. M.V.Sc thesis, Rajasthan University of Veterinary and Animal Science, Bikaner.

Patnayak, G.R., Patro, B.N., Dass, S.K. and Nayak, S. 2003. Survey and performance evaluation of Ganjam sheep. The Indian Journal of Small Ruminants, **9**(1): 47-79.

Piper, L.R., Bindon, B.M. and Davis, G.H. 1984. Single gene inheritance of the high litter size of the Booroola Merino. Genetics of reproduction in sheep/edited by RB Land, DW Robinson.

Poonia, J.S. 2004. Growth performance of Munjal sheep. The Indian Journal of Small Ruminants, **10**(2): 137-139.

Poonia, J.S., 2008. Reproductive performance of Munjal sheep. Indian Journal of Small Ruminants, **14**(1): 121-123.

Poonia, J.S., Singh, B. and Sangwan, M.L. 1988. Appraisal of genetic variability in growth traits of Nali and divergence among its different grades. Indian Journal of Animal Sciences, **58**: 1446-1447.

Prince, L.L.L., Kumar, S., Mishra, A.K. and Arora, A.L. 2008. Growth performance of Chokla sheep under semi-arid condition of Rajasthan. The Indian Journal of Small Ruminants, **85**(1): 41-43.

Ranga, P.K. and Singh, R. V. 2008 Genetic Polymorphism of Booroola Fecundity gene in Garole Sheep. International Booroola Workshop, Maharashtra, India. **23**: 205

Rao, S.T.V., Reddy, Y.R., Veerabramaiah, K. and Suresh, J. 2004. Non genetic factors affecting pre and post weaning body weights in two strains of Nellore sheep. The Indian Journal of Small Ruminants, **10**(1): 86-87.

Ravimurugan, T., Thanaseelaan, V., Piramanayagam, S. and Balachandran, S. 2007. Effect of non-genetic factors on birth weight and body measurements of Vembur lambs. The Indian Journal of Small Ruminants, **13**(1): 100-102.

Reddy, R.Y. and Naidu, T.P. 2011. Genetic trends on growth performance of Nellore breed of sheep. Indian veterinary Journal, **88**(2): 73-74.

Reddy, R.Y., Naidu, T.P. and Virojirao, S.T. 2009. Growth performance of Nellore breed of sheep in India. The Indian Journal of Small Ruminants, **15**(1): 118-120.

Roberts, J.A. 2000. Frequency of the prolificacy gene in flocks of Indonesian thin tail sheep: a review. Small Ruminant Research, **36**(3): 215-226.

Sahani, M.S., Bapna, D.L. and Mehta, S.C. 2002. Factors influencing pre and post weaning body weights in Marwari sheep. Indian Journal of Animal Sciences, **72**(8): 704-705.

Sambrook, J. and Russell, D.W. 2001. Molecular Cloning: A laboratory manual. Cold Spring Harbor Laboratory press, New York, USA. 3rd edition.Volume **1**.

Sarvana, R.V., Sivakumar, K., Singh, D.A.P., Ramesh, V., Muralidharan, J. and Devendran, P. 2007. Non genetic factors affecting birth weight of Mecheri lambs. The Indian Journal of Small Ruminants, **13**(2): 228-230.

Sezenler, T., Ceyhan, A., Yuksel, M.A., Onaldi, A.T. and Yildirir, M. 2016. Effect of parity and type of lambing on performance and udder traits of Bandirma ewes. Indian Journal of Animal Science. **86**: 572-577.

Shackell, G.H., Hudson, N.L., Heath, D.A., Lun, S., Shaw, L., Condell, L., Blay, L.R. and McNatty, K.P. 1993. Plasma gonadotropin concentrations and ovarian characteristics in Inverdale ewes that are heterozygous for a major gene (FecX1) on the X chromosome that influences ovulation rate. Biology of reproduction, **48**(5): 1150-1156.

Shah, R.R. and Patel, M.M. 1990. Genetic and non-genetic factors affecting age and weight at first breeding in Patanwadi and its crosses with exotic sheep. The Indian Journal of Animal Sciences, **60**: 1134-1136.

Sharma, B.S. 1989. Studies on the Performance of Magra Sheep and its Crosses with Fine Wool Breeds in Arid Zone. M.V.Sc. Thesis, Rajasthan Agricultural University, Bikaner.

Sharma, M.K. 1998. Comparative Study of Nali and Marwari Breeds of Sheep in Arid Zone of Rajasthan. M.V.Sc. Thesis, Rajasthan Agricultural University, Bikaner.

Sharma, M.K., Sharma, N.K., Singh, V.K. and Beniwal, B.K. 2003. Genetic evaluation of Nali and Marwari sheep in arid zone of Rajasthan. The Indian Journal of Small Ruminants, **9**: 65-68.

Sharma, N.K. 1999. Comparative performance of Karakul and Marwari Breeds of Sheep in Arid Zone of Rajasthan. M.V.Sc. Thesis, Rajasthan Agricultural University, Bikaner.

Sharma, P.R. 1995. Selection indices for genetic improvement of Nali sheep. M.V.Sc. thesis, Rajasthan Agricultural University, Bikaner.

Sharma, P.R., Beniwal, B.K., Singh, V.K. and Dass, G. 1999a. Growth of Nali sheep in arid zone of Rajasthan. Indian Journal of Animal Sciences, **69**(12): 1065-1066.

Sharma, P.R., Beniwal, B.K., Singh, V.K., Dass, G. and Sharma, B.S. 1999c. Wool production of Nali sheep in arid zone of Rajasthan. Indian Journal of Small Ruminants, **5**(1): 9-13.

Sharma, R.C., Arora, A.L., Kumar, R. and Narula, H.K. 1999b. Impact of genetic and non genetic factors on growth profile in Malpura and Avikalin lambs. Indian Journal of Animal Sciences, **69**(10): 820- 822.

Sharma, R.C., Arora, A.L., Kumar, S., Mishra, A.K. and Mehta, B.S. 2009. Milk yield of Malpura and Awassi * Malpura ewes and its effect on lamb growth. Indian Journal of Animal Sciences, **79**(5): 504-506.

Shivkumar, T. 2003. Effect of genotypes on live weights and live weight gains of Mecheri and Dorset Quarter breeds. Indian Veterinary Journal, **80**(7): 680- 682.

Shivkumar, T., Balasubramanyam, D., Jawahar, T.P.K., Gopi, H. and Jaishankar, S. 2009. Growth and Reproductive performance of Madras Red sheep under field conditions. The Indian Journal of Small Ruminants, **15**(2): 248- 252.

Shivkumar, T., Soundararajan, C., Palanidorai, R., Kumar, G., Mahendrans, M. and Malathi, G. 2006. Factors affecting birth weight in Madras red lambs. The Indian Journal of Small Ruminants, **12**: 115-116.

Shukla, R.K. 1973. Quantitative Genetic Studies on Some Economic Traits of Sheep Breeds of Gujarat. Ph.D Thesis, Agricultural University, Sardar Krishi Nagar, Gujarat.

Singh, B. and Prakash, B. 1986. Factors affecting body weights in Gaddi sheep and its crosses with Russian Merino and Rambouillet. Indian Veterinary Journal, **63**: 143-146.

Singh, B., Chopra, S.C. and Arora, C.L. 1984. Genetic analysis of some economic traits in Russian Merino sheep. Indian Veterinary Journal, **61**: 866-870.

Singh, G. and Dhillon, J.S. 1992. Factors affecting body weights of Avikalin lambs. The Indian J. Anim.Sci., **62**(9): 855-860.

Singh, G. and Koli, O.P. 1997. Factors affecting reproduction traits of Bharat Merino sheep under hot semi-arid climate. The Indian Journal of Small Ruminants, **14**(2): 17-23.

Singh, G., Singh, V.K., and Mishra, R.K. 1980. Seasonal variation in performance of ewes of Corriedale, Coimbatore and their crosses. Cheiron, **9**: 179-186.

Singh, H. 2012. Studies on different methods of sire evaluation for growth traits in Marwari sheep. M.V.Sc thesis, Rajasthan University of Veterinary and Animal Science, Bikaner.

Singh, P.K., Banik, S., Ganai, T.A.S. and Sarkar, T.K. 2007. Non-genetic factors affecting greasy fleece yield of Corriedale sheep. The Indian Journal of Small Ruminants, **13**(2): 199-201.

Singh, R. N. 1980, AICRP- Sheep for mutton: Annual Report, CSWRI, 1980, 24-43.

Singh, V.K. 1990. Genetic evaluation of Karakul and its Crosses with Indigenous Coarse Wool Breeds in North Western Arid Region. Ph.D thesis, Rajasthan Agricultural University, Bikaner.

Singh, V.K., Dass, G., Mehta, S.C. and Sharma, P.R. 1998. Selection in Marwari sheep: 1. Performance of selection line. The Indian Journal of Small Ruminants, **4**(1): 1- 4.

Singhal, R.S. 1996. Studies on the performance of Marwari sheep and its crosses with fine wool breeds in arid zone. M.V.Sc. thesis, Rajasthan Agricultural University, Bikaner.

Sinha, N.K. and Singh, S.K., 1997, Genetic and phenotypic parameters of body weight, average daily gain and first shearing wool yield in Muzaffarnagari sheep. Small Rumin. Research, **26**(1/2): 21-29.

Sivakumar, A. 2008 Variability of DNA sequences for *FecB* gene in Garole, Muzaffarnagari and their cross bred sheep. Thesis, M.V.Sc. Deemed University, Indian University Reseach Institute, Izatnagar, India. Abstract.

Souza, C.J., MacDougall, C., Campbell, B.K., McNeilly, A.S. and Baird, D.T. 2001. The Booroola (*FecB*) phenotype is associated with a mutation in the bone morphogenetic receptor type 1 B (BMPR1B) gene. Journal of Endocrinology, **169**(2): R1-R6.

Sudhakar, A., Rajendran, R. and Rahumathulla, P.S., 2013. Detection of Booroola (*FecB*) mutation in Indian sheep—Nilagiri. Small ruminant research, **113**(1): 55-57.

Sukhapatra, N. O. 2010. Evaluation of Polymorphism of Fecundity (BMPR-1B and GDF-9) Genes in Garole and Kuzi Breeds of Sheep. Thesis, M.V.Sc. Deemed University, Indian Veterinary Research Institute, Izatnagar, India. Abstract.

Swain, N., Gopikrishna, G., Gaur, D. and Sanyal, P.K. 2004. A long term study on the production performance of Bharat Merino sheep in a sub-temperate region of Tamilnadu, The Indian Veterinary Journal, **81** (6): 679-682.

Tailor, S.P. and Yadav, C.M. 2010. Feed resource availability and growth performance of Sonadi sheep in their native tract. The Indian Journal of Small Ruminants, **16**(1): 120- 121.

Tailor, S.P. and Yadav, C.M. 2011. Growth performance of pre and post weaning Sonadi lambs and adults in the native tract. The Indian Journal of Small Ruminants, **17**(2): 221-224.

Tailor, S.P., Gupta, L. and Nagda, R.K. 2007. Productive and reproductive performance of Sonadi sheep in their native tract. The Indian Journal of Small Ruminants, **13**(1): 51-54.

Thiruvenkadan, A.K., Karunanidhi, K., Murugan, M., Arunachalam, K. and Babu, R.N. 2010. Non genetic factors affecting growth rate of Mecheri sheep. Indian Veterinary Journal, **87**(2): 149- 151.

Tomar, A.K.S., Mehta, B.S. and Singh, G. 2000b. Genetic and non-genetic factors affecting growth in Bharat Merino Sheep, Indian J. Anim. Sci, **70**(6): 647-648.

Tomar, A.K.S., Mehta, B.S., Jaishankar, J. and Singh, G. 2000a. Genetic studies on growth and greasy fleece yield in Bharat Merino sheep, Indian J. Anim. Sci, **70**(5): 537-539.

Tu, Y.R. 1989 Selection for reproduction rate in Australian Merino Sheep: direct responses. Australian Journal of Agricultural Research, **29**: 327-350

Umeel, Z.S., Dalal, D.S., Dahiya, S.P. and Patil, C.S. 2018. Estimation of genetic parameters for production traits in Munjal sheep. Indian Journal of Small Ruminants, **24**(1): 31-34.

Verma, P.K., Joshi, A., Kumar, S., Maurya, B.P., Gulyani, R. and Mittal, J.P. 2005. Reproductive performance of Marwari sheep reared by farmers in hot arid environment. The Indian Journal of Small Ruminants, **11**(2): 84-88.

Vitt, U.A., Hayashi, M., Klein, C. and Hsueh, A.J.W. 2000. Growth differentiation factor-9 stimulates proliferation but suppresses the follicle-stimulating hormone-induced differentiation of cultured granulosa cells from small antral and preovulatory rat follicles. Biology of reproduction, **62**(2):370-377.

Waghmode, P.S., Sawane, M.P., Panwar, V.D. and Ingawal, M.V. 2008. Effect of non-genetic factors on growth performance of Madgyal sheep. Indian Journal of Animal Science, **14**(1), 127-130.

Wang, G., Mao, X., George, D.H., Zhao, Z., Zhang, L. and Zeng, Y. 2003. DNA tests in Hu sheep and Han sheep (small tail) showed the existence of Booroola (*FecB*) mutation. Journal of Nanjing Agricultural University, **26**(1): 104-106.

Wilson, T., Wu, X.Y., Juengel, J.L., Ross, I.K., Lumsden, J.M., Lord, E.A., Dodds, K.G., Walling, G.A., McEwan, J.C., O'Connell, A.R. and McNatty, K.P. 2001. Highly prolific Booroola sheep have a mutation in the intracellular kinase domain of bone morphogenetic protein IB receptor (ALK-6) that is expressed in both oocytes and granulosa cells. Biology of reproduction, **64**(4): 1225-1235.

Yadav, D.K., Singh, G., Jain, A., Singh, S. and Paul, A.K. 2009. Fitting of growth models and evaluation of Marwari sheep under field conditions. The Indian Journal of Animal Sciences, **79**(12): 1242-1244.

Yatoo, S.A, Taggar, R.K., Chakraborty, D., Kumar, N., Kumar, D. and Vohra, V. 2015. Status of *FecB* gene mutation in dorper sheep from Jammu. Journal of Animal Research **5**(4): 253.

Yue, G. H. 1996. Reproductive characteristics of Chinese Hu sheep. Animal Reproduction Science, **44**: 223-230.

Zuo, B., Qian, H., Wang, Z., Wang, X., Nisa, N., Bayier, A., Ying, S., Hu, X., Gong, C., Guo, Z. and Wang, F. 2013. A study on BMPR-IB genes of Bayanbulak sheep. Asian-Australasian journal of animal sciences, **26**(1): 36

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Appendix

ANNEXURE-I

Sample code; tag no; Sex; Sire no; Dam no; Litter size; Genotype of 124 Muzaffarnagari sheep samples

S No	Animal no	Sex	Sire no	Dam no	Litter size	Genotype
1	7562	F	6845	6864	2	++
2	7678	F	6871	6578	2	++
3	7686	F	7189	6968	2	++
4	7718	F	7133	7144	2	++
5	8040	F	0	7402	2	++
6	8116	F	7635	7206	2	++
7	8132	F	7625	6878	2	++
8	8194	F	7603	6912	2	++
9	8210	F	7683	7000	2	++
10	8216	F	7625	7494	1	++
11	8218	F	7621	7066	1	++
12	8248	F	7581	7532	1	++
13	8254	F	7567	7138	1	++
14	8260	F	7581	7472	2	++
15	8262	F	7641	6916	2	++
16	8264	F	7625	7166	2	++
17	8270	F	7567	7392	1	++
18	8272	F	0	7338	1	++
19	8274	F	7589	7418	1	++
20	8278	F	7589	7914	2	++
21	8298	F	7585	6896	2	++
22	8300	F	7581	7422	2	++
23	8308	F	7635	7866	1	++
24	8310	F	7589	7962	1	++
25	8316	F	7585	6970	2	++
26	8322	F	7641	7212	2	++
27	8326	F	7639	7264	2	++
28	8334	F	7683	7862	1	++
29	8336	F	7603	7582	1	++
30	8360	F	7621	7206	2	++
31	8362	F	7609	7004	1	++
32	8376	F	7635	7414	2	++
33	8378	F	7797	7048	1	++
34	8434	F	7621	6732	1	++
35	8436	F	7635	7494	2	++
36	8438	F	7641	7666	2	++
37	8440	F	7641	7666	2	++
38	8458	F	7603	7068	2	++
39	8474	F	7829	6926	1	++

40	8482	F	7815	7734	2	++
41	8486	F	7641	7222	2	++
42	8512	F	7625	7178	1	++
43	8514	F	7621	7542	2	++
44	8530	F	7815	8100	1	++
45	8550	F	7625	7304	1	++
46	8568	F	0	6926	1	++
47	8576	F	7625	7048	2	++
48	8580	F	7621	7500	2	++
49	8582	F	7621	7500	2	++
50	8600	F	7851	6878	2	++
51	8672	F	8055	7360	2	++
52	8698	F	8115	7652	2	++
53	8724	F	0	8168	2	++
54	8748	F	8135	7030	2	++
55	8750	F	8115	8336	2	++
56	8870	F	8311	8168	2	++
57	8872	F	8311	8168	2	++
58	8880	F	8311	8262	2	++
59	8894	F	8335	7628	2	++
60	8902	F	8311	7538	2	++
61	8942	F	0	7500	2	++
62	8946	F	0	6878	1	++
63	8956	F	0	7360	1	++
64	8966	F	8325	7652	1	++
65	8968	F	8335	6640	2	++
66	8970	F	7123	6593	2	++
67	8974	F	7019	6830	1	++
68	8988	F	8367	8474	2	++
69	8994	F	8341	7862	2	++
70	9000	F	8353	8308	2	++
71	9002	F	8353	8308	2	++
72	9028	F	8353	8016	2	++
73	9032	F	8239	7652	2	++
74	9046	F	8325	8030	2	++
75	9058	F	8335	8482	2	++
76	9064	F	8239	7792	2	++
77	9066	F	8239	7792	2	++
78	9088	F	8367	8467	2	++
79	9092	F	8335	7882	2	++
80	9096	F	8409	8122	2	++
81	7123	M	6727	6537	1	++
82	7133	M	6737	6922	1	++
83	7189	M	6845	6640	1	++
84	7581	M	7133	6593	1	++
85	7585	M	7123	6830	1	++
86	7589	M	6831	6840	1	++
87	7603	M	7123	7120	1	++
88	7603	M	7123	7120	1	++

89	7621	M	7019	7062	1	++
90	7625	M	7007	7200	1	++
91	7635	M	7123	7058	2	++
92	7639	M	6831	6984	1	++
93	7641	M	6845	7086	1	++
94	7683	M	6831	6850	2	++
95	7815	M	7095	7168	1	++
96	7851	M	7395	7118	1	++
97	8055	M	7123	7078	1	++
98	8103	M	7567	7412	1	++
99	8115	M	7635	7500	1	++
100	8131	M	7581	6932	1	++
101	8135	M	7567	6758	1	++
102	8157	M	7603	6946	1	++
103	8239	M	7595	7078	1	++
104	8261	M	7567	7872	1	++
105	8311	M	7851	6954	1	++
106	8325	M	7635	7148	1	++
107	8335	M	8115	7706	2	++
108	8341	M	7095	7166	2	++
109	8353	M	7635	7396	1	++
110	8367	M	7683	7578	1	++
111	8409	M	7621	6986	1	++
112	8555	M	8157	7768	2	++
113	8561	M	8115	7408	1	++
114	8563	M	8115	7708	1	++
115	8621	M	8135	7930	1	++
116	8683	M	8115	8068	1	++
117	8685	M	8115	8076	1	++
118	8691	M	8189	8316	1	++
119	8709	M	8115	7718	1	++
120	9179	M	8709	8162	1	++
121	9181	M	8685	8310	2	++
122	9197	M	8561	8116	1	++
123	9199	M	8621	8648	1	++
124	9205	M	8555	8200	1	++

ANNEXURE-II

Chemicals/Equipments/Lab wares/ miscellaneous items

1.	**Chemicals**	**Source**
	Agarose (low EEO)	SRL
	Ammonium chloride	SRL
	Amyl alcohol	Glaxo laboratories
	Beta-mercaptoethanol	Spectrochem
	Boric acid	SRL
	Bromophenol blue	Hi-media
	Chloroform	Qualigens
	EDTA di sodium salt	SRL
	Ethanol	Bengal chemicals
	Ethidium bromide	SRL
	Formaldeyde	Qualigens
	Glacial acetic acid	Qualigens
	Hydrochloric acid	Qualigens
	Isoamyl alcohol (extra pure AR)	SRL
	Isopropanol	SRL
	Magnesium chloride	Qualigens
	Nuclease free water	Thermo Scientific
	Oligonucleotides (custom made)	IDT
	Phenol (extra pure AR)	SRL
	Potassium bicarbonate	SRL
	Potassium dichromate	Glaxo Laboratories
	RNA Xpress reagent^{TM}	Himedia
	Sodium acetate	Qualigens
	Sodium chloride	SRL
	Sodium dodecyl sulfate	SRL
	Sodium hydroxide	SRL
	Sucrose	Qualigens
	Sulphuric acid	Qualigens
	Tris base	Qualigens
	Tris HCL	SRL
	Ultra- resolution agarose	Hi-media
2.	**Equipments**	**Source**
	Autoclave	Scientronic instruments
	Centrifuge R8C	REMI
	Deep Freezer (-20°C)	Leonard
	Distillation plant	Scientronic instruments
	Gel documentation system	Syngene

	Horizontal gel electrophoresis apparatus	Bangalore Genei
	Hot air oven	S. P. Scientronic Instruments
	Ice box	Torson
	Ice flaking machine	Scotsman
	Incubator	S. P. Scientronic Instruments
	Laminar air flow	Tunco
	Magnetic stirrer	Scientronic instruments
	Micro-centrifuge RM 12C	REMI
	Micropipette (all ranges)	Qualipette
	pH meter	Tunco
	Power pack	Bangalore genei
	Refrigerator	Godrej
	Spectrophotometer	Beckman
	Thermal cycler	Applied Biosystems
	UV transilluminator	Gloworn
	Vortexer	Scientronic instruments
	Water bath	S.P. scientific instruments
	Weighting balance (physical)	laboratory balance Indus.
	Weighing balance (Digital)	Scientronic instruments
3.	**Lab wares**	**Source**
3.1	**Glass wares**	
	Beakers, conical flasks	Borosil
	Measuring cylinders, Pasteur pipettes	Borosil
	10 ml pipettes, reagent bottles	Borosil
3.2	**Plastic wares**	
	Polypropylene centrifuge tube	Tarson
	Eppendorf tube (1.5 ml and 0.5 ml)	Axygen USA
	PCR tube (0.2 ml)	Axygen USA
	Microtips (All ranges)	Axygen USA
	MicroAmp® Fast 8-Tube Strip and Caps	Invitrogen

4. Miscellaneous items

Adhesive tapes
Aluminum foils
Autoclave label
Black and white films
Blotting paper
Burette
Cello-tape
Cotton
Disposable gloves
Papers
Pestle and mortar
Needles
Para film
Porcelain basin
pH paper
Racks
Scissors
Thermometers
Threads
Tissue paper filters
Forceps, Marker pen
Plastic ziplock bag

ANNEXURE-III

Buffers and solutions

1. **2.7% EDTA solutions (pH 8.0)**

EDTA Disodium salt	2.7 gm
Double distilled water (up to)	100 ml

Adjust pH 8.0 using NaOH pellets

Sterilized by autoclaving and stored at room temperature

2. **0.5 M EDTA solution (pH 8.0)**

EDTA Disodium salt	186.1gm
Double distilled water (up to)	1000 ml

Adjust pH 8.0 using NaOH pellets

Autoclaved and stored at room temperature

3. **RBC lysis buffer (1X)**

Ammonium chloride (NH_4Cl)	8.3 gm
Potassium bicarbonate ($KHCO_3$)	1.0 gm
0.5 M EDTA (pH 8.0)	299 µl
Double distilled water (up to)	1000 ml

Autoclaved and stored at room temperature

4. **5 M NaCl solution**

Sodium chloride	29.22 gm
Double distilled water (up to)	100 ml

Autoclaved and stored at room temperature

5. **DNA extraction buffer**

1M tris buffer (pH 8.00)	5 ml
5 M NaCl	40 ml
0.5 M EDTA buffer (pH 8.00)	2 ml
Double distilled water (up to)	500 ml

Autoclaved in batches of 100 ml and stored at room temperature

6. **10% SDS**

SDS (Sodium Dodecyl sulfate)	10 gm
Autoclaved double distilled water (up to)	100 ml

(Adjust pH 7.2 using Conc. HCl). Heat in water bath at 60?C to dissolve and then store at room temperature. SDS solution should not be autoclaved.

7. **3 M sodium acetate**

Sodium acetate (anhydrous)	24.6 gm
Double distilled water (up to)	100 ml

(Adjust pH 5.5 using glacial acetic acid)

Autoclaved in batches of 20 ml

8. Tris saturated phenol preparation

a) Measure the required volume of phenol, add 8-hydroxyquinoline to a final concentration of 0.1% (it is an anti-oxidant gives yellow colour to phenol)

b) Extract phenol once/twice with equal volume of 0.5 M Tris base (pH 10.5).

c) Then with equal volume of Tris base pH 8.0 until the pH of the phenol phase is >7.8

d) Add 0.2% ?-mercaptoethanol and mix (antioxidant and cleaves disulfide bond)

e) Finally, 0.1 M Tris base (pH 8.0) is added to about 1/3rd volume of phenol and store in amber coloured bottle at 4?C.

9. 3 M sodium acetate

Chloroform	24 ml
Isoamyl alcohol	1 ml

Mix thoroughly and store in amber coloured bottle at 4°C.

10. Phenol: chloroform: isoamyl alcohol preparation (25:24:1)

Chloroform: Isoamyl alcohol (24:1)	25 ml
Tris saturated phenol	25 ml

Mix thoroughly and store in amber colored bottle at 4°C.

11. 70% ethanol

Ethanol	70 ml
Autoclaved double distilled water	30 ml

Mix thoroughly and store in amber colored bottle at 4°C.

12. 1 M Tris HCI (pH 8.0)

Tris HCI	157.6gm
Doubled distilled water (up to)	1000 ml

Adjust pH 8 using NaOH pellets

Autoclave and store at 4°C

13. 1X TE

1 M Tris buffer	250ml
0.5 M EDTA (pH 8.0)	50 ml
Double distilled water (up to)	25 ml

Autoclave and store at 4°C

14. 5X TBE

Tris base	54 gm
Boric acid	27.5 gm
0.5 M EDTA (pH 8.0)	20 ml
Autoclaved distilled water (up to)	1000 ml

Autoclave and store at room temperature

15. 6 X Gel loading Dye (Sambrook *et al.*, 1989)

a) Type I

Bromophenol blue	0.25%
Xylene cyanol	0.25%

Sucrose in water	40 % (w/v)

Mix and store at 4°C.

b) Type IV

Bromophenol blue	0.25%
Sucrose in water	40% (w/v)

Mix and store at 4°C

16. Ethidium bromide (10mg/ml)

Ethidium bromide	10 mg
Autoclaved distilled water (up to)	1 ml

Wrap in aluminum foil and store in dark place at room temperature.

17. Phosphate buffered saline (PBS)

NaCl	8gm
KCl	0.2gm
Na2HPO$_4$	1.44 gm
KH2PO$_4$	0.24gm
Distilled water (up to)	800 ml

Adjust pH to 7.4 with HCI. Add water to 1 liter. Autoclaved and stored at room temperature.

ANNEXURE-IV

Enzymes, Biologicals and Kits

1.	***Taq* DNA polymerase enzyme** (1 U/ml)	Thermo Scientific
2.	**10 X *Taq* DNA polymerase buffer**	Thermo Scientific
3.	**Proteinase K** (20 mg/ml)	Thermo Scientific
4.	**Primers** (100 pmole/µl)	IDT
5.	**100 bp DNA Ladder** (10 bands of double stranded DNA fragments ranging from 100 to 1000 bp)	Thermo Scientific
6.	**50bp DNA ladder**(13 bands of double stranded DNA fragments ranging from 50 to 1000 bp)	Thermo Scientific
7.	**dNTPs** (25mM each)	Thermo Scientific
8.	**PCR Master Mix** (2X)	Thermo Scientific

VITAE

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